Ship handling simulator for assessing on-board advanced navigation support systems and services --- Introduction of intelligent ship handling simulator ---

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Abstract

In most ship-handling simulators, ships except own ship, hereinafter this is called target ships, follow their predefined routes or instructor's individual orders. Therefore, they cannot adapt to environmental conditions. The lack of the adaptation sometimes leads them to perform irregular movements such as illegal close approach, which offends the law of the road. The irregular movements prevent a proper simulator training or assessment of support systems.

On the other hand, it is expected that many advanced navigation support systems or services based on e-Navigation strategy will be introduced in near future. They use ICT such as ship-to-ship communication to exchange value-added information. The exchanged information may change both ships' manoeuvre. To introduce such on-board advanced navigation support systems or services, it is necessary to be assessed their usefulness and availability by experts based on the experience of using them before their implementation.

For this purpose, a framework for controlling target ships has been developed by adding a distributed process to an existing simulator. The distributed process gathers information of target ships from the simulator and utilise them to make navigational orders to the target ships based on implemented on-board advanced navigation support systems or services then send back the order to the simulator. This framework makes it possible for all target ships to perform intelligent manoeuvre. As the first step, an intelligent ship-handling simulator, which reproduces collision avoidance manoeuvre of target ships, has been developed by using the framework and applied to a congested sea area.

1. Introduction

Recently, many organizations use ship-handling simulators. The simulator has been used mainly in two purposes: one to train mariners. It is also used for assessing marine systems.

Many ship-handling simulators are actually used for mariners training and they have raised the educational effect, because trainees can learn professional skills quickly and effectively based on their actual experiences of tasks by using simulator. The merits of the use of simulators to train mariners were studied by the Committee on Ship-Bridge Simulation Training, and they emphasized the importance of the validity of training scenarios [Committee on Ship-Bridge Simulation Training, 1996].

On the other hand, with the recent rapid advances in ICT, the introduction of new services using new communication systems such as Automatic Identification System Application Specific Messages (AIS/ASM) [Alexander et al. 2010] [Fukuto et al. 2009] have been promoted. When introducing such new systems and services, safety assessment and cost benefit analysis are required. However, it is difficult to measure the effect of such systems quantitatively, because usually there are no existing systems and experiences to use them. Because of that, the effects or benefits of the new systems are estimated by experts based on their knowledge and their experience of the use of a prototype of the new system. The experience of the use of them is essential to get proper expert judgements. Ship-handling simulators are a good tool to get such experiences.

To make effective experience of the experts in a certain traffic flow, we need to control all ships in simulator except own ship, hereinafter they are called target ships, to express the effect of the new systems. Because the information provided by the new support system may affect to the target ship's manoeuvre.

Conventional ship-handling simulators usually move target ships along the predefined route. An operator of the simulator also can control only selected target ship by ordering heading and speed individually. Therefore, basically target ships are not able to adapt to other target ship's manoeuvre and it may cause their irrational manoeuvre.

To control all target ships, we have developed a framework for implementing advanced navigation support functions to target ships by using distributed process concept. A framework for intelligent target ships and vessel automatic control algorithm has also been proposed by Hua Wang [Hua Wang et al. 2011]. The idea and mechanism for installing intelligent function seems similar to our framework but they do not mention detail of the framework for connecting to real time systems. In addition, in their paper, only the results of CA action of relatively simple encounter situations of the same type and size of ship. Therefore, it is not clear if their CA algorithm can be applied to real traffic, which composed of a variety of type and size of ships.

The framework has been made for NMRI's ship-handling simulator and an automatic collision avoidance (CA) system was introduced to the simulator by using the framework to realize so called "Intelligent ship-handling simulator", which makes it possible for the target ships to perform CA actions against other ships in 2011 [Fukuto et al. 2011]. Then we applied the "Intelligent ship-handling simulator" to the vessel traffic of off south sea area of the entrance of Tokyo bay to examine the validity of the intelligent ship-handling simulator.

2. The framework for implementing advanced functions

A framework for implementing advanced functions, such as an automatic collision avoidance system, has developed.

In General, target ships in ship-handling simulator move along their predefined and individual route. In addition, many simulators have a manual target ship control function for changing selected ship's manoeuvre. To change the target ship's course and/or speed from a simulator operator's console, first the operator should select a target ship and change its navigation mode from simulation mode to manual mode, then input new course or new speed. Our framework uses modified manual target ship control function enabling to control all target ships with inter-process communication using connectionless UDP.

Figure 1 illustrates the system diagram of NMRI's intelligent ship handling simulator. The region enclosed by the dotted line shows a configuration of original simulator and the region enclosed by the dashed line shows a configuration of the intelligent simulator. NMRI's simulator is built as a multi-process system. Only the processes related to target ship control is shown in the diagram. To control all target ship manoeuvres automatically, a distributed process named intelligent system process (ISP) has been made as an additional process to a ship-handling simulator. The process is implemented by using proposed framework. The

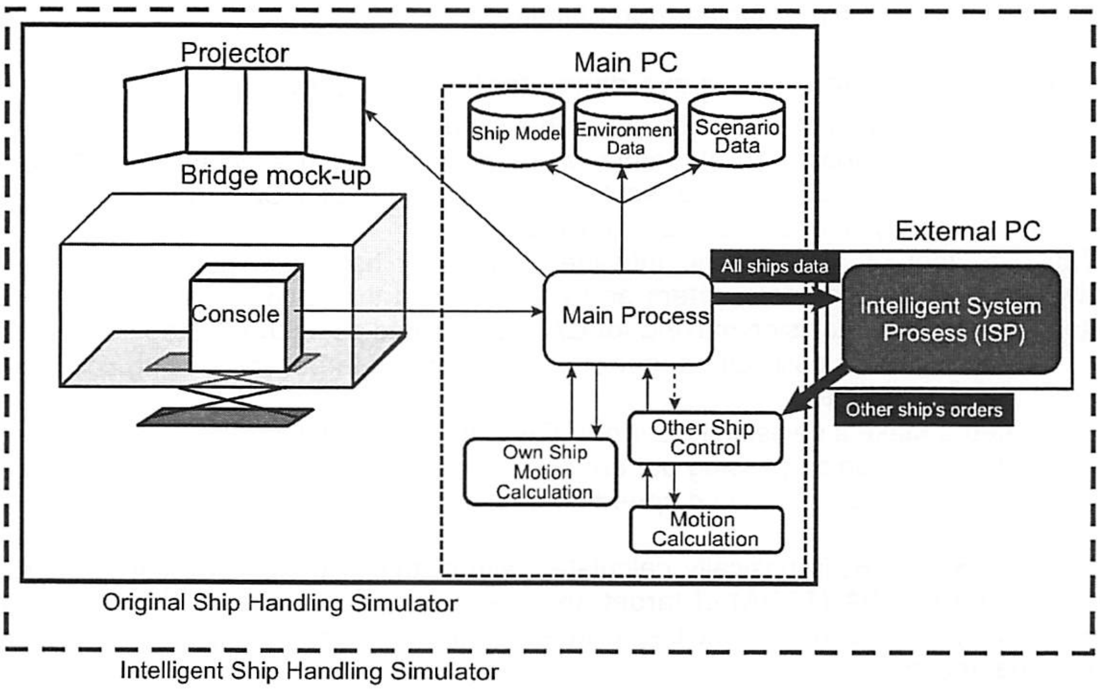

Fig. 1 System diagram of intelligent ship-handling simulator

framework is composed of following three functions. (1) Communication function between main processes of the simulator and the ISP, (2) Calculation function for making orders to individual target ships based on implemented advanced function to the ISP, (3) Communication function between Target ship control processes of the simulator and the ISP.

The communication function between main process and the ISP sends traffic information from main process to the ISP.

The calculation function calculates individual target ship's orders based on their predefined route, traffic conditions and geographical conditions. The function first gathers necessary information for making new order to all target ships and then calculates the orders based on implemented advanced support functions. In the intelligent simulator, automatic collision avoidance function is implemented to the ISP.

The communication function between other ship control process and the ISP sends the order from the ISP to other ship control process. The other ship control process also calculates the order for individual target ships to follow their predefined route. However, when the order comes from the ISP, the original order is overridden by the ISP's order.

To implement the framework, a UDP message sending function to send necessary information for calculating target ship's orders is added to the main process and a UDP message receiving function to override original target ship's order is also added to the other ship control process.

In order to perform decision making for CA, a lot of static information such as predefined route and ship characteristic parameters of the target ships is needed. Dynamic state variables of target ships, such as position, speed and course, are also needed in every one second to give proper orders. On the other hand, the amount of transferring information should be reduced as much as possible to keep running the simulator in real time. From the viewpoint of minimalizing the amount of communication during simulation runs, the necessary information for making decision making of CA is exchanged in following manner. The ISP reads the static data from the scenario definition file on the simulator in initialization phase of simulation. The ISP receives broadcast UDP messages including dynamic data of all target ships every second in simulation run phase. It also sends back the orders of all target ships to the other ship control process using a LAN with UDP protocol. By using the framework, the ISP works in real time at one-second interval in this case. Even if the ISP processing time exceed one second, it is possible to obtain valid calculation results by increasing the interval within suitable range of time.

3. Algorithm of automatic collision avoidance for the intelligent

3.1 Outline of the algorithm of automatic collision avoidance

Authors are developing an algorithm of automatic collision avoidance (ACA) for the simulator [Hasegawa 2012]. In this section, an algorithm of ACA implemented in the intelligent ship-handling simulator is briefly introduced.

The algorithm of ACA for the intelligent simulator has been developed in Osaka University using Fuzzy inference system and we confirmed that it could solve simple 3 ship encounter problem. The decision making for CA is performed as following steps.

Step1: Assess collision danger of all encountered target ships using collision risk index CR.
Step2: Make a decision to perform CA to the target ships.
Step3: Decide on passing pattern based on encountered situation of target ships
Step4: Output course and speed change order to realize the passing pattern

3.2 Collision risk

Collision Risk (CR) is basically calculated with distance to closest point of approach (DCPA) and time to CPA (TCPA) of target ships using fuzzy inference. The membership function for fuzzy rule condition has been determined based on the results of a series of simulator experiments.

Because the size of ship and its manoeuvrability affect to collision risk, DCPA and TCPA has been modified using ship length L and ship manoeuvrability parameter time constant T.

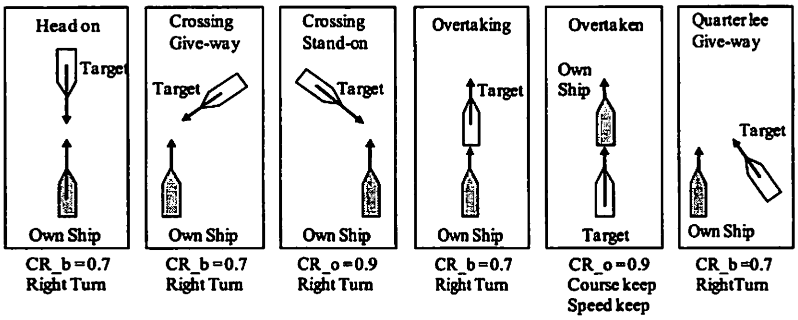

Fig. 2 Encounter patterns and their characteristics

3.3 Decision making to perform CA and its passing pattern

Decision of the necessity of CA and its passing pattern is depend on the CR value and encounter situation. In our algorithm, encounter condition is divided into six cases and then their passing pattern and CR criteria for starting CA action are defined. Figure 2 shows the six encounter cases and the passing pattern and the CR criteria for each case. The CA action of target ships is determined with the set of passing patterns and CR criteria. In addition, when one-to-many encounter occurs, first CRs for all encountered ships are calculated and then the CA action is taken to the ship that has the largest CR value.

3.4 Navigation mode

Target ships have following 4 navigation modes. (1) Waypoint (WP) mode, (2) Avoiding mode, (3) Parallel manoeuvring mode and (4) Returning mode. Figure 3 illustrates the 4 navigation modes in CA action for crossing encounter.

When CR is small and the target ship does not need CA action, the target ship sails in WP mode, which makes the ship to follow its predefined route. Once the CR exceeds the criteria for starting CA action, the navigation mode of the ship is changed from WP mode to avoiding mode to perform CA action. New course is determined as the CR to be smaller than the criteria. The parallel manoeuvring mode makes the ship to navigate parallel to the predefined route and the returning mode leads the ship to the original route. The mode change is occurred when the CR of the next navigation mode becomes less than the criteria. Finally, when the conditions for returning to the predefined route are met, navigation mode will return to the WP mode and the CA action ends.

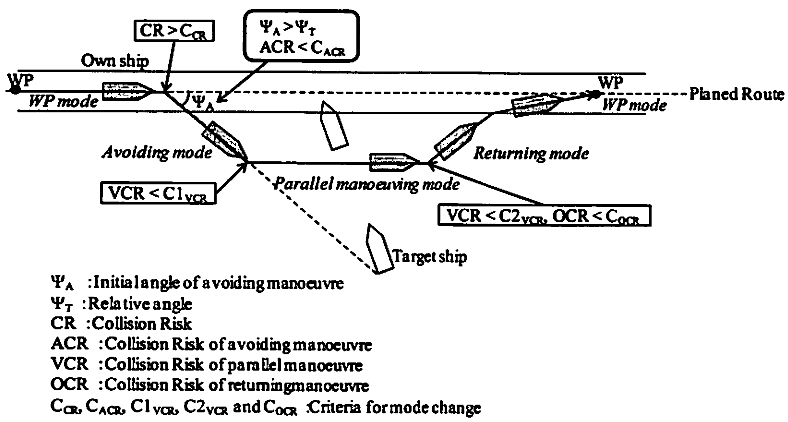

Fig. 3 Procedures of collision avoidance manoeuvring

4. Results of a simulation run in congested sea area

To demonstrate the effectiveness of the framework and the ACA algorithm, a series of simulation runs with the intelligent simulator were carried out. As the basic 3 ship encounters

Table I Observed traffic data with AIS

Length(*L*) Type	*L*≦50m	*L*≦100m	*L*≦150m	*L*≦200m	*L*≦300m	300m≦*L*	Total
Tanker	0	10	1	0	0	1	12
Cargo ship	0	3	0	3	0	0	6
Ferry	0	2	0	0	0	0	2
PCC	0	0	0	0	1	0	1
Tug	0	1	0	0	0	0	1
Total	0	16	1	3	1	1	22

were already tested, we compared the observed traffic flow and simulation traffic flow of the scenario, which is made by the observed traffic flow.

4.1 Scenario

The predefined routes of the scenario are made with the observed traffic flow recorded by AIS. Figure 4 shows the trajectories of observed traffic flow and Table I is a target ship data in the observed traffic flow. There are 22 observed ships in the scenario and a 160m northbound cargo ship was selected as the own ship. The traffic flow is mainly divided into three groups. There are a southbound ship group from The Uraga Suido traffic route, a northbound ship group and a ship group crossing the two groups' course. The three ship groups make various complicated and real encounter situations.

Own ship was operated by one of author of this paper. In this scenario, the Own ship was operated to go straight to the entrance of the Uraga Suido traffic route without CA even if it encountered stand on crossing ship as the observed ships do so.

4.2 Comparison between observed flow and simulated flow

Figure 4 shows the observed traffic flow of the south entrance of the Uraga Suido traffic route and Figure 5 illustrates the trajectories of target ships simulated by the intelligent simulator with the scenario obtained by the observed traffic flow. The traffic flow is almost agreed with the simulated trajectory except the CA actions between the ships crossing mainstream and their encountered ships. It tells us that the intelligent simulator does not initiate unnecessary CA action and it makes the target ship to perform proper CA action if necessary.

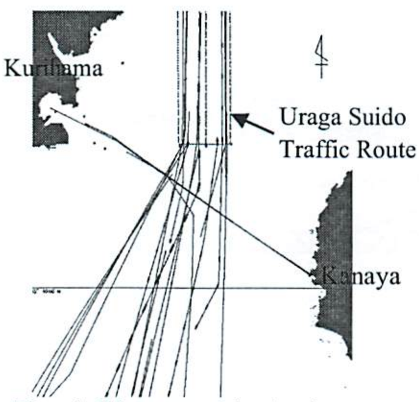

Fig. 4 Observed trajectory

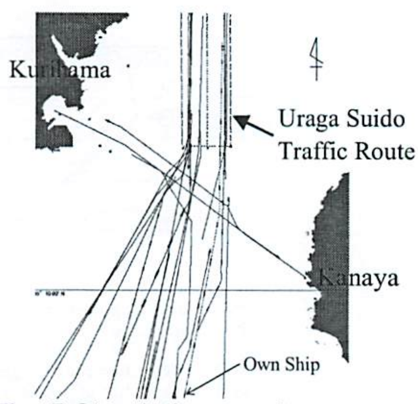

Fig. 5 Simulation result

To show the detail of the deference between the simulation results and observed traffic, two CA cases are closed up in Figure 6 and Figure 7. The dotted lines are the observed target ship's paths and solid lines are the trajectories of simulated ships. The ship shapes are drawn every one-minute.

In Figure 6, own ship go up to the north straight to the entrance of the Uraga Suido traffic route without CA action to Ship A (79m ferry). Ship A took CA action to the right to pass the stern side of own ship. The CA action follows our ACA algorithm, which includes

Table II Ships in Case 1

	Type	Gross Tonnage	Length
Ship A	Ferry	3,300 ton	79. m
Ship B	Ferry	3,500 ton	77. m
Ship C	Tanker	1,300 ton	75. m
Ship D	Tanker	160,000 ton	340. m
Own Ship	Cargo	11,800 ton	161. m

Table III Ships in Case 2

	Type	Gross Tonnage	Length
Ship E	Cargo	26,000 ton	225. m
Ship F	Tanker	499 ton	63. m
Ship G	Tanker	699 ton	65. m
Ship H	Tug	166 ton	35. m

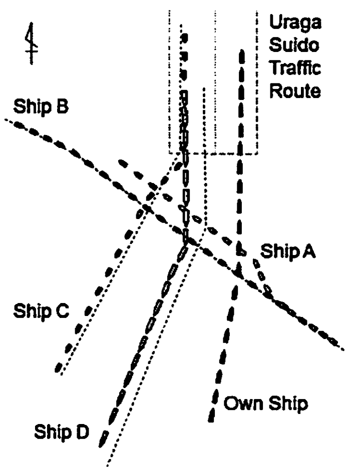

Fig.6 CA results of Case 1

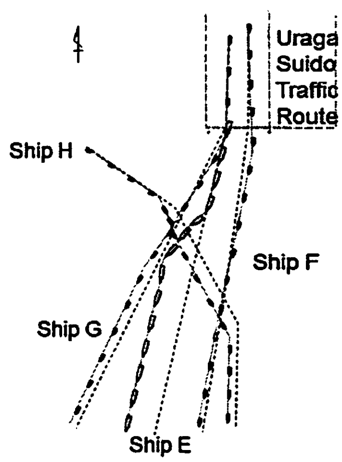

Fig.7 CA results of Case2

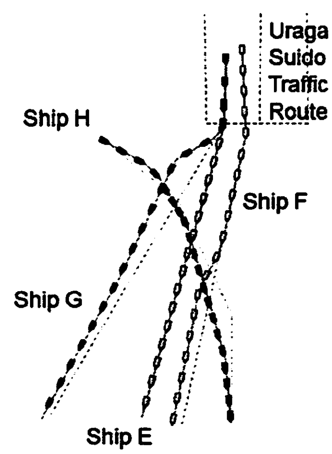

Fig.8 CA results of Case2 with modified algorithm

the emergency CA action to irregular close approach of give way ship. On the other hand, Ship A passed just own ship's astern by turn to the left not to disturb own ship in observed path. Ship A may took such action to follow "Maritime Traffic Safety Act in Tokyo Bay", which is local rule to give the priority to huge ships in traffic route. In this case, authors think left turns in emergency CA action is not safe without exchanging navigational intensions. Therefore, we did not modify our algorithm.

Ship E (255m Cargo) and Ship H (35m Tug) in Figure 7 are also deviated from observed path. First, Ship E took CA action to the right to Ship H and then Ship H also took CA action for Ship E because Ship E took CA action too late and Ship H assessed that Ship E's action was not enough. Actually, CA action of Quarter lee give way ship is difficult to the poor manoeuvrability ships. To cope with this problem, additional consideration or tuning of parameter is needed. On the other hand, observed path shows that Ship H kept its course even it was the give way ship to Ship H and Ship H passed just astern of the Ship E. The reason for this action may be the same as that of Case 1. It is a rule, which forces a small stand on ship to avoid a big give way ship if the big ship go along the main stream of traffic flow. Authors confirmed the reason experiencing the CA action at both Ship E and Ship H's bridge using the intelligent simulator. Then authors added the rule to ACA algorithm as a rule applying to the ship over 200m in length. Figure 8 shows the result applying the additional rule. Ship E kept its course and Ship H passed stern side of Ship E. Although the differences in the details, the simulation result agreed with the observed path in general.

5. Conclusion

An intelligent simulator has been developed by using a framework for implementing advanced support systems and services to a simulator and an automatic collision avoidance algorithm using Fuzzy inference technique. The framework provides the function for controlling all target ships from the outside of the simulator. The intelligent simulator reproduced real traffic flow by dynamically calculating mutual relationship among target ships such as collision avoidance. The reproduced real traffic flow is expected to raise the effectiveness of the ship-handling simulator for training crewmembers.

In addition, the framework is also good tool to install newly developed advanced support systems and services into all target ships. Through the experiences of the use of such systems more suitable assessment is expected.

As the next step, authors plan to brush up the automatic collision avoidance algorithm by applying actual traffic flow data. Authors also plan to install an Automatic Navigation Intension Exchange Support System to the intelligent simulator to assess the effectiveness of it.

Acknowledgment

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