Development of Automated Ship Operation Technologies

— MEGURI 2040 Unmanned Ship Demonstration Experiment Project —

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1. INTRODUCTION

In the field of ship operation, technological development for ship operation support and automation together with the registration and establishment of regulatory framework in the International Maritime Organization (IMO) are underway. In coastal navigation in Japan, the advancing age of seafarers and difficulty of securing seafarers in the future are urgent issues, therefore continuous efforts to improve safety, reduce the workload on crew and strengthen cost competitiveness are necessary. To address these problems, various types of projects in connection with operation support and automated ship operation are being carried out under lead of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and other organizations. As part of those efforts, Mitsubishi Shipbuilding Co., Ltd. is participating in the Joint Technological Development Program for Demonstration Experiments of Unmanned Ships with the Nippon Foundation.

Since the 1980s, Mitsubishi Shipbuilding has experience in commercializing support systems for ship operators called the SUPER ASOS (Advanced Ship Operation Support System) and the Super Bridge-X. The target of the technological level in the present demonstration experiment is the Class II level as defined in the Nippon Kaiji Kyokai (ClassNK) "Guidelines for Concept Design of Automated Operation and Autonomous Operation.". In the experiment, advanced technologies including AI, image processing and utilization of cloud computing technologies will be installed on a large ferry, and automated operation technologies will be developed and verified, aiming at unmanned ship operation. The category of development are as follows:

1) Automation of port entering and leaving and navigation
2) In-service engine room monitoring and land-based monitoring of operational information

2. SCOPE OF DEMONSTRATION EXPERIMENT

In this demonstration experiment, maneuvering experiments are being conducted with an automated ship with a crew on board over a period of approximately 2 years from February 2020 to March 2022. Basically, development is being carried out targeting the equivalent of level 2 in the above-mentioned ClassNK Guidelines, preconditioned on fallback operation by the crew. A risk analysis is conducted by Class NK in the stage of system design, and the preconditions of operation, preparations and the ODD for conducting a safe demonstration experiment is clarified. It is expected through this demonstration experiment, clarification of the effectiveness of the functions developed for the experiment, their performance limits, and items for future improvement will be identified.

The experiment will be carried out under various environmental conditions when entering and leaving port, navigating in congested waters, and sailing in the open ocean, to verify the effectiveness and accuracy of the functions, system linkage among various devices, ship motion control, influence of marine meteorology and weather conditions, telecommunications, engine room monitoring and onshore monitoring.

3. EQUIPMENT

3.1 Outline of Ship

The ship is a large long-distance ferry used on a coastal route, and is equipped with a 2-shaft CPP in the propulsion system, 2 rudders and bow and stern side thrusters. Table 1 shows the principal particulars and main propulsion equipment.

* Mitsubishi Shipbuilding Co., Ltd.

Table 1 Outline of ship

Ship owner	Shin Nihonkai Ferry Co., Ltd.
Ship operator	Tokyo Kyushu Ferry Co., Ltd.
Shipyard	Mitsubishi Shipbuilding Co., Ltd.
Keel laid Commissioned	August 2020 End of June 2021
Gross tonnage (tons)	15,400 (approx.)
Deadweight (tons)	5,440 (approx.)
Full load displacement (tons)	18,000 (approx.)
Vehicle capacity	12 m trucks: 154 Passenger cars: 30
Passenger capacity	268 persons
Ship dimensions	L (length) = 222.5 m (approx.) B (breadth) = 25 m (approx.) D (depth) = 20.4 m (approx.)
Planned speed (knots)	28.3

3.2 Automated Operation Equipment

This demonstration experiment project will be carried out by adding the equipment developed for automated operation to the normal equipment of the ship, and not by construction of a ship which is fully equipped for automated operation. The equipment installed for this experiment is generically called the Smart Ferry System. The layout of the equipment is shown in Fig. 1.

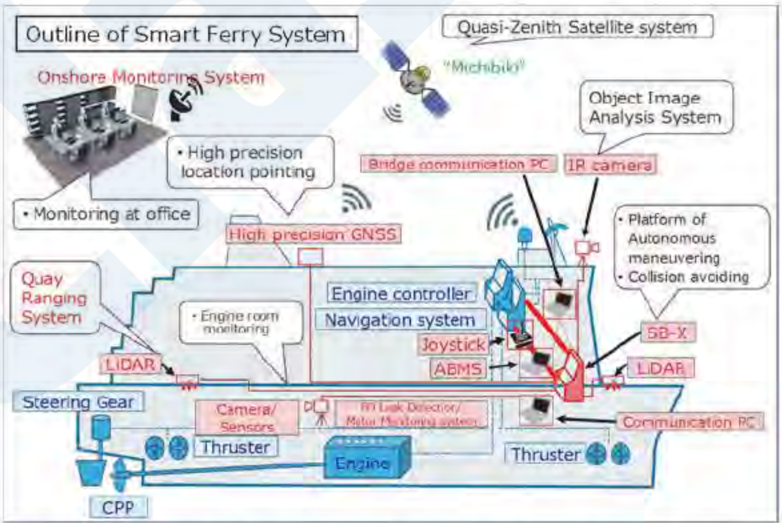

Figure 1 Outline of installation layout of Smart Ferry System

4. FUNCTIONS OF INDIVIDUAL DEVICES

The essential functions that comprise the system for the unmanned operation demonstration experiment are the navigation-related functions of recognition of other ships, automatic collision avoidance and automatic berthing and unberthing, and the function of remote monitoring for remote condition monitoring of the ship's plant, which comprises the propulsion equipment and its auxiliary equipment. In this project, prototypes of the various devices developed for the Smart Ferry System will be installed, the effectiveness of each device in actual waters will be evaluated by a demonstration experiment, and the subjects for development will be identified from the acquired data.

Table 2 shows an outline of the functions of developed devices.

Table 2　Outline of functions of developed devices in Smart Ferry System

Function	Corresponding system	Outline
Recognition of other ships	Object Image Analysis System	Live video in front of the ship with multiple telescope and wide-angle cameras, performs recognition of other ships, buoys and other objects by AI-based image recognition of the acquired images, and displays the results on a monitor. The direction, distance, velocity and heading direction of the detected objects are calculated from the images and displayed. Target recognition is strengthened in addition to radar and AIS.
Automatic ship navigation	Automatic Maneuvering System	Performs navigation tracking the planned course and time.
Automatic ship collision avoidance	Automatic Maneuvering System	Judges the necessity of collision avoidance corresponding to the operation mode (normal voyage, narrow waterway, etc.) based on the TCPA/DCPA against other ships. The rectangular shape safety territories around the own ship and other ships is taken into considered. In cases where collision avoidance is necessary, the system calculate a collision avoidance course and return course and issues rudder steering commands (speed reduction commands if required).
Automatic ship berthing and unberthing	Autonomous Berthing Maneuvering System	Tracks the planned port entering and leaving courses by actuator control of the AI system, referring to high-accuracy GPS data and gyro data.
Quay ranging	Quay Ranging System	Calculates and displays the distance to the quay, the relative speed and the relative angle by LiDAR units installed on the ship for the hazardous distance and speed alarms.
Remote monitoring	Fuel oil (FO) Leak Detection System	Detects fuel leaks from piping by image analysis.
	Motor Condition Monitoring System	Monitors the currents of motors and performs trend analysis. Used in anomaly prediction and diagnosis of motors.
	Onshore Monitoring System	Transmits maneuvering information, information on the engine section plant, including the above, and engine section alarms obtained in the ship to an onshore office, etc. so the ship's condition can be understood from the land side. The accumulated data are used as data for ship anomaly prediction and maintenance by long-term analysis.

5.　FEATURES OF DEVELOPED TECHNOLOGIES

Development in a short term was achieved by integrating the newly developed equipment utilizing AI and image analysis technologies and the ship's normal equipment and devices, and also applying predictive diagnostic technologies owned by this company and its group companies to the ship. The features of these technologies are described below.

5.1 Object Image Analysis System

This system live shoot the area in front of the ship with an infrared camera and automatically classifies the acquired images in real time. The basic system was constructed by photographing ships operating in ports and passing through straits, and then conducting AI machine learning with approximately 10 000 datapoints of learning data. As classifications, objects are classified as ships, buoys, fishing gear and others. It is also possible to successively acquire and add learning data during demonstration experiments.

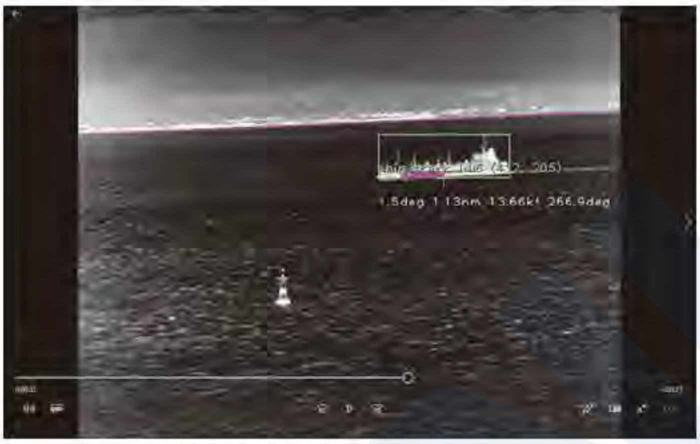

Figure 2 Object Image Analysis System

In order to use these data as information for collision avoidance maneuvering in addition to radar and AIS data, the system is also equipped with a feature that calculates the distance and heading to target objects and the velocity and heading direction of the objects from images. A correction function for ship motion and posture changes is also provided to improve the accuracy of various values calculated from images. Individual data are integrated or separated appropriately in the automatic maneuvering system and used in setting objects of collision avoidance.

The system is also equipped with graphical GUI for display of analysis results.

5.2 Automatic Maneuvering System

In this system, the functions of this company's navigation support system, which provides information support to the ship operator, were significantly improved to enable automatic tracking of set courses for which unmanned operation is possible, speed control by setting the ship's target time of arrival, and automatic creation of collision avoidance courses and collision avoidance maneuvering.

Figure 3 Automatic Maneuvering System

Electronic chart is incorporated in the system, and the system is equipped with a tracking function that navigates the ship so as to minimize deviations between the set course and the ship during normal navigation. It also automatically creates courses that avoid shallow waters by setting the safe water depth contour line of the electronic chart, and maneuvers the ship by properly controlling the ship's autopilot and CPP remote controlling gear.

Collision avoidance is a critical issue for automated ship operation technology. This system creates collision avoidance courses by performing calculations for all objects recognized by the ship's radar, AIS and Object Image Analysis System. In setting the range and collision avoidance, the operation patterns, including the collision avoidance range and speed reduction, are changed depending on the navigation mode, i.e., the steady sailing, inland sea, narrow waterway and in-port modes.

The basis of the collision avoidance setting function is calculation of the time and distance to the point of closest approach of all objects and the provisions of the Act on Preventing Collision at Sea. In addition to that, creation of more practical collision avoidance courses has become possible by asking the opinions of operators and captains while conducting simulations of a large number of assumed encounter patterns in the development stage to consider the characteristics of large-scale coastal ferries, and the factors such as the encounter distance in the bow and stern directions and two sides of the ship, the weighting of the priority order of collision avoidance patterns in congested waters, etc. is incorporated in algorithms for collision avoidance.

5.3 Autonomous Berthing Maneuvering System

For large ferries, safety and high-accuracy maneuvering within the limited space of the port is required when entering and leaving ports. In this project, the following composition was used to satisfy these requirements.

1) Highly accurate understanding of the ship's position by the GPS Quasi-Zenith Satellite System (QZSS) and high-accuracy positioning correction (MADOCA: Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis).
2) Use of the ship's position, heading, speed and other navigational information decided by the captain as setting data for entering and leaving port.
3) Operation of actuators by the AI-based maneuvering system, which tracks the above-mentioned course decided by the captain.

It is possible to secure safety and high accuracy by the above 1) and 2), and robust control against external disturbances, etc. is possible by utilizing 3): actuator control by AI for the tracking function.

This AI system was developed by the deep reinforcement learning technique to perform actuator control so as to minimize deviation from the course. This autonomous berthing technology is a new system which has not been reported previously.

Figure 4 Autonomous Berthing Maneuvering System - Simulation

In large ships, a grasp the ship's response characteristic to steering, that is, a ship motion model, is important. Therefore, a motion model for use in simulations was constructed based on the motion parameters acquired by basin tests using a model of the ship concerned. A berthing/unberthing maneuvering system was developed, and its accuracy was verified by performing actual port entering/leaving operation in a model experiment using the developed system. The robustness of control against wind and waves was also verified in the simulations and model experiment.

Figure 5 Autonomous Berthing Maneuvering System – Model Test

5.4 Quay Ranging System

In this system, small-scale LiDAR units are installed forward and aft on the ship, and the relative distance, relative speed (approach speed of the ship to the quay) and relative attitude of the ship to the quay at medium to close distances are obtained by measurements and calculations based on irradiation of the LiDAR toward the quay. The assumed use of this system is mainly as an alarm during approach. For this experiment, the system was installed on the ship side (rather than the land side) to enable use in any port and to avoid damage by waves, the LiDAR units were mounted at the height of the main deck, which can secure an adequate height above the sea surface. Calculation method of an irradiation angle which are applicable from medium distances to a close distance of 1 meter were developed.

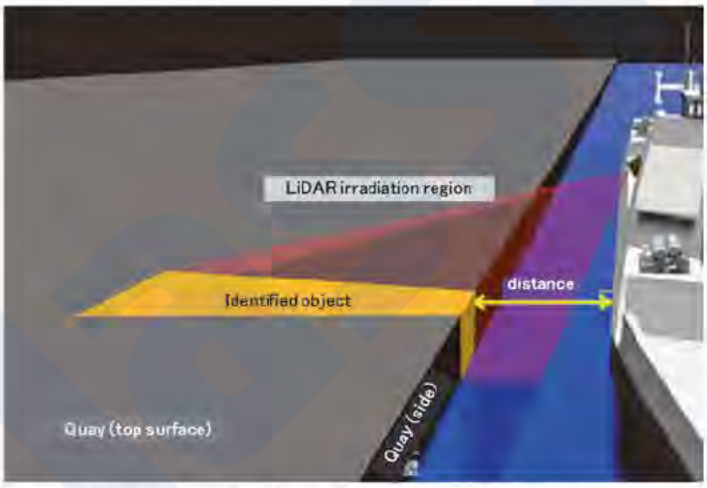

Figure 6 Outline of Quay Ranging System

5.5 FO Leak Detection System and Motor Monitoring System

When considering future automated navigation and unmanned navigation, in addition to automation of voyage maneuvering, it will also be essential to respond to malfunctions of the ship's equipment. Since automatic repair and recovery of equipment is physically impossible, and installation of redundant equipment for all devices is unrealistic in terms of economy and space, a system which enables preventive maintenance is necessary. A system for condition monitoring and monitoring from shore is the key to this.

The fuel oil (FO) leak detection system utilizes image analysis to detect small fuel leaks, which are the most critical problem for fire prevention in the engine room. The system comprises cameras and an image analysis computational section, and can easily be retrofitted in areas with limited space. The image analysis unit detects fuel leaks as an abnormal condition based on learning of the normal condition. Sensitivity and detection threshold values are set in line with the level of illumination level in the actual environment.

Figure 7　FO Leak Detection System

The motor monitoring system performs anomaly detection by measuring the current from motors, utilizing technology developed for land-based power plants. Continuous data observation by this system can provide a more accurate prediction for motor operation.

Figure 8　Motor Monitoring System - Sensors

Data which will contribute to preventive maintenance based on the characteristics of the ship's plant will also be collected by digitalizing propulsion plant data of the ship in accordance with a M0 checklist.

5.6　Onshore Monitoring System

Monitoring and support from shore will be essential in automated navigation and unmanned navigation. The data from navigation-related sensors and engine section alarms and the data log acquired on the ship are all transmitted as data to a cloud server, and can be accessed from the appropriate webpage. This enables monitoring from any onshore office on the ship operation side, without relying on a dedicated device.

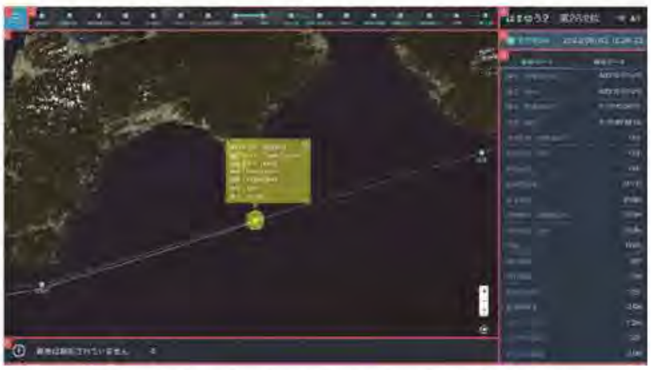

Figure 9　Onshore Monitoring System

Three-dimensional visualization of locations where alarms occur is also possible from designated terminals by using the 3D design data of the engine room.

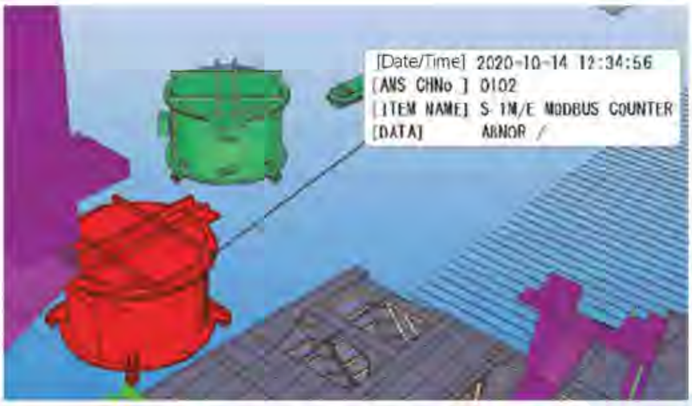

Figure 10 3-D visualization of Alarming part

The problem of cybersecurity is also an important challenge for automated navigation. Although the present case only involves transmission from the ship to a cloud server, and is not intended to perform remote operation of the ship from land, cybersecurity measures were implemented at each location, and the robustness of the safety measures was verified by a penetration test conducted by an outside company specializing in cybersecurity.

6. PURPOSES OF DEMONSTRATION EXPERIMENT AND FUTURE ISSUES

In the demonstration test, various types of measurements and observation and evaluation by the ship's operator will be carried out, contributing to future development.

The evaluation items are ① Comparison with operation by crew, ② Accuracy of operation on an actual ship, ③ Rational linkage with object recognition devices, ④ Effectiveness of onshore monitoring, ⑤ Effective accuracy of sensors and robustness of the maneuvering accuracy under actual marine meteorology and weather conditions.

In addition to the performance improvement of the system described above, it will also be necessary to solve a variety of other problems as future issues for practical application. These include application for operation in various ports with different conditions, development of control method that more closely approximates to the operation by crew, reduction of the cost of the devices, the optical limitations and cost of cameras, linkage of control with the quay side during approaching, and techniques for quick, low cost construction of ship motion models.

Among these efforts, as a technique for automatic planning of courses for entering and leaving various ports, we plan to develop a prototype of a simulation method using the evolutionary computation method CMA-ES, and will verify this technique with the aim of practical application in the future.

7. MEGURI 2040 PROJECT

This project is currently being carried out under the Joint Technological Development Program for Demonstration Experiments of Unmanned Ships with the Nippon Foundation, as part of that organization's "MEGURI 2040" project, in cooperation with the ship's owner, the Shin Nihonkai Ferry Co., Ltd. The development of devices and systems is being carried out with the cooperation of the following universities and companies: Osaka Prefecture University, Osaka University, Brains Corporation, Aidea Inc., Pioneer Smart Sensing Innovations Corporation, MHI Marine Engineering, Ltd. and Kawasaki Heavy Industries, Ltd.

Over the period from 2020 to June of 2021, construction and installation of the various systems on this ship and commissioning and tests will be carried out, followed by the demonstration experiment after the ship enter into service.