ON THE PROJECT TO DEVELOP IT-BASED ADVANCED SHIP OPERATION TECHNOLOGIES AND THEIR APPLICATION TO MARITIME EDUCATION

Hideo Yabuki,
Yoko Uchida,
Tadatsugi Okazaki,
Ruri Shoji,
Tokyo University of Marine Science and Technology
E-mail: yabuki@kaiyodai.ac.jp

Abstract. Following a rapid introduction of Information Technology (IT) into navigational equipment and ship operation supporting systems, development of a new educational method to teach IT-based advance ship operation technology is strongly desired. This paper describes the outline of the TUMSAT project which aims at developing both advanced IT-based ship operation technologies and a curriculum to provide students with sufficient knowledge on these technologies.

1. INTRODUCTION

Information Technology (IT) has found its way into shipping to achieve safe and efficient marine transportation as is exemplified by the IMO e-Navigation Strategy. In order to lead the way in this new field, the Tokyo University of Marine Science and Technology (TUMSAT) launched a new research and development project in 2008 on IT-based advanced ship operation and control technologies, i.e., Maritime Broadband Communication System and Advanced Ship Operation and Control System. The TUMSAT also intends to integrate the outcome of this project into its curriculum to provide young professionals, who will be working for the maritime industry, MET institutions, and the maritime authorities, with sufficient knowledge in advanced marine-related IT technologies.

It is a 3-year project between 2008 and 2010, and is run by four groups: the Maritime Broadband Communication System Group, the Electronic Navigation System Group, the Advanced Ship Operation and Control System Group, and the Advanced Management System for Marine Engineering Group.

The first group attempts to develop a communication system which enables ships at sea and land-based personnel to share ship operation information. The second group aims at developing a navigation assistance system following the e-Navigation Strategy proposed by the IMO. The third group focuses on ship control technologies such as tracking control, ship to ship operation, and automatic berthing. The last group endeavors to develop a knowledge bank system for marine engineering operation.

In this paper, the authors introduce the outline of two research outcomes obtained in 2008. One is the development of Maritime Broadband Communication System that is installed onboard the university training ship Shioji Maru [1]. The other is a practical education method to teach undergraduate students on tracking control engineering using the autopilot of Shioji Maru [2].

2. DEVELOPMENT OF THE MARITIME BROADBAND COMMUNICATION SYSTEM

2.1. Outline of the system

The purpose of the maritime broadband communication system is to realize a new seamless communication service between ships and shore users which is derived by a high speed and a high capacity communication network system. This system, called the Marine Broad Band Network (MBB), has been developed by the Maritime Broadband Communication System Group with the support of 7 manufacturers and companies in Japan.

The MBB utilizes the JSAT Inc.'s satellite and the network service of NTT Communications, Inc. The communication speed of the system is confirmed to be 1 Mbps in up link and 1.2 Mbps in down link between the Satellite and the training ship Shioji Maru by full-scale experiments. In order to realize the broadband communication between ships and shore users, we need a real time data observation system and data transmission technique utilizing the onboard Local Area Network (LAN), and we also have to establish a unified standard of signal communication. Since the establishment and standardization of the onboard LAN system are essential, our project has been technically supported by the Japan Marine Equipment Association.

The MBB system makes it possible to provide seafarers with the same Internet environment as the one on the shore, and useful information for safe navigation, such as weather and wave prediction data, is made available to the Master.

2.2. Applications of MBB communication to the marine transportation

Examples of the application of MBB communication for the safe and efficient marine transportation are shown in Table 1.

Table 1

Examples of the application of MBB network

Field	Item	Form	Contents
Welfares	Welfares for crew	Image,Data	TV phone, Internet, Mail, TV, etc.
Medical	Remote medical service	Image,Data	Diagnosis to patient
Safe Navigation	Outside and inside watch	Image,Voice	Lookout by camera, etc.
Monitoring	Hull monitoring Engine monitoring Cargo monitoring	Data	Monitoring of hull stress, navigation information, ship's motion, engine operating data, etc.
Information Support to Ship	Environmental information	Data	Weather & wave forecasting, Weather routing, Route information, etc.
Guidance	Way point, Tracking and control	Data	Guidance and control of ships in ocean and port
Ship Management	Damage control Ship performance	Data,Image	Damage control, Long term performance management, etc
Risk Management	Hazard at sea	Data,Image	Real time information exchange

2.2.1. Image Data Communication

The most powerful effect that will be obtained by the realization of MBB is the exchange of image data. The shore users and the onboard users can receive or send real and clear image data at the time of their demand.

For example, the image data exchange between ships and shore users is very useful in the case of damage diagnosis of main engine and other machineries. Fig. 1 shows the engine monitoring by the engineer with a head mounted camera in the engine room. The real time image data can be sent easily to shore users through the MBB, and not only onboard seafarers but also the technical staff on the shore can monitor the state of the engine and understand details of the damage clearly. This technique can also be applied to remote medical service for a patient onboard, who can be diagnosed remotely by a doctor on the shore.

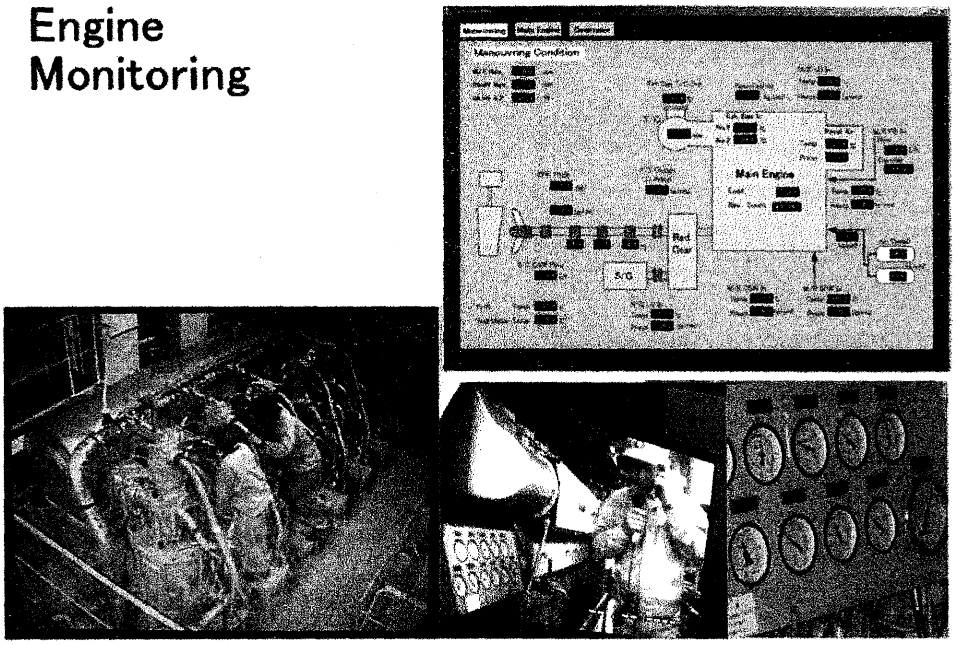

Fig. 1. Engine monitoring with a head-mounted camera

2.2.2. Ship Monitoring System

Nowadays, energy saving in ship operation to promote an eco-society has become the highest priority in the marine transportation. In the ship operation, most of the energy loss is caused by the increase of hull resistance and frequent irregular change of engine revolution due to ship oscillation in a rough sea. Therefore, continuous monitoring and analysis of the ship operation data such as speed, hull motion, wind, wave, the state of engine operation, etc., are important for the energy saving navigation. Fig. 2 shows an example of the display of these ship operation data. However, this kind of work has recently become difficult for the crew due to their reduction in number and the drop in skill. Because of this, the technical staff on the shore can monitor the real time ship operation data instead, and give proper advice to the onboard seafarers for safe and effective operation by analyzing the received data. The displayed time history of hull motion and the data analyzed are shown in Fig. 3.

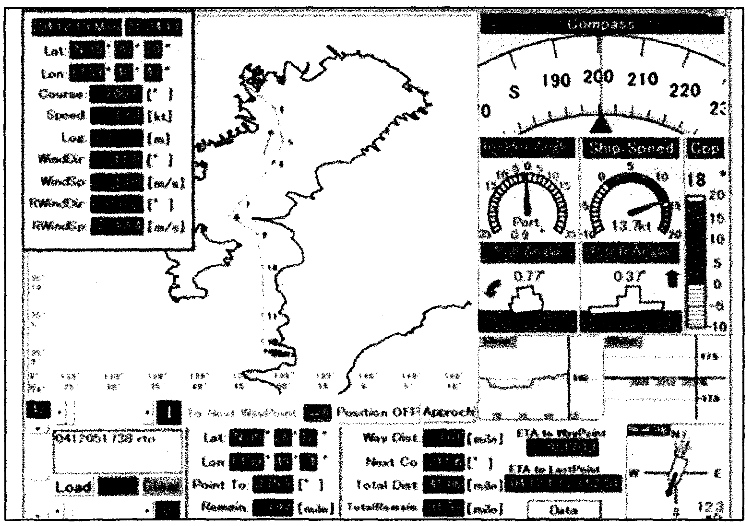

Fig. 2. Example of the display of ship operation data

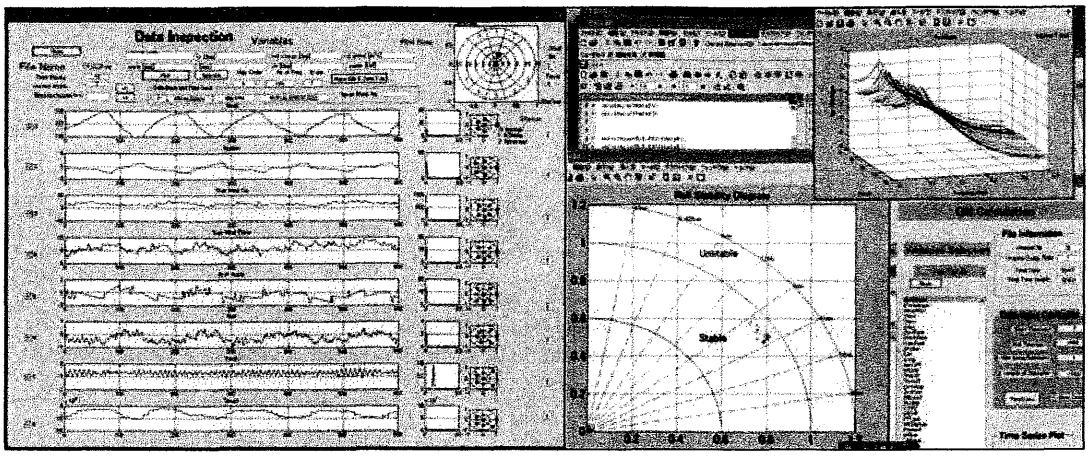

Fig. 3. Displayed time history of hull motion and analyzed data

2.2.3. Long Term Engine Operation Management

Real-time engine operation data is transmitted to the shore server through the MBB and is distributed to each ship, which is stored as a database. For instance, the technical staff can estimate the proper sea margin of each ship by analyzing the long term operation data and informing it to the onboard engineers. Fig. 4 shows the example of the sea margin analysis. The above-mentioned engine operation database can be used for the prediction of seasonal effect and aging effect on the fuel-saving operation, as well as the proper time of hull cleaning in the dockyard.

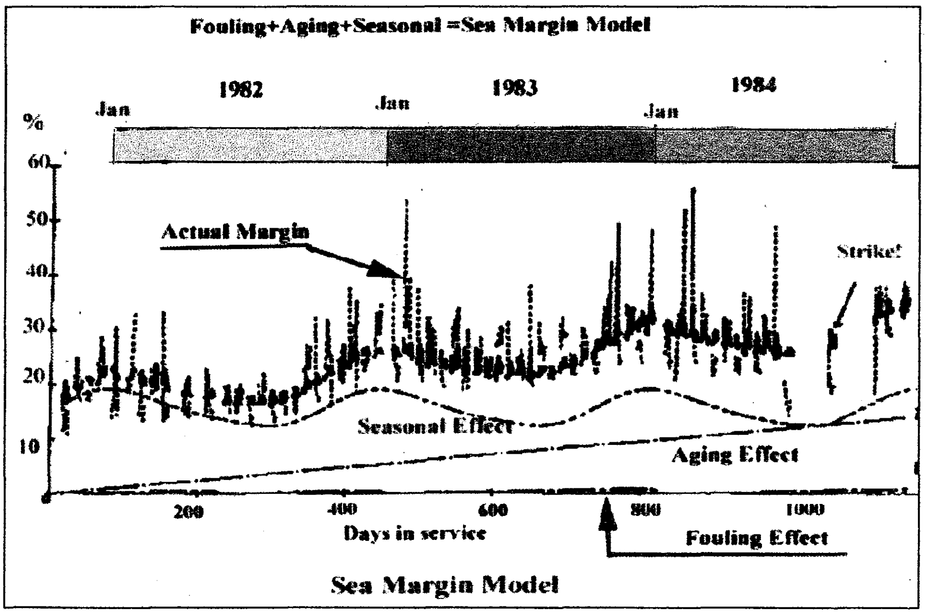

Fig. 4. Example of the sea margin analysis

2.2.4. Ship's Weather Routing

Although domestic ships can provide economical and ecological transportation compared to the vehicles, their operation schedule depends on the marine environment such as wind, wave and current. A voyage plan to minimize the fuel consumption is made prior to the departure, taking into account the change of weather and the effect of current along the route. However, since the forecasted weather condition often changes during sailing, there is a ship's demand to get the latest optimal route information for re-routing calculated based on the present ship operation data via MBB and the updated precise weather forecasting data. Fig. 5 shows the image of this optimal weather routing navigation.

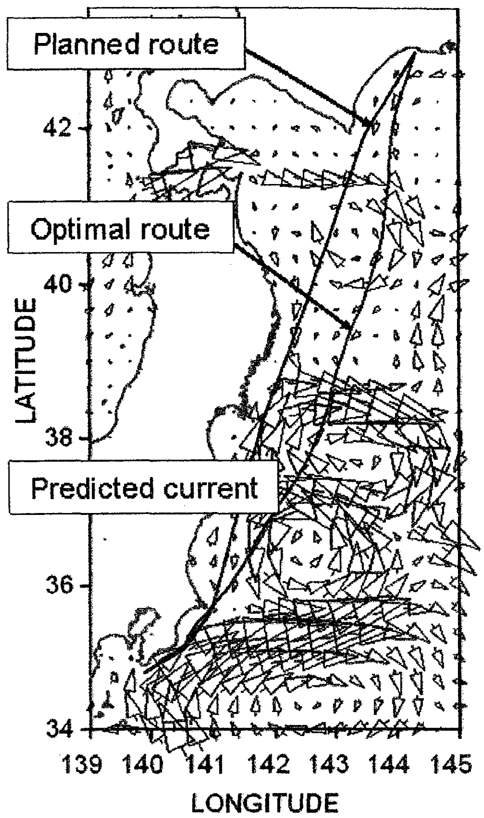

Fig. 5. Image of the optimal weather routing navigation

The Maritime Broadband Communication System Group has already carried out the actual ship operation experiment using a domestic merchant ship [3] and confirmed that the proposed method is feasible and effective for the fuel-saving operation.

3. DEVELOPMENT OF THE PRACTICAL METHOD OF TEACHING MARINE CONTROL ENGINEERING USING A TRAINING SHIP

In this section, the authors introduce a method to teach the conventional control theory to the third year faculty students using the training ship Shioji Maru.

A lecture on the general control theory is first given and how to design autopilot systems is taught making use of the MATLAB and SIMULINK as program languages. Autopilot system is just one of several conventional automatic control systems, but it makes a good introduction for students to understand the PID control theory.

Designing of a control law for actual system is carried out in the following well-known procedures: (1) Identification, (2) Designing, (3) Simulation, (4) Actual Test, (5) Evaluation and Modifying.

The developed teaching method for the students is designed following the above procedures and it uses an actual training ship instead of a small model craft in the laboratory. Fig. 6 shows the procedure of the proposed teaching method.

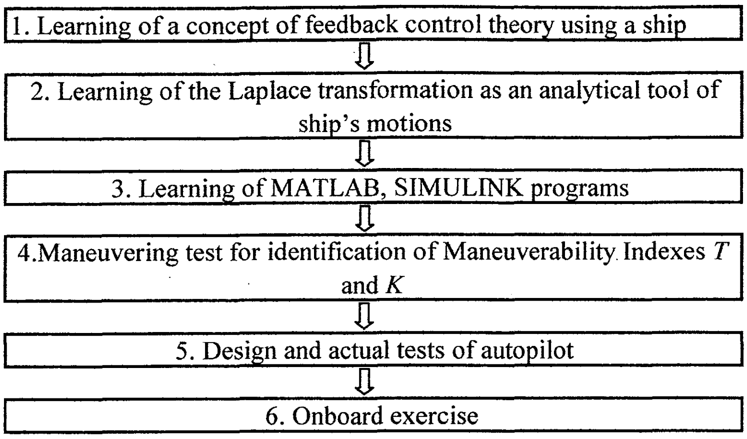

Fig. 6. Procedure of the teaching method on marine control engineering

3.1. Classroom lecture on the feedback control theory and onboard experiments

The ship's autopilot system provides useful information on the concept of feedback control theory, and that is why we have our students design the ship's autopilot in order to teach them the above classical control theory.

As the first step, the teacher has the students understand that the feedback system dealt with in this lecture using an actual ship is one of the important techniques to solve not only the ship's course keeping problem but also more general similar ship control problems.

Fig. 7 shows a comparison of the block diagram between the ship's autopilot system and the first order system treated in the control theory.

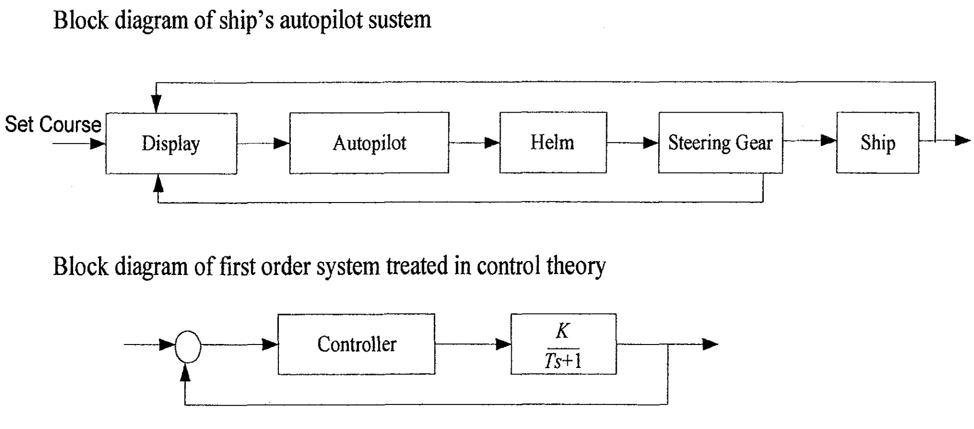

Fig. 7. Block diagram of the autopilot and the first order system

In terms of the ship oscillation theory, the ship's motions are generally classified into two typical systems. One is the first order system which does not oscillate. This system corresponds to ship's yawing motion which is exerted by a rudder. The other is the second order oscillating system which corresponds to a rolling motion in waves.

In particular, the ship's autopilot system that aims to keep the ship's course to the desired direction is a typical control system on the first order system. Therefore, by learning the autopilot system, the students can master other designing techniques that also make use of different first order large systems.

The Laplace transform technique is an important tool for system analysis and designing of effective control system. The teacher should teach the theory by use of actual system, not the concept of the system. In this lecture, we select a ship's course keeping problem as a first order system and a ship's rolling motion as a second order system.

The famous model for representing a ship's yawing motion by steering is Prof. Nomoto's KT model [4] and it can be described as following equation.

$$T\dot{r} + r = K\delta \qquad (1)$$

where r is a turn rate of ship's yaw and δ is a rudder angle, T is the index representing a ship's transient characteristic, and K is the index representing a ship's turning characteristic.

The transfer function of this model is

$$G(s) = K/(Ts+1) \qquad (2)$$

The feature of this lecture is that the students study the standard classical control theory using the MATLAB and SIMULINK programs and the actual training ship.

MATLAB and SIMULINK are the most powerful programming languages for designing a control system, and TUMSAT utilize these program languages as a fundamental education tool for students. Moreover, we can build up an actual executable real time control target program using the MATLAB, xPC target system. The xPC target system consists of the server PC, in which Analog/Digital, Digital/Analog and Serial COM interface are installed, and the client PC which has MATLAB and SIMULINK installed. The students make a program as shown in Fig. 8 using the SIMULINK.

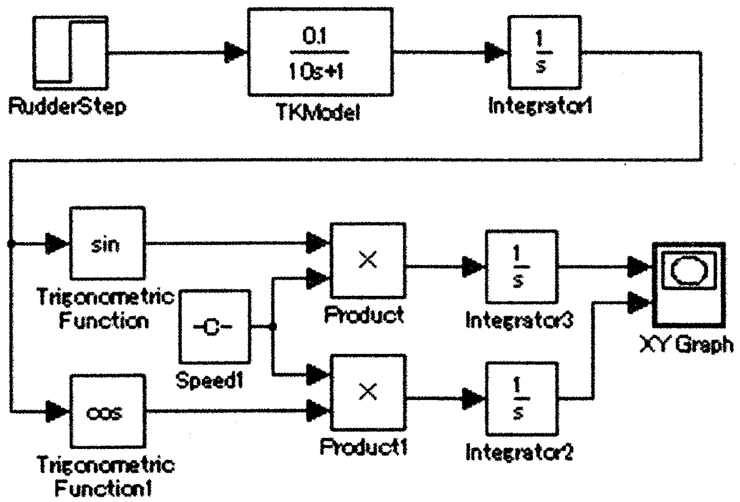

Fig. 8. SIMULINK program for the ship's yaw motion model

In general control theory, the designer must input a special signal such as the step input and the impulse input to the target system for identification of the system. In the field of naval architecture, the designer executes an actual sea trial called the Zigzag test (Z-test) for identifying the parameters T and K.

In the proposed teaching method, the students conduct Z-test by themselves onboard training ship SHIOJI MARU and identify the parameter T and K. It can also be executed automatically by the xPC target system.

3.2. Design of autopilot and its evaluation

The next step is to design an autopilot for Shioji Maru which has both course keeping function and course tracking function. Fig. 9 shows a diagram of the PID autopilot system designed by our students.

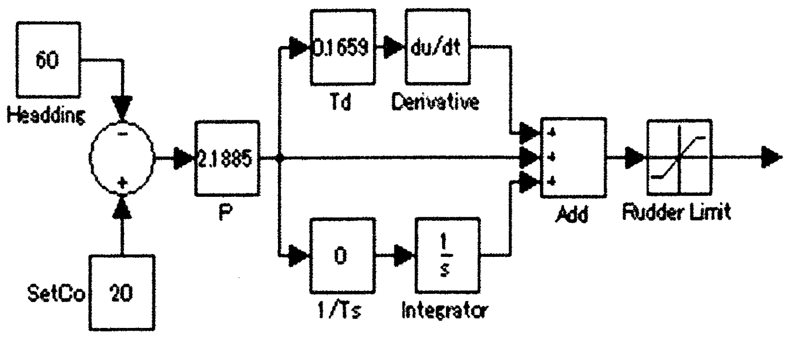

Fig. 9. PID autopilot designed by a student

Usually, the tuning of PID gains is made using the rule of thumb method after the sea trial. However, the SIMULINK system has a support system to preliminarily check the tuning results of PID gains prior to the sea trial. Therefore we teach the Ziegler-Nichols method, the limiting sensibility method and the root locus design method using the SIMULINK at the preparatory lecture.

After completing the preparatory exercises, the students take the challenge to carry out actual onboard tests with PID gains set by them selves. Fig. 10 shows the result of the actual course keeping test using Shioji Maru.

The last step of the exercise is the design of the course tracking function and their evaluation. In the exercise, 15 students are divided into 3 small groups and the work described below is assigned to each group. This exercise is a competition, and is conducted onboard Shioji Maru using the experiment facility shown in Fig. 11.

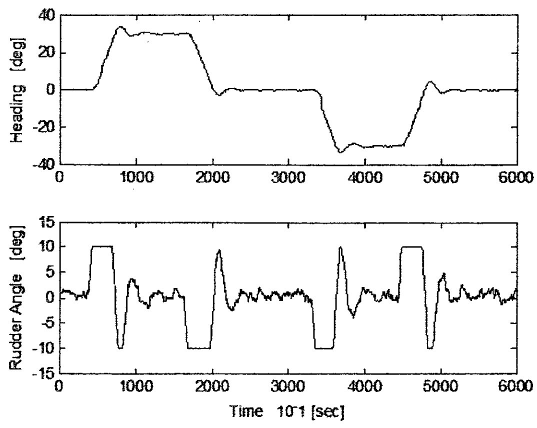

Fig. 10. Result of the actual course keeping test using Sioji Maru

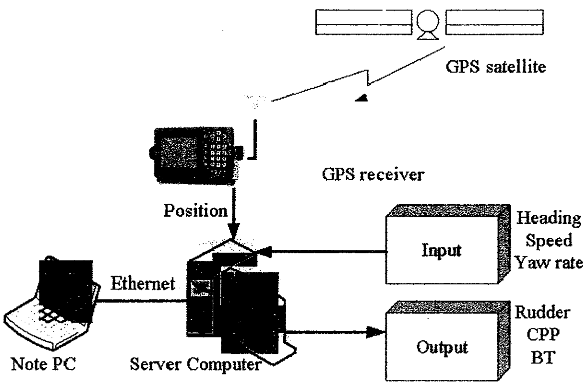

Fig. 11. Experiment facility in Shioji Maru

Assignment Directions: Design an automatic tracking system to track along the given line, using the autopilot designed in the last exercise. The ship's positions can be observed by DGPS (Differential Global Positioning System).

Fig. 12 shows the result of the best performer in the exercise. It is possible for the instructor to evaluate the fundamental knowledge of the students on the autopilot easily through this onboard exercise.

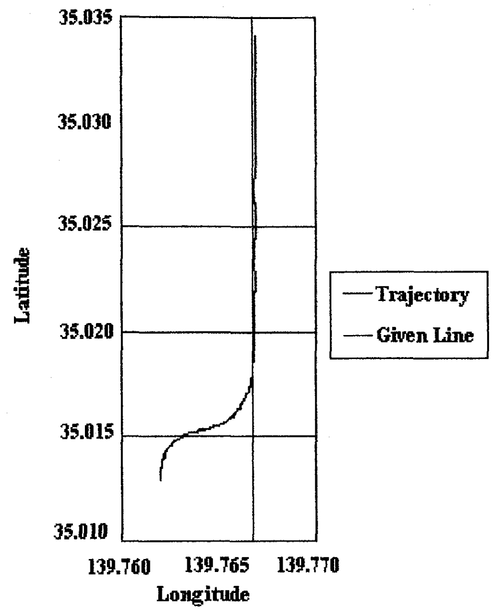

Fig. 12. Result of the top performance of the exercise

4. SUMMARY

In this paper, the authors introduced two outcomes of the IT-based advance ship support system research project in the TUMSAT.

On the Maritime Broadband Communication System, we described the necessity of a high speed, high capacity communication system between ships and the shore, and introduced some of the applications which utilize the MBB network for ship operation support from the shore. We believe that the Maritime Broadband Communication System such as MBB is effective to realize a safe and energy-saving eco-navigation system.

We developed two educational programs on the ship control. One program is to learn the PID control theory using the autopilot and the other is for the learning of the linear oscillation theory. Usually, the automatic ship control technique and the basic linear oscillation theory are taught using a small model in the laboratory. The proposed teaching method utilizes the actual training ship and the students can experience the way the above theory is applied to actual ship-handling. This will be a good help for students to understand these complicated control theories. As our next step, we are planning to develop a program for students to learn about the remote communication theory utilizing the satellite-based ship to shore network system installed in Shioji Maru.

References

[1]. Shoji R. et al., "Development of Maritime Broadband Communication", Proceeding of the 1st workshop on Development of Advanced Ship Support System using Information Technology, TUMSAT, February 2009.

[2]. Okazaki T. et al., "Practical Education for Marine Control Engineering Using an Actual Training Ship", Proceeding of the 1st workshop on Development of Advanced Ship Support System using Information Technology, TUMSAT, February 2009.

[3]. Takashima K. et al., "Energy Saving Navigation for Coastal Ships Based on Precise Environmental Forecast", Proceeding of Asia Navigation Conference 2007.

[4]. Nomoto K. et al., "On the steering of ships," ISP, vol. 4, 1957.