A Challenge to Development of Technology on Autonomous Navigation

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1. Introduction

Designing the Future of Full Autonomous Ship (DFFAS) is one of the consortiums of MEGURI2040[1)2)] autonomous ship project which promoted by The Nippon Foundation. This paper attempts to ROUTE PLANNER with the outcome of the demonstration test which conducted from February 26th to March 1st, 2022 in Japan.

2. DFFAS Project

"DFFAS Project" is a project launched in 2020 by a consortium of more than 60 companies and organizations including domestic and international partners. With a view to long-term industrial growth, we expect the following effects by developing future-oriented technologies through Open Innovation. Development of a high-dimensional system by bringing together the knowledge of experts and future researchers from different companies and industries. Establish core rules for autonomous navigation technology, contribute to the development of the industry as a whole, and create a forum where new players can participate in the competition. Draw up a GRAND DESIGN for autonomous ships in Japan and realize their implementation into society.

Early this year 2022, Demonstration test was conducted by 749 GT containership "Suzaku" equipped with a container which stored the autonomous navigation system and make a round trip between Tokyo Bay and Ise Bay using the system. A purpose of this test is to bring about a logistics revolution in Japan through the diffusion of autonomous navigation technology.

As shown in Fig. 1, the DFFAS autonomous navigation system (DFFAS system) consists of an "automatic navigation planning and control system (vessel side)" that performs autonomous functions, a "fleet support system (land side)" that supports the vessel from land, and a "communication infrastructure system" that manages communication lines and information management control.

Fig. 1 DFFAS system configuration.

3. Concept of route planner in DFFAS

In DFFAS, a voyage plan that covers a range from a departure port to an arrival port is defined as a long-term voyage plan, and a revised voyage plan that deviates from an originally planned route for avoidance, etc. is defined as a short-term voyage plan. Here, a route planner refers to a design module whose task is to design short-term voyage plans. The main task of planner is not only design avoidance plans, but it is also responsible for designing berthing and unberthing maneuvering plans that are susceptible to disturbances during low-speed navigation.

In this section explains a workflow when planning a voyage plan centered on the planner. Fig.2 is a diagram briefly explaining the roles of the components and the flow of information between them. Planner simulates the positions of own ship and other ships in a near future based on constantly updated sensor information (own ship and target information, etc.) and a currently adopted voyage plan (monitoring route) and predicts a risk of collision. Design a short-term voyage plan in a form that ensures the safety parameters given by the shore side system as necessary and send the short-term voyage plan to the information integration unit which is called as Action Planning Unit (APU) located in the same subsystem. The sent short-term voyage plan is route-checked by the APU, and if there are no problems, the actuators are controlled by the control device DTC (Drive Train Controller) of the same subsystem.

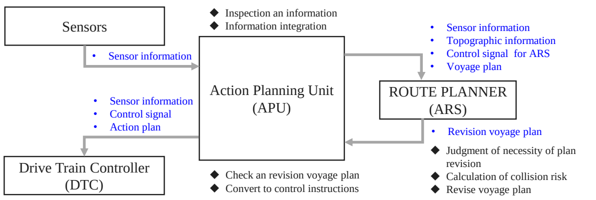

Fig. 2 Signal flow around route planner.

The route planner in DFFAS was handled by a module called ARS (Advanced Routing Simulation and planning) developed by the authors (Fig. 3).

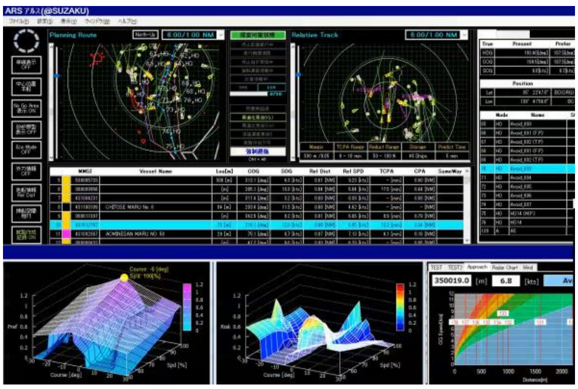

Fig. 3 ARS screen just before entering "Uraga Channel".

Since 2016, authors start research on sea area assessment and ship avoidance and conducted the test by actual ships by coastal carrier (Loa 161m), pure car carrier (Loa 199m) and "Suzaku" was the third ship. Authors made significant improvements to the issues arose through previous tests.

4. Outline of Demonstration tests

The demonstration tests were conducted as a round trip between the port of Tokyo and the port of Tsu-Matsusaka. The demonstration tests include a test of remote control from the Fleet Operation Center which established in Makuhari, Chiba Prefecture, Japan. Fig.4 show the Outline of the demonstration test.

Test1(West Bound): 2022/02/26(Sat) - 2022/02/27(Sun)

Test 2(East Bound): 2022/02/28(Mon) - 2022/03/01(Tue)

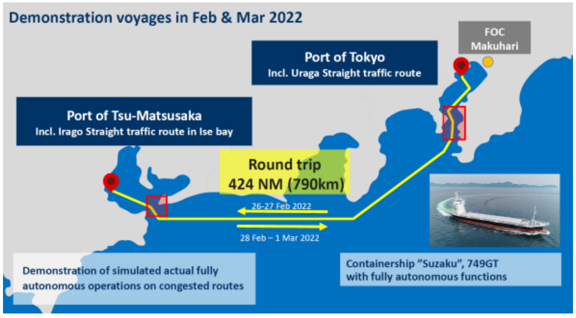

Fig.4 Outline of the demonstration.

Fig. 5 Validation ship "Suzaku".

5. Test results

Tables 1 and 2 shows the breakdown (by time and distance) of autonomous navigation, remote operation (remote), and operation by onboard crew (seafarers) during the Demonstration voyage. And Table 3 shows results of planner's performance. During the demonstration test, there were times when the ship's crew temporarily switched to manual operation, but during the approximately 20-hour one-way trip, autonomous navigation achieved 97.4% on the outbound trip and 99.7% on the return trip. We have achieved autonomous navigation at a high rate including Tokyo Bay Uraga Channel and Ise Bay Irago Channel, which are highly congested waters in Japan.

Table 1 Voyage records by the time

Navigation Route	Sailing Hours [hh:mm]			Total	Achievement ※1
	By System	By Remote	By Seafarer		
Test 1 West Bound	19:23	00:16	00:31	20:10	97.4%
Test 2 East Bound	18:03	01:31	00:04	19:38	99.7 %

*1 Percentage of total time for "System" and "Remote" out of total navigation time

Table 2 Voyage records by the distance

Navigation Route	Distance [NM]			Total	Achievement ※2
	By System	By Remote	By Seafarer		
Test 1 West Bound	199.3	2.8	5.4	207.5	97.4%
Test 2 East Bound	197.4	18.2	0.8	216.4	99.6 %

*2 Percentage of total distance for "System" and "Remote" out of total navigation time

Table 3 Voyage plan output record

Navigation Route	Number of outputs	Number of re-outputs *3	Number of approvals	Number of rejections		
				By System	By Seafarer	Total
Test 1 West Bound	107	63	99	5	3	8
Test 2 East Bound	39	17	35	3	1	4

*3 Within 5 minutes

On the other hands, As shown in "Number of outputs" and "Number of re-outputs" in Table 3, 63 out of 107 outputs in Test 1 and 17 out of 39 outputs in Test 2 were re-output within 5 minutes. This means that the other ship's behavior prediction ability is immature, and the plan is being output with no leeway. Also, in the preparation stage, veteran captain's expert judges were useful in evaluating the plan output by the route planner. However, in order to improve the development speed in the future, it will be necessary to development objective evaluation methods for autonomous navigation equivalent to expert judges.

6. Conclusion

During this demonstration, we successfully conducted the first in the world fully autonomous operation of long-distance voyages including highly congested areas. The success ratio of fully autonomous operation was 98.5% in total. On the other hand, it was confirmed that the following points are particularly need to be improved and developed.

- Improving ability to predict behavior of other ships for efficient route design.
- Development objective evaluation methods for autonomous navigation equivalent to expert judges.

Acknowledgments

The DFFAS project was under MEGURI2040 which is autonomous ship project supported by Nippon Foundation. Would like to thank Nippon Foundation and all the people involved in DFFAS for giving me this opportunity.

Reference

1) The Nippon Foundation HP, news release, https://www.nippon-foundation.or.jp/en/what/projects/meguri2040

2) Japan Marine Science Inc HP, news release, https://www.jms-inc.jp/news/detail/39/en

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