MMAR 2002 2 – 5 September 2002, Szczecin, Poland
8th IEEE International Conference on Methods and Models in Automation and Robotics

AUTOMATIC PASSAGE PLANNING FOR VESSELS BASED ON EXPERT KNOWLEDGE

Makoto ENDO†, Kazuhiko Hasegawa‡

† Toyama National College of Maritime Technology, Department of Maritime Technology, Shinminato, Toyama 933-0293, Japan, endo@toyama-cmt.ac.jp
‡ Osaka University, Department of Naval Architecture and Ocean Engineering, Suita, Osaka 565-0871, Japan, hase@naoe.eng.osaka-u.ac.jp

Abstarct. The authors have tried to develop the maneuvering assistance information system for small inland vessels and have especially studied on the automatic passage planning system. In this paper, the automatic passage planning system based on standardized expert knowledge of maneuvers in a port and ship-handling skills on a small inland vessel is discussed. The proposed passage planning system consists of following four phases; 1) Finding a path under geographical and legal r estrictions, 2) Planning a chain of elemental passages, 3) Planning a route and 4) Planning a chain of elemental maneuvers and their maneuvering orders. Simulation along the planned passage by the system shows the good tracking performance. In order to verify the algorithm of the passage planning system, simulator experiments by skillful operators have been executed. And also the maneuvering assistance system including the automatic passage planning is outlined.

Key Words. Vessel, passage planning, support system, skill based automation

1. INTRODUCTION

When a large vessel enters and leaves a port, a pilotage by a pilot is provided to the vessel with a legal basis. This pilotage keeps the safety operation of the vessel and contributes the safety and effective port operation. But in Japan, almost 10 or more times as many as the number of legal piloted vessels have accessed ports. Almost all of them are small inland vessels which have no legal basis on not only pilotage but also VTS: Vessel Traffic Service and AIS: Automatic Identification System. Many marine accidents on the small inland vessels had been occurred in and around Japanese ports. From a viewpoint of safety port operation and efficient traffic management, maneuvering assistance for whole vessels, including small inland vessels, entering and leaving ports should be provided and it would be possible by using the current communication and navigation technologies.

If information of an appropriate planned passage, like a pilotage, for each inland vessel entering a port is provided to the vessel automatically, her operator can maneuver the vessel more safely and enter a port without any delay. The authors have tried to develop the maneuvering assistance information system for small inland vessels and have especially studied on the automatic passage planning system [2,4]. In this paper, the automatic passage planning system based on standardized expert knowledge of maneuvers in a port and ship-handling skills on a small inland vessel is discussed. Simulation along the planned passage by the system shows the good tracking performance. In order to verify the algorithm of the passage planning system, simulator experiments by skillful operators have been executed.

2. AUTOMATIC PASSAGE PLANNING SYSTEM

In order to realize the automatic passage planning system, first of all, the standard paradigm of passage planning by expert and skillful mariners is investigated by questionnaire surveys and passage planning experiments

2.1 Passage Planning Paradigm

Expert captains have much experiences to maneuver vessels. Pilots have not only much experiences to maneuver vessels but also much priori knowledge on the target port.

A passage planning for a vessel in a water area should be produced based on these priori experiences and knowledge. This planned passage has to include a planned route and a maneuvering plan. The standard passage planning consists of two planning. One is route planning and the other is planning maneuvers.

Planning a route

A route should be planned in according with planning guidelines, such as UKC, distance off, recommended and legal passage and etc. This route is a chain of quadrilateral elemental pa ssages. Each quadrilateral elemental passage is defined by its width, length and course. For planning a route, the priori knowledge on the target water area is necessary.

Planning maneuvers

A maneuvering plan is to maneuver a vessel along with the planne d route. Maneuvers of the vessel are classified into some kinds of elemental maneuvers, such as course alternation, turning, stopping and etc., as shown in Fig. 1. This maneuvering plan should compose a chain of elemental maneuvers and maneuvering orders. For planning maneuvers, the priori knowledge on maneuverabilty characteristics of the vessel is needed.

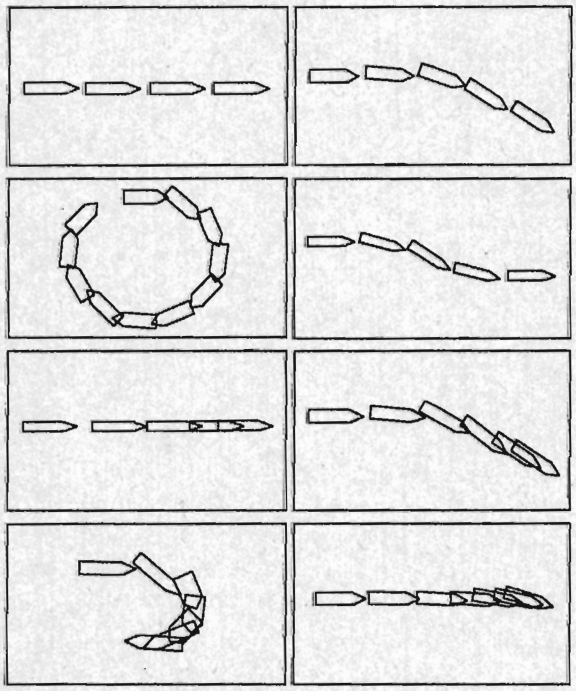

Fig. 1 Elemental Maneuvers

2.2 Phased Process of Passage Planning System

Computational reproducing the above-mentioned standard passage planning paradigm of expert and skillful mariners was tried, in order to get a appropriate passage plan for a ship in a water area automatically. The standard passage planning paradigm consists of following four phases.

- 1^{st} ***Phase:*** Finding a path under geographical and legal restrictions
- 2^{nd} ***Phase:*** Planning a chain of elemental passages
- 3^{rd} ***Phase:*** Planning a route
- 4^{th} ***Phase:*** Planning a chain of elemental maneuvers and maneuvering orders

Necessary functions corresponding with each passage planning phase were developed and the details of the functions and the phases are described in the next section..

2.3 Simulation of the Passage Planning

Simulations based on the above-mentioned standard passage planning paradigm, which consists of 4 phases, were executed. Planning a passage for a 499GT inland vessel, through the Rainbow Islands: a imaginary sea area, from the origin/start in a open sea to the destination/goal in front of a berth in the North Bay, were simulated. Simulation result on each phase is shown in Fig.2 – Fig.5. The origin/start is at the lower left and the destination/goal is at the upper right in the Rainbow Islands, as shown in Fig.2 – Fig.4. Principal particulars of the target ship, which is a 499GT inland vessel, is shown in Table 1.

Table 1. Principal particular of 499GT Inland v essel

Gross Tonnage	498 T	
Length p.p.	70.00 m	
Breadth	11.80 m	
Depth	7.20 m	
draft	3.78 m	
MCR	2400 ps x 260 RPM	
NOR	2050 ps x 240 RPM	
Bow Thruster	203 ps x 2.03 t	
Stern Thruster	162 ps x 1.52 t	
RATING	RPM	SPEED(kt)
Navigation Full	240	12.4
Full Ahead	240	12.4
Half Ahead	180	9.3
Slow Ahead	120	6.2
Dead Slow Ahead	60	3.1

- 1^{st} ***Phase; Finding a path***

In the Rainbow Islands, there are many No -Go areas, which are defined by the water depth contour lines of the chart, based on the UKC: under keel clea rance of the vessel. Paths from the origin to the destination should avoid No-Go areas and also should be freed from a deadlock caused by concaved No-Go areas, such as ports and bays. In order to search paths, edge:(No-Go areas) tracing Deadlock-Free algorithm was used. Some paths were found and the shortest

path of them was selected, as shown by the gray colored line in Fig. 2. But there are often some recommended passages or legal based passages in and around ports. Re-finding another shortest path through the recommended entrance passage from the origin to the destination was done, because there is a recommended passage around the entrance of the North Bay in the Rainbow Islands. Finally the shortest path through the recommended passage was selected, as shown by the black solid line in Fig. 2.
shortest path through the recommended passage.

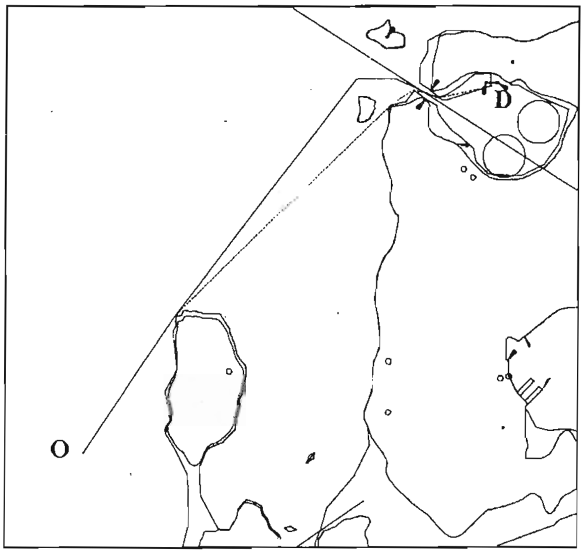

Fig. 2 Shortest Path

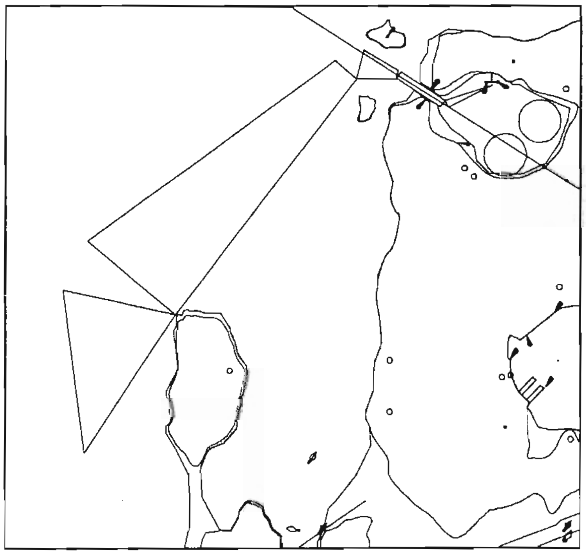

Fig. 3 Chain of Elemental Passages

- ***2***

- ***2^{nd} Phase: Planning a chain of elemental passages***

The above path is only a chain of straight segments. A chain of continuous passages, along the path, with margins of safety should be created. To keep safety margins of passages, maximum navigable width of each passage was searched. If an obtained width is too narrow compared with a recommended distance off in the guideline, this narrow passage should be divided into two passages with enough distance off. Continuity of two passages was secured to set the outlet of the passage and the inlet of the next with the same width. A chain of continuous elemental passages, as shown in Fig.3, was obtained.

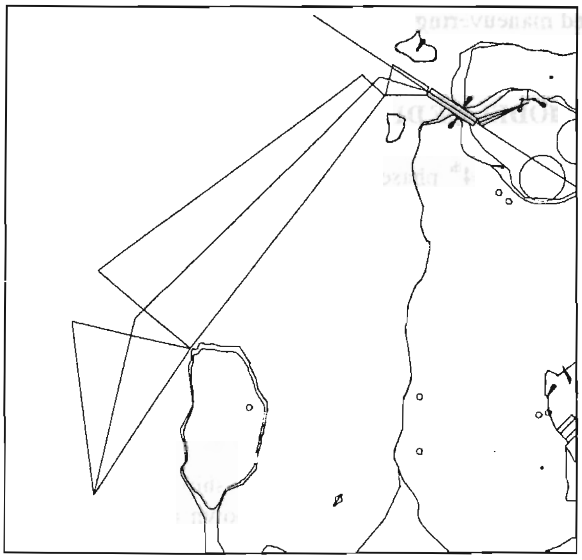

Fig. 4 Planned Route

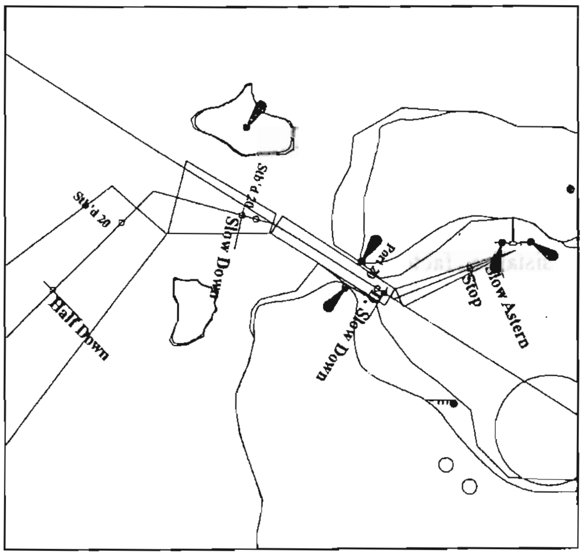

Fig. 5 Chain of Elemental Maneuvers and Orders

3^{rd} Phase: Planning a route

A planned route based on the above chain of elemental passages, which keeps center of each passage, was proposed, as shown in Fig. 4. If an angle between two courses at a waypoint is larger than the set maximum angle, such as 90 degrees, one more new waypoint should be added around the original waypoint to decrease the alteration angle. And if an angle between two courses at a waypoint is less than 5 degrees, this waypoint should be removed.

- ***4th Phase: Planning a chain of elemental maneuvers and maneuvering orders***

According to vessel maneuvering guidelines on course alterations and decelerations, wheel over positions, rudder orders, telegraph orders and their positions were fixed on the above planned route. Fig. 5 shows the proposed chain of elemental maneuvers and maneuvering orders finally.

3. MODEL OF DECELERATION MANEUVERS

The above 4th phase: planning a chain of elemental maneuvers and maneuvering orders should be based on the standard maneuvers. In order to get the model of standard maneuvers and orders by expert and skillful mariners, questionnaire surveys and passage planning experiments on deceleration maneuvers were executed. Through these surveys and experiments, a model of standard deceleration maneuvers was found.

When the speed response of the ship motion to a telegraph order, such as the half down and the slow down orders, is approximated to a first order differential equation as shown by the following, the standard deceleration maneuvers and orders have been executed at each twice the time of constant T of the equation.

$$m\frac{dv(t)}{dt} + c \cdot v(t) = k \cdot n(t) \quad v(t): Speed[m/s] \;\; n(t): RPM$$

$$\text{Time Constant } T = {}^{m}\!/_{c}$$

Constants of the above equation, which are m: mass, c: resistance factor and k: thrust factor, can be estimated from the principal particulars of the ship.

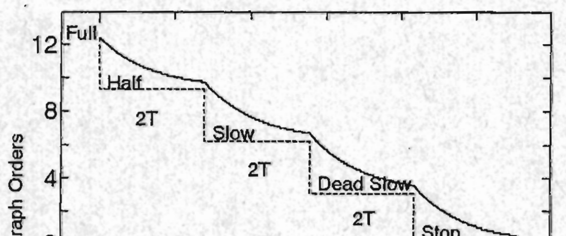

Fig. 6 Model of deceleration maneuvers on a 499GT inland vessel

Fig. 6 shows standard deceleration orders based on this model and their simulated responses of the 499GT inland vessel. Distances from the stopping position at each telegraph orders were roughly coincided with the results of questionnaire surveys on deceleration maneuvers.

4. VERIFICATION OF THE AUTOMATIC PASSAGE PLANNING SYSTEM

In order to verify the automatic passage planning system, the plans generated by the system had been compared with the plans of expert mariners.

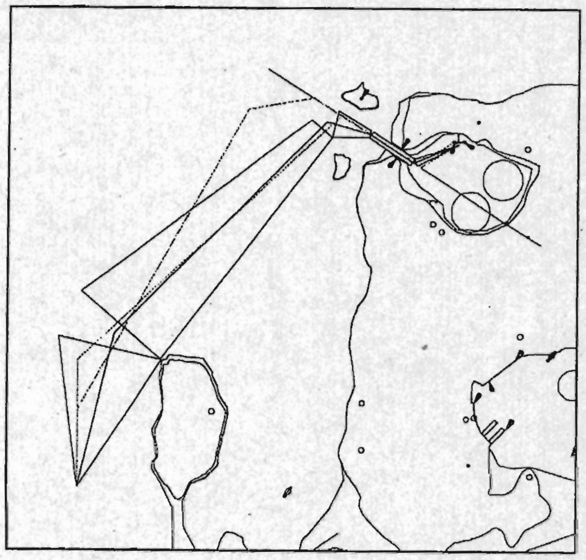

Fig. 7 Routes of the experts and the system

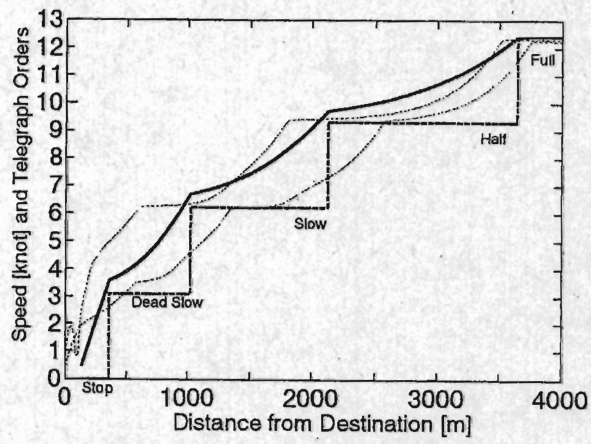

Fig. 8 Deceleration of experts and the system(model)

Fig. 7 shows the planned routes of two expert mariners and the system. The gray colored lines are of the experts and the black line is of the system. Fundamental difference between them is not found.

The results of simulator experiments on maneuvering the vessel from the origin to the destination by two expert mariners are shown in Fig. 8, comparing with the result of the above-mentioned deceleration model.

The gray colored lines shows simulator experimental results and the black line is on the model. These three lines are similar. It is obvious that the model can generate the standard deceleration maneuvers and orders.

The passage plans generated by the system is generally accepted by simulator testees as expert mariners. But appropriateness of the generated passage plans and usefulness of the system were not verified quantitatively.

5. PORTABLE INFORMATION SYTEM FOR MANEUVERING ASSISTANCE

How to provide a passage plan for a vessel on the sea is another big problem. From 1998, the authors have developed a portable information system for maneuvering assistance, by using the current communication and navigation technologies, to solve this problem [2,4]. A prototype of the system as a vessel terminal is shown Photo. 1 and some field tests of the system in the sea were already executed.

Photo. 1 Prototype of Vessel Terminal

6. CONCLUSIONS AND PERSPECTIVES

The author concludes by listing important points of this study.

- The automatic passage planning system, which is one of the countermeasures answering the requests of vessels and port operators, was proposed.
- Simulation results of the passage planning system show that the system can reproduce the passage which the expert mariners plans usually
- It is considered that the system is effective to increase safety and economical efficiency on port management.

7. REFERENCES

1. A, J, Swift: BRIDGE TEAM MANAGEMENT – A Practical Guide -, The Nautical Institute, UK, 1993
2. Makoto Endo, S. Niimura, T. Otani, T. Ugajin: Development of Remote Safety Management System for Small Vessels, Proceedings of International Symposium Information on Ships ISIS98, Germany, 1998, pp. 6.1-6.7
3. National Research Council: MINDING THE HELM - Marine Navigation and Piloting -, National Academy Press, USA, 1994
4. Makoto Endo: SHORE-BASED PILOTAGE INFORMATION SYTEM, Proceedings of 5th Conference on Manoeuvring and Control of Marine Craft MCMC2000, Denmark, 2000, pp. 293-298