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Implementation of Automatic Ship Berthing using Artificial Neural Network for Free Running Experiment

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Abstract: Ship berthing has always considered as a multiple input multiple output phenomenon. And such controlling action becomes even more sophisticated when the ship approaches to a pier especially in low speed. The current and presence of wind also make the task more complicated. But, if a human brain can be replicated by any artificial intelligence technique to perform the same necessary action that human brain does, then automatic operation during complete berthing process is believed to be possible by many researchers. For that purpose as an initial stage of this research, artificial neural network is chosen as one of AI techniques for automatic berthing and to increase its learnability, concentration is given on the consistency of the teaching data provided. To do that, nonlinear programming method is used where ship's actual behavior is predicted using famous manoeuvring mathematical group model. After successfully training, ANN controller is tested for various known and unknown condition including wind disturbances and found good results. Finally, to verify the simulated successful results, the current research is based on execution of free running experiment with the implementation of automatic ship berthing using the same trained ANN where adequate decisions for command rudder and propeller revolution taken are decided automatically depending on real time multiple input parameters.

Keywords: Free running experiment, Artificial Neural Network (ANN), Non Linear Programing, Manoeuvring Mathematical Group (MMG), Global Positioning System (GPS), Gyroscope.

1. INTRODUCTION

Ship handling during berthing has considered as one of the most sophisticated tasks that a ship handler has to face. Each ship's response is different during manoeuvring and presence of wind and other external disturbances make the task of berthing more complicated especially in low speed. As a result, since 1997 the annual cost of dock damage claims increase from $3 million to $12 million. And almost 70% of the these claims can be put down to bad handling, errors in ship control, tug error or pilot error. To reduce such accidents, the use of automation for ship berthing would be a great relief. To bring the automation in ship berthing different researchers tried different algorithms. Different types of controller such as feedback control, fuzzy theory, neural network, optimal control theory and expert system are tried to cope with such situation. The first research in automatic ship berthing using ANN was started by Yamato *et al.* (1990) but he then changed his approach and adapted expert system. Fujii *et al*. (1991) then used both supervised and non-supervised learning system to construct neural network based controller for AUVs and compared the results. Since then Hasegawa *et al.* (1993), IM *et al.* (2001, 2002) and many others have continued such research for berthing purpose. But their success was up to certain limit. Especially the maximum wind velocity consideration was limited to somewhat small value and the cross wind was crucial. Moreover, for training the neural network the teaching data contained lack of consistency. As a result, even such data are used for training net, it often possesses confusion when using non-teaching data for berthing process. To eliminate such difficulties and to make the controller more robust, in this research the whole manoeuvring plan is divided into three basic elementary manoeuvres which are course changing, step deceleration and stopping. For course changing part, a new concept is used to ensure the consistency of the teaching data which is named as virtual window concept (Ahmed *et al.*, 2012). Using this concept ships from any possible heading angle can make necessary course change to merge with the imaginary line well ahead from the berthing goal point. Imaginary line is another concept that most of the ship handlers follow during approaching the pier and it is usually imagined making a certain angle like $30^{\circ} \sim 45^{\circ}$ to the pier. For course changing manoeuvre, using NPL method (Sugita *et al.*, 2012) four virtual windows are formed with rudder angles restricted within $\pm 10^{\circ}$, $\pm 15^{\circ}$, $\pm 20^{\circ}$ and $\pm 25^{\circ}$. If a ship passes through its desired position of any window, then by taking the calculated command rudder using NPL method, it is guaranteed to reach the imaginary line well ahead. After merging with imaginary line, ship commands to go straight by following sequential telegraph order which is constructed maintaining speed response equation. Finally the engine idling time is tuned in such a way that when engine idling followed by propeller revering, ship will stop as close to the berthing point as possible which is assumed to be at a distance of 1.5 m from the pier for further tug assistance. Therefore the term berthing is not appropriate here to use, but this can be considered as a part of berthing followed by automatic tug assistance which will be studied as future work.

For different initial headings of ship and for the four virtual windows, all complete berthing process are then combined to a make a single set of consistent teaching data. Here, teaching data not only include the variations of ship heading and position but also variations in command rudder angle. And this makes the trained network more robust. As it has already proved that using separate controller for rudder and propeller revolution command are more effective than using centralized controller by IM *et al.* (2001) thus in this research separate controller is also given preference.

While considering wind disturbances, for course changing part by adjusting the rudder the ANN itself can take adequate decision considering gust wind of different velocities and from different directions. But, when ship moves straight along with imaginary line and its velocity gradually reduces then the effect of such wind is very severe. So, PD controller is implemented instead of ANN to control the rudder action while the propeller revolution is wholly decided by ANN. As a result it will be a combined effort of PD and ANN controller during low speed straight forward motion.

Finally, after making several successful simulations for different wind velocities (maximum 1.5 m/s) from different directions (Ahmed *et al.*, 2012), the implementation of automatic ship berthing is planned and executed for the first time with virtual window concept and some results are included.

2. MATHEMATICAL MODEL AND ITS VALIDATION

2.1 Subject Ship and Coordinate System

In this research, the mathematical model is developed for 3 meter Esso Osaka model ship. Principal particulars of the corresponding model ship used for simulation and experiment are shown in Table 1.

Table 1. Principal particulars and parameters of model ship

Hull		Propeller		Rudder	
L (m)	3	D_p (m)	0.084	b (m)	0.083
B (m)	0.48	P (m)	0.06	h (m)	0.1279
D (m)	0.2	Pitch Ratio	0.7151	A_R (m^2)	0.0106
C_b	0.831	Z	5	Λ	1.539

The coordinate system used to formulate the equation of motion together with the wind direction consideration is shown in Fig. 1. Here ship heading is assumed as clockwise and wind direction as anti-clock wise positive. However such assumptions can be altered in program code.

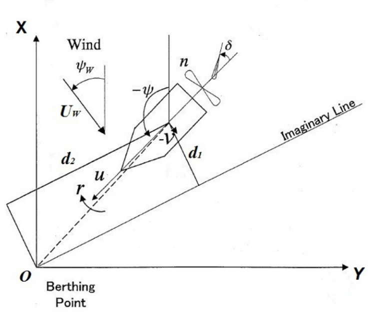

Fig. 1. Coordinate system

A modified version of mathematical model based on MMG (23rd ITTC meeting) for describing the ship hydrodynamics in three degree of freedoms is used for this model ship. The equations of motion as well as measured hydrodynamic forces are considered at CG (centre of gravity) of the ship. The corresponding equations of motions are expressed in the following form:

$$(m+m_x)\dot{u}-(m+m_y)vr = X_H + X_P + X_R + X_W$$
$$(m+m_y)\dot{v}+(m+m_x)ur = Y_H + Y_P + Y_R + Y_W$$
$$(I_{ZZ}+J_{ZZ})\dot{r} = N_H + N_P + N_R + N_W$$

X_H, Y_H, N_H: Hydrodynamic forces and moment acting on hull
X_P, Y_P, N_P: Hydrodynamic forces and moment due to propeller
X_R, Y_R, N_R: Hydrodynamic forces and moment due to rudder
X_W, Y_W, N_W: Hydrodynamic forces and moment due to wind

2.2 Validation of the Mathematical Model

To validate the mathematical model and to judge the predictability during course changing, turning simulations for four different rudder angles are compared with the free running experiment result for both port and starboard turning. The comparisons are shown in following figures.

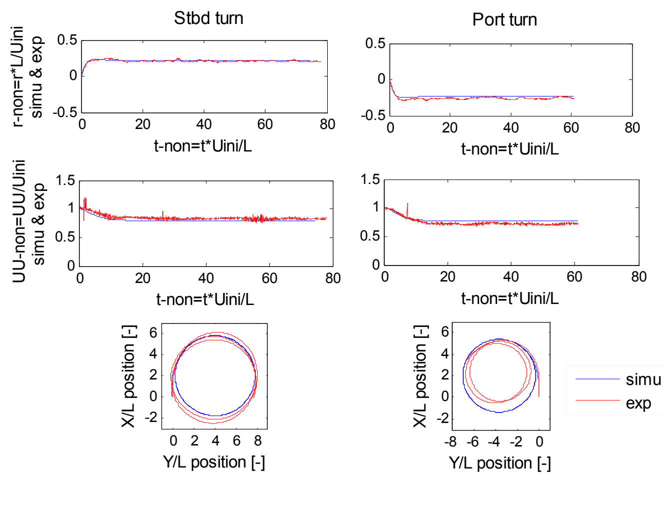

Fig. 2(a). Turning circle compassion for $\pm 10^{\circ}$