

# Automatic Ship Berthing using Artificial Neural Network Based on Virtual Window Concept in Wind Condition

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**Abstract:** Automatic berthing control is one of the unresolved problems in the field of ship control. Many methods and theories were developed to achieve the goal of performing automatic berthing of ship. Among them Artificial Neural Network (ANN) has found to be the most successful one by many researchers. But still questions arise about the consistency of teaching data which are used to train ANN and also about the capability of ANN to cope with wind disturbances. To investigate such phenomena, consistent teaching data based on four virtual windows (for restricted rudder angle  $\pm 10^\circ$ ,  $\pm 15^\circ$ ,  $\pm 20^\circ$  and  $\pm 25^\circ$ ) are created using optimal steering with the help of nonlinear programming language (NPL) method. Then trained ANN is used to validate its workability in case of no wind condition first. In case of gust wind, separate ANN is trained with reconstructed teaching data and to deal with any abrupt condition, ANN-PD controller is introduced whose effectiveness is well verified not only for teaching data but also in case of non-teaching data even in case of severe wind condition.

**Keywords:** Artificial Neural Network, Gust wind, Non Linear Programming.

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## 1. INTRODUCTION

Ship berthing has always demands a sophisticated control due to the requirement of multiple input and output parameters including data of environmental disturbances. So if we want to do it in automatic way, it is obvious that we must find such controller which can best suit to such sophisticated phenomenon. To achieve that purpose, many researches have been carried out by many researchers. 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 (1990) but he then changed his approach and adapted expert system. Since then Hasegawa *et al.* (1993), IM *et al.* (2001), Nakata, Nishino have continued the research. But, still there are lots of problems remain unsolved when using ANN in case of automatic ship berthing. For an example, how to create teaching data in more consistent way to teach ANN. As some of researchers created teaching data by performing experiment where the rudder and rps are controlled manually, thus teaching data creation were time consuming as well as lack of consistency. First consistent teaching data for teaching ANN was made by Xu (2012) but he analysed limited direction of wind blowing together with uniform wind disturbances up to certain small limit. But, in real case wind blows in gust form rather than uniform and from any possible direction which have not been investigated yet in case of berthing problem. Moreover, in case of wind disturbances he adjusted the rps according to the requirement manually rather

than by ANN. So, this research is highly concentrated on creating consistent teaching data using NPL method and also checks the effectiveness of trained ANN in case of no wind and gust wind condition where maximum wind velocity is considered as 1.5 m/s from different directions which is considered as maximum one in most ports in Japan for berthing.

In this research to ensure a safe and appropriate berthing manoeuvre, the whole manoeuvring plan is divided into three basic elementary manoeuvres which are course changing, step deceleration and stopping. For course changing manoeuvre, using NPL method (Sugita, 2012) four virtual windows are found where rudder angles are restricted within  $\pm 10^\circ$ ,  $\pm 15^\circ$ ,  $\pm 20^\circ$  and  $\pm 25^\circ$ . Each point on such windows indicates a particular ship heading angle together with the point's coordinate as ship's initial position. NPL method ensures the command rudder angle taken for such cases to direct the ship with optimal time manoeuvre so as to merge with imaginary line well ahead which is 15L from berthing point. Imaginary line is that line which most captains use to direct their ship course towards the berthing pier. 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 such that when engine idling followed by propeller reversing, ship will stop as close to the berthing point as possible.

After preparing the teaching data, two separate ANN controllers have been investigated to find the suitable number

of hidden layers together with appropriate number of neurons in each layer which best suit to the teaching data for command rudder angle and rps output and such suitability is determined by considering minimum squared error (MSE). To emphasize more weights on consistency, both Networks are categorized into two based on the ship's initial position whether on left hand side or right hand side of imaginary line.

In case of wind disturbances, same types of teaching data are reconstructed but this time considering gust wind of different velocity and from different direction. Moreover, when ship moves straight along with imaginary line and its velocity gradually reduced then the effect of such wind is very severe. So, PD controller is introduced during straight running to make the complete set of teaching data.

Finally, the effectiveness of ANN is verified by performing automatic berthing simulations even under different initial conditions with teaching data and wind disturbances.

## 2. SUBJECT SHIP AND MATHEMATICAL MODEL

### 2.1 Subject ship model

In this research, 3 meter model ship of Esso Osaka is used as subject ship. Principal particulars of the corresponding model ship are shown in Table 1.

Table 1. Principal particulars and parameters of model ship

Hull		Propeller		Rudder	
$L$ (m)	3	$Dp$ (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	$Ar$ (m <sup>2</sup> )	0.0106
$Cb$	0.831	$Z$	5	$\Lambda$	1.539

### 2.2 Coordinate System

The coordinate system used to formulate the equation of motion together with the wind direction consideration is shown in Fig. 1.

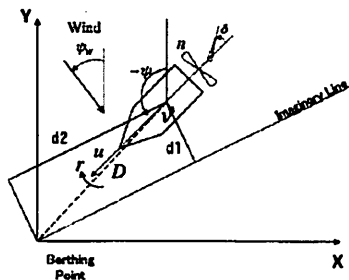


Fig. 1. Coordinate system

### 2.3 Mathematical Model

A modified version of Mathematical Model based on MMG for describing the ship hydrodynamics in three degree of freedoms is used for Esso Osaka 3 meter 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:

$$(m + m_x)\ddot{u} - (m + m_y)\dot{v}r = X_H + X_P + X_R + X_W$$

$$(m + m_y)\dot{v} + (m + m_x)ur = Y_H + Y_P + Y_R + Y_W$$

$$(J_{zz} + J_{zz'})\dot{r} = N_H + N_P + N_R + N_W$$

$X_H, Y_H, N_H$ : 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

## 3. Teaching data Creation

### 3.1 Manoeuvring Plan for Berthing

In order to ensure safe and appropriate berthing manoeuvre the whole berthing procedure is divided into three basic elementary manoeuvres. Minimum time course changing, step deceleration and finally propeller reversing to stop the ship. In case of no wind condition, during straight running along with imaginary line, no rudder angle is taken. But in case wind disturbances, ship deviation from imaginary line is adjusted by PD controller.

Kose (1986) proposed two concepts by analysing the manoeuvring procedure followed by the captain in case of real large ship to ensure safety. One is that the goal of berthing manoeuvre is supposed to be at some interval distance before pier instead of approaching the pier board to board. The second one is planning a manoeuvre which allows a well-to-do operation in case of any critical situation.

In this research, to ensure Kose's two proposed concepts, the supposed berthing goal is assumed to be at a distance 1.5 times of ship length from the pier. However, the ship approaches the pier along with a imaginary line which makes an angle  $30^\circ$  with the pier. Other one is that, to cope with any un-expected situation rudder angle is restricted within  $\pm 10^\circ$ ,  $\pm 15^\circ$ ,  $\pm 20^\circ$  or  $\pm 25^\circ$  depending on her initial position on virtual window and in case of wind disturbances, the PD controller during straight running is restricted to take rudder angle within  $\pm 5^\circ$ .

#### 3.1.1 Minimum Time Course Changing Manoeuvre

Nonlinear programming method is used to get optimal steering which satisfies the constraints given in form of termination conditions. Here, the objective function is time which ensures minimum time steering and optimal variable is command rudder angle.

Four different types of rudder restriction are considered to get their corresponding virtual windows. Here, virtual window denotes that window whose corresponding points indicate a particular initial condition to simulate with a particular heading angle of ship and initial position to start which is

same as coordinate of such points. The constraint conditions used in nonlinear programming method are shown in Table 2.

**Table 2. Constraints used in optimal course changing**

Objective function	Course changing time	
Optimal variable	Command rudder angle, $\delta$ -order	
Initial Conditions	Ship velocity	Half Ahead
	Heading angle	$\psi$
	Position	$(x, y)$
	Others	$v=0; r=0; \delta=0$
Termination Conditions / Equality constraints	Heading Angle	240 [deg]
	Position	On the imaginary line
	Ship velocity	Free
Non equality constraints	Rudder restriction	$ \delta  \leq 10 / 15 / 20 / 25$ [deg]

### 3.1.2 Deceleration and Stopping Manoeuvre

As Endo has surveyed the contents of deceleration manoeuvring during the real navigation cases, ships usually approach the berthing goal by dropping the ship velocity step by step as a standard deceleration manoeuvring. In this research, deceleration manoeuvring is performed by dropping ship speed from Half Ahead  $\rightarrow$  Slow Ahead  $\rightarrow$  Dead Slow Ahead  $\rightarrow$  Stop Engine step by step in a straight course. The step changing time is as much as time constant  $T_p$  of ship speed response equation which is shown in the following:

$$T_p \frac{dU(t)}{dt} + U(t) = K_p n(t)$$

$U(t)$  : Ship velocity (m/s);  $n(t)$  : Propeller revolution (rps)

$T_p$  : Time constant;  $K_p$  : Gain

In case of stopping manoeuvre, slow astern is used as telegraph order. Since engine idling is followed by propeller reversing thus engine idling time is also adjusted such that the ship can reach as close as possible to the berthing point during propeller reversing stage. The total available distance considered during deceleration and stopping manoeuvre is 15 times of ship length according to IMO standard.

## 3.2. Teaching data Creation

### 3.2.1 Teaching data for no wind condition

Considering the above mentioned manoeuvring plan, teaching data are created based on the ship's initial heading angle starting from  $90^\circ$  to  $230^\circ$  (for  $\pm 10^\circ$  restricted rudder angle) at  $20^\circ$  interval when ship comes from left hand side of imaginary line and  $-270^\circ$  to  $240^\circ$  at same interval in case of right hand side. Maximum rudder angle taken in the teaching data is fully dependent on ship's initial position and the corresponding virtual window.

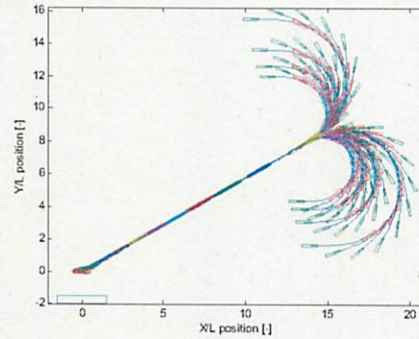


Fig. 2. All teaching data for no wind condition

### 3.2.2 Teaching data for wind condition

To make ANN understand about the influence of wind disturbances, teaching data are reconstructed considering wind speed as 0.2, 0.6 and 1.0 m/s and wind direction as  $45^\circ$ ,  $135^\circ$ ,  $225^\circ$  and  $315^\circ$ . Such teaching data also include PD controller during straight running to cope the deviation ship position in low speed. But, the command rudder angle during turning and the telegraph order remains same as in non wind condition. Because, such command rudder angle during turning as well as telegraph order are expected to be modified by ANN itself after training depending on wind influences.

## 4. CREATING NET USING ANN

### 4.1.1 Training function, transfer function and performance function

Training function based on Lavenberg-Marquardt algorithm is used to train the net. In case of transfer function, log-sigmoid is found suitable. And performance of the trained network is judged depending on calculated mean squared error value (MSE).

If the normalized teaching data are considered in the following form:

$$\{p_1, q_1\}, \{p_2, q_2\}, \dots, \{p_n, q_n\}$$

$p$ : Input of network;  $q$ : Target output

Consequently, MSE can be calculated as follows:

$$MSE = \frac{1}{n} \sum_{i=1}^n e(i)^2 = \frac{1}{n} \sum_{i=1}^n (q(i) - O(i))^2$$

$O$ : Output of network

### 4.1.2 Construction of Artificial Neural Network

In this research, two separate neural controllers are used to control command rudder angle and rps instead of central controller as its effectiveness has already proved by previous researchers. Appropriate number of hidden layer and the

corresponding number of neurons for networks are determined observing the minimum MSE value. The resulting ANN can be demonstrated in following figure:

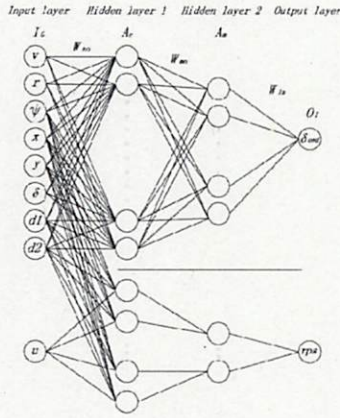


Fig. 3. Artificial Neural Network construction

For command rudder output, input parameters for the net are  $v$ : sway velocity;  $r$ : yaw rate;  $\psi$ : heading angle;  $(x, y)$ : ship's position;  $\delta$ : actual rudder angle;  $d1$ : distance to imaginary line;  $d2$ : distance to berthing point.

For rps, input parameters are  $u$ : surge velocity;  $\psi$ : heading angle;  $(x, y)$ : ship's position;  $d1$ : distance to imaginary line;  $d2$ : distance to berthing point.

In case of wind disturbances, Surge velocity is added in addition as an input parameter when training net for command rudder angle to understand the wind influence in terms of velocity drop.

### 5. VERIFICATION OF ANN IN NO WIND CONDITION

Verification of ANN has done using not only the same initial ship position and states with teaching data but also with those different from the teaching data. The following figures illustrate such verification. In those figures the squared dotted line ensures the assumed successful zone for berthing.

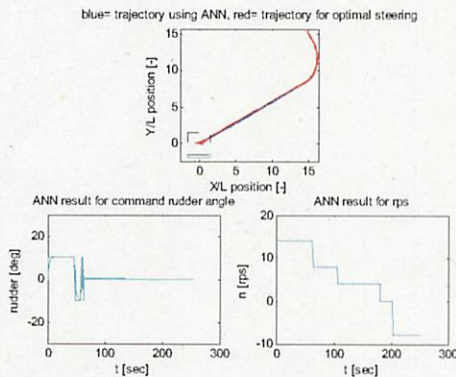


Fig. 4. Initial heading  $150^\circ$  with rudder restriction  $\pm 10^\circ$

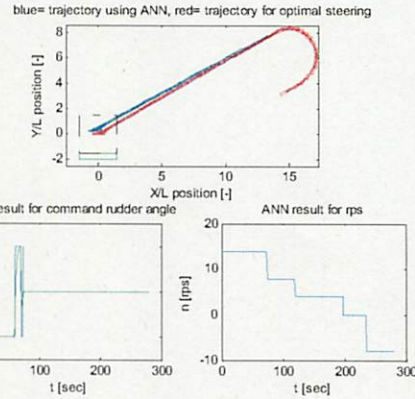


Fig. 5. Initial heading  $-300^\circ$  with rudder restriction  $\pm 20^\circ$

Fig. 4 illustrates for same initial position and states with teaching data where Fig. 5 illustrates completely different one.

## 6. VERIFICATION OF ANN IN GUST WIND CONDITION

### 6.1 Wind Force Model

To consider the influence of wind disturbances during ship manoeuvring, famous Fujiwara wind model is used for calculating wind forces and moment. The following equations are used for such calculation.

$$X_w = \frac{1}{2} C_X \rho V_R^2 A_T$$

$$Y_w = \frac{1}{2} C_Y \rho V_R^2 A_L$$

$$N_w = \frac{1}{2} C_N \rho V_R^2 A_L L_{OA}$$

$X_w$ : Fore-aft component of wind force;

$Y_w$ : Lateral component of wind force;

$N_w$ : yawing moment;  $V_R$ : relative wind speed;

$C_X, C_Y, C_N$ : coefficients calculated using Fujiwara's model

### 6.2 ANN-PD Controller for Gust wind

In case of gust wind condition, ANN taught with reconstructed teaching data for wind disturbances is used. The rps order is fully controlled by ANN during whole berthing process but in case of command rudder angle, ANN controller is used only during course changing and PD controller is introduced during straight running. Thus, ANN together with PD controller is used to cope with any possible wind disturbances. In this research the following expression for PD controller is used where the corresponding coefficients are decided by trial and error to ensure earlier response during deviation.

$$\delta_{order} = C_1 * (\psi_d - \psi) - C_2 * \dot{\psi} - C_3 * d_1$$

$$\Rightarrow \begin{cases} \text{if } \delta_{order} > 0^{\circ}, \delta_{order} > 5^{\circ} \\ \text{if } \delta_{order} = 0^{\circ}, \delta_{order} = 0^{\circ} \\ \text{if } \delta_{order} < 0^{\circ}, \delta_{order} > -5^{\circ} \end{cases}$$

$\psi_d$ : Desired heading angle;

$d_i$ : Deviation from imaginary line;

$C1=0.30$ ;  $C2=0.08$ ;  $C3=0.010$

The following figures illustrate the effectiveness of ANN-PD controller for both teaching and non-teaching data.

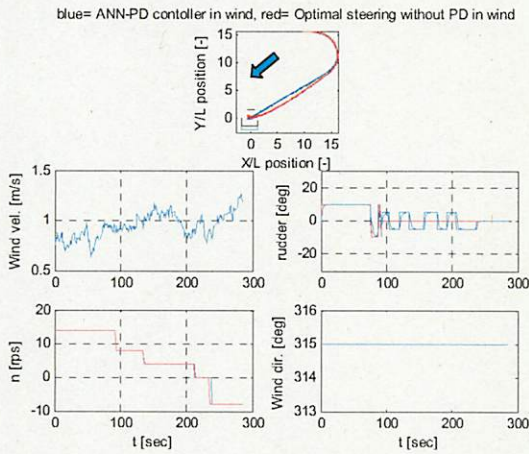


Fig. 6. Average wind velocity 1.0 m/s, wind direction 315°, initial ship heading 90° with rudder restriction ± 10°

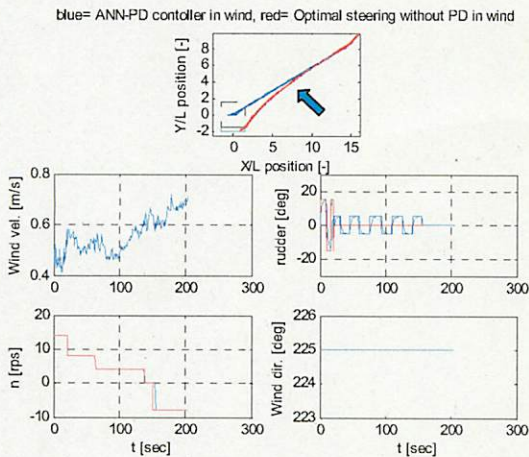


Fig. 7. Average wind velocity 0.6 m/s, wind direction 225°, initial ship heading 225° with rudder restriction ± 15°

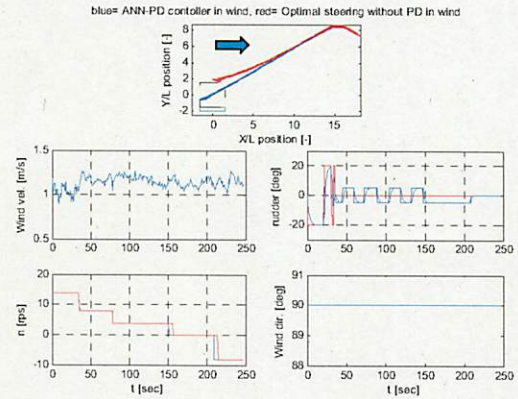


Fig. 8. Average wind velocity 1.0 m/s, wind direction 90°, initial ship heading 300° with rudder restriction ± 20°

### 6.2 ANN-PD Controller above wind speed 1.0 m/s

In this research, although teaching data include wind speed upto 1.0 m/s but the effectiveness of ANN-PD controller is also tested for severe wind condition upto 1.5 m/s. In such cases, the following two modifications are considered:

- 1) It has investigated that, if the ship's position before reversing propeller becomes less than 0.9 times of ship length from berthing goal point then reversing with half astern is better than using slow astern as it takes less distance to reduce speed to minimum value. Thus, in such cases ANN results for slow astern are substituted by half astern value.
- 2) Sometimes, after simulating with ANN-PD controller ship's velocity still remains little bit higher. In such cases, if it remains greater than 0.05 m/s then continuation of propeller reversing is permitted until the velocity becomes less than 0.05 m/s.

The following figures illustrate the effectiveness of ANN-PD controller in case of different ship positions and sates.

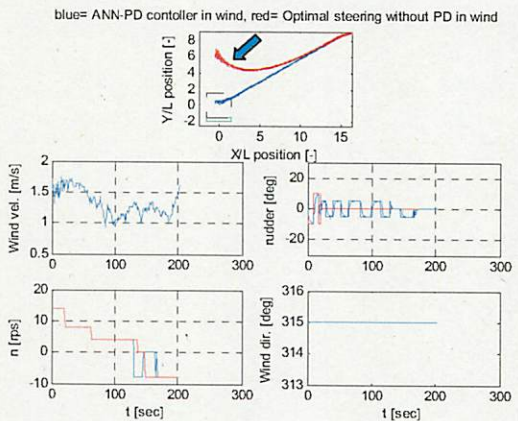


Fig. 8. Average wind velocity 1.5 m/s, wind direction 315°, initial ship heading 250° with rudder restriction ± 10°

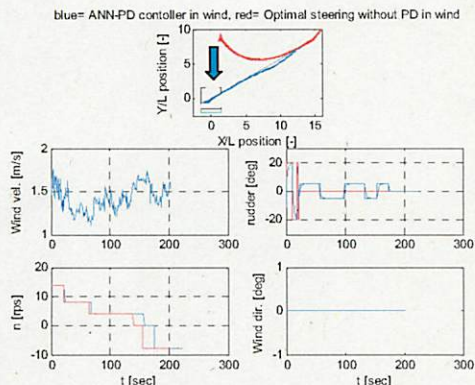


Fig. 9. Average wind velocity 1.5 m/s, wind direction  $0^\circ$ , initial ship heading  $220^\circ$  with rudder restriction  $\pm 20^\circ$

The following three figures show the effectiveness of ANN-PD controller for different gust distribution.

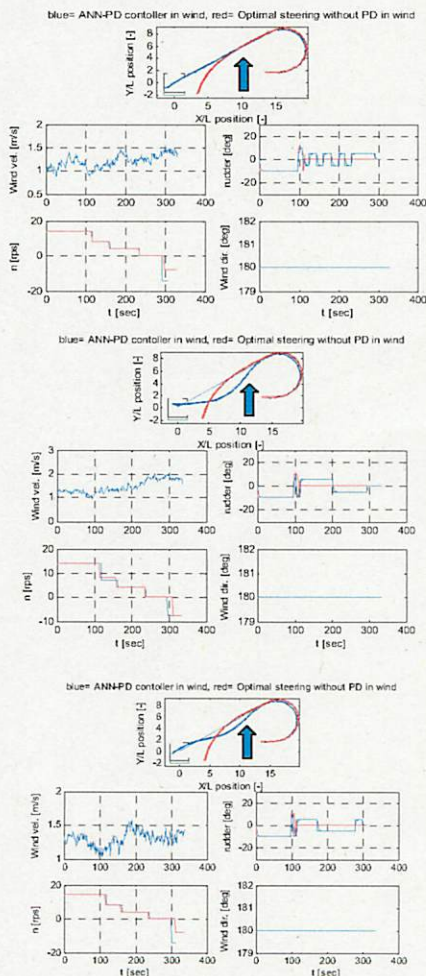


Fig. 10. Average wind velocity 1.3 m/s, wind direction  $180^\circ$ , initial ship heading  $-270^\circ$  with rudder restriction  $\pm 10^\circ$

## 6. CONCLUSIONS

In this research, using NPL method teaching data are created in more consistent way where teaching data not only include variation in ship's initial heading angle and position but also in restricted command rudder angle for the first time which offer greater flexibility to created Net. To learn such complex relationship double hidden layer concept is introduced with minimum MSE value. For no wind condition ANN itself can ensure satisfactory results not only for teaching data used but also for non-teaching data. In order to consider wind disturbances during berthing gust wind instead of uniform wind is investigated for the first time to train ANN. Such trained ANN together with PD controller during straight running is well verified to proof its effectiveness in different situations. In case of severe wind condition, with slight modifications effectiveness of ANN-PD controller is again proved by investigating different ship's heading angles and positions. Such combined controller is also investigated for different gust distribution of wind where other particulars remain same.

As a next step, it is very important to perform experiment to judge the effectiveness of ANN-PD controller in real cases.

## ACKNOWLEDGEMENTS

We would like to acknowledge K. Sugita and Xu Guangin for their kind advice and necessary discussions on this research.

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