Ship's Course Changing Controller in Low Speed under Wind Conditions

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Abstract

Maneuvering in harbor is considered as one of the most sophisticated and difficult maneuvers in ship's operation. Much knowledge and experience are demanded to accomplish berthing. Automation of berthing is highly needed to meet the decrease of the number and aging of crew. In berthing, the environmental factor that affects ship the most is wind while current and wave affect the least. This wind effect is made worse because ship's speed will be slowed down during the berthing process. Therefore in this part of research, effects of wind disturbance on marine vessels that are in the process of berthing in the harbor were analyzed by using a turning test. The influence of wind included in the process of designing a controller for the ship to keep and change its direction. Basically, for both types of controller, it is used Proportional Derivative (PD) controller type, only the coefficients for each controller have different parameters. A new algorithm for controller to change direction under the influence of winds is used in this study. The algorithm is based on several factors. The main thing is to make the same yaw rate, either when there is wind or no wind. Results from simulations show good performance when the ship changed direction or turn under the influence of wind. The result is almost equal to the control of PD when there is no wind.

Keywords: PD Controller, Wind Influence, Automatic Berthing, Neural Networks

Abstrak

Manuver di pelabuhan adalah salah satu manuver paling canggih dan sulit dalam pengoperasian kapal. Banyak pengetahuan dan pengalaman yang harus dimiliki untuk berlabuh dengan sukses. Otomasi berlabuh sangat diperlukan untuk memenuhi penurunan jumlah dan penuaan dari awak kapal. Dalam hal berlabuh, faktor lingkungan yang mempengaruhi manuver kapal yang paling kuat adalah angin sedangkan arus dan gelombang adalah paling sedikit. Efek angin ini menjadi lebih buruk karena kecepatan kapal akan melambat selama proses berlabuh.Oleh karena itu, pengaruh dari gangguan angin terhadap kapal laut yang sedang dalam proses berlabuh di pelabuhan telah dianalisa dengan menggunakan tes berputar (turning test). Pengaruh dari angin dimasukan dalam proses merancang kendali untuk kapal menjaga arahnya dan untuk merubah arahnya. Pada dasarnya, untuk kedua jenis kendali ini digunakan pengendali Proportional Derivative (PD), hanya koefisien untuk masing-masing parameter berbeda. Algoritma baru untuk system kendali untuk merubah arah di bawah pengaruh angin digunakan dalam penelitian ini. Algoritma ini didasarkan pada beberapa faktor. Yang paling utama adalah ingin membuat laju simpang (yaw) yang sama, baik ketika ada angin dengan tidak ada angin. Hasil dari simulasi menunjukan kinerja yang baik ketika kapal berganti arah atau berbelok di bawah pengaruh angin. Hasilnya hampir menyamai kendali PD ketika tidak ada angin.

Kata kunci: Pengendali PD, Pengaruh Angin, Berlabuh Otomatis, Jaringan Syaraf Tiruan

1. Introduction

Automatic berthing of a ship using neural networks controller has been done by several researchers. The first research in automatic ship berthing using neural networks was started in 1990 by Yamato *et al* [1]. However, Yamato left the field of automatic berthing using neural networks for the field of automatic berthing using expert systems. Hasegawa *et al* took over and continued the research since then.

Hasegawa *et al* has made several advancements in this field such as automatic teaching data creation to make data more consistent for the training of the neural networks [2]. However, the practical robustness needed by the system under environmental disturbances such as wind has not been achieved yet, especially when the speed of ship is very slow.

Therefore, in this first part of the research, the effect of wind disturbance on the ship during berthing process in the harbor was analyzed. There were two cases that were investigated; course keeping and course changing.

For course keeping, PD controller was adopted to keep the ship on course during approaching berthing line and during approaching berthing point with deceleration. As for the course changing, it was proposed a new algorithm based on PD controller that would work well even under wind influence from all direction.

2. Model ship and its dynamic equations

The model ship that is used for numerical simulation is Esso Osaka. The ship is scaled back to 3 meters. Principal particulars of Esso Osaka are shown in Table.1.

Table 1. Ship principal particular

Hull	Ship type Length (LPP) Beam (B) Draft (d) Block Coefficient (Cb)	Tanker 3.00(m) 0.48 (m) 0.20 (m) 0.8293
Propeller And Rudder	Rudder Height (HR) Propeller Diameter (Dp) Propeller Pitch (P) Rudder area ratio (AR/Ld) Aspect ratio (Λ)	0.128(m) 0.084 (m) 0.059 (m) 1/59.66 1.539

While the system coordinate of the ship is shown in the Figure 1.

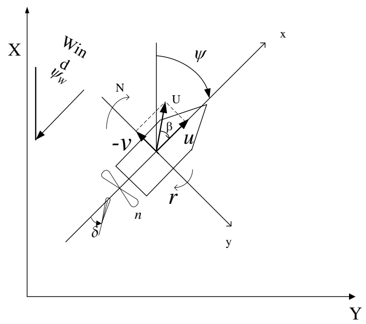


Figure 1. Ship's system coordinates

The mathematical models based on MMG (Mathematical Model Group) model for describing the ship dynamics in three degree of freedoms are used for simulation. The equations are described below:

$$m(\dot{u} - vr) = X$$
$$m(\dot{v} + ur) = Y \qquad (1)$$
$$I_{ZZ}\dot{r} = N$$

Where, m is the mass of ship

I_{ZZ} is the moment inertia of ship

u, v, r is the surge velocity, sway velocity, and yaw rate respectively

The X, Y, and N forces and moment are composed of propeller, hull, rudder, and wind components. The contribution of forces from hull, propeller, rudder, and wind components are written down with subscripts H, P, R, and W respectively.

$$X = X_H + X_P + X_R + X_W$$
$$Y = Y_H + Y_R + Y_W \qquad (2)$$
$$N = N_H + N_R + N_W$$

The hydrodynamic coefficients of hull, rudder, and propeller are described in Hasegawa [2].

3. Wind forces and wind gust

The steady wind disturbance that affects the ship dynamics is described below.

$$X_W = 0.5\rho_A A_T U_A^2 C_{FX}(\psi_A)$$
$$Y_W = 0.5\rho_A A_L U_A^2 C_{FY}(\psi_A) \qquad (3)$$
$$N_W = 0.5\rho_A A_L U_A^2 L C_{MZ}(\psi_A)$$

Where,

ρ_A is mass density of air

A_T is transverse effective projected area

A_L is lateral effective projected area

U_A is relative wind velocity

ψ_A is relative angle of encounter wind

C_{FX}, C_{FY}, and C_{MZ} are wind forces and moment coefficient.

The wind forces and moment component are derived based on Fujiwara's results for tankers [3].

The wind gust was added for some purposes such as testing the course keeping controller and course changing controller. However, it was not used for investigating the effect of wind on ship during turning test and directional stability test. Davenport equation is used in predicting the wind gust component of the wind the equation is shown below. And also, the profile of the wind gust is shown in Figure 2.

$$S_z(n)dn = 4\kappa \bar{V}_1^2 \frac{x}{(1+x^2)^{4/3}} \qquad (4)$$

Where $S_z(n)$ is power spectrum at height z

n is frequency

$\bar{V}_1$ is velocity at standard referenced height 10 m

κ is drag coefficient referred to mean velocity at 10 m

x is $1200\,n/\bar{V}_1$, where $n/\bar{V}_1$ is in cycles per meter

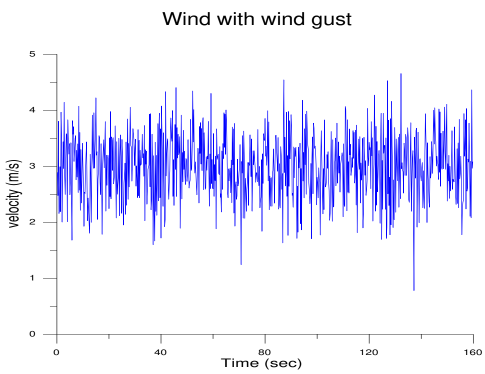


Figure 2. Wind gust profile

4. Turning Test

To test the wind influence on the ship, mainly turning test was used. The procedures for turning test are as the following. First, the ship runs straight with steady speed and zero yaw rate condition. After those conditions are reached, the rudder is moved to new setting.

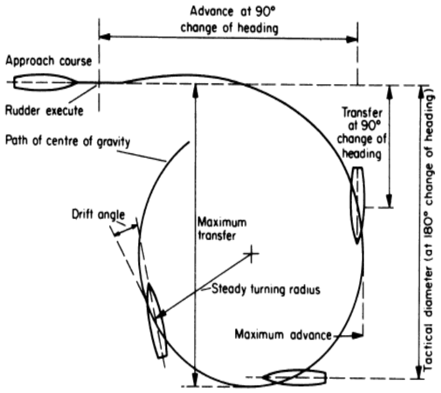


Figure 3. Turning Test

Finally, when the ship is already turning in circular, we can calculate parameters of interest such as turning diameter, drift angle β, etc. The turning test process is shown in Fig. 3.

5. PD Controller

For course keeping, PD (Proportional Integral Derivative) controller was used to control the ship. PD controller in this research is defined as the following equations:

$$\delta = K_p(1+T_d s)(\psi_d - \psi) + K_i d \qquad (5)$$

Where δ is rudder angle command
Kp is proportional constant
Td is time derivative constant
Ki is distance correction constant
ψ is actual heading of the ship
ψ_d is the desired heading

6. Course changing

The previous research used "Bang bang" control to change the course of the ship. This method is the usual way a captain of a ship changing the course of his ship. First, at certain point, far from the point it should change its course, the captain orders a certain rudder angle δ to be taken. Then at certain heading angle, the captain is taking reverse counter rudder angle – δ to reduce the yaw rate. Finally when the desired heading angle is achieved, the rudder was put back in zero degree position. Fig.4 shown below is describing the method.

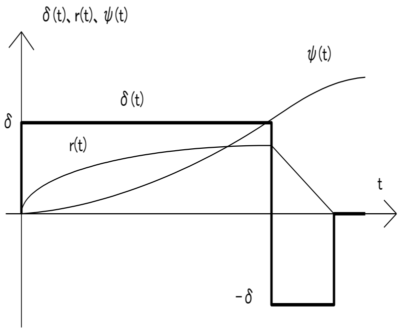


Figure 4. "Bang bang" control for course changing

7. Wind influence

In this section, the influence of wind on the ship during course keeping was discussed. As well known, in case of turning, the ship cannot maintain it steady turning, but drifting to a certain direction relating to the wind direction as shown in Fig.5. Here we call it as *turning drift angle*.

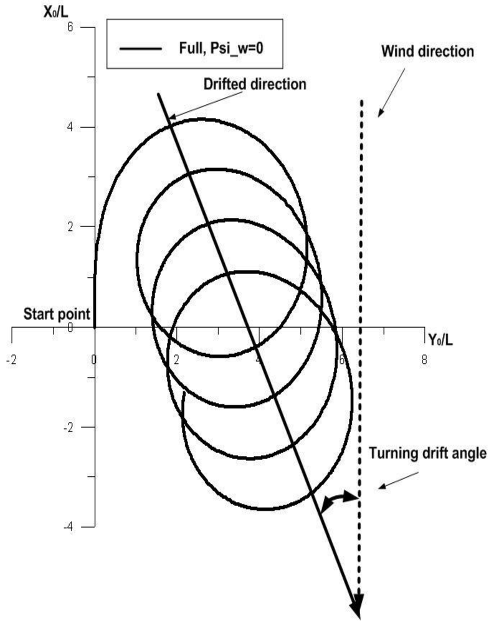


Figure 5. Turning test under steady wind

The simulation of turning tests under steady wind was carried out to investigate the effect of ship speed as well as the ratio of wind speed and ship speed. The ship speeds were chosen to reflect the deceleration maneuver that was suggested by Endo *et al* [4]. This deceleration maneuver was used also in the berthing maneuver. The relation of turning drift angle resulted by rudder angles taken during simulation of turning test is shown in Fig.6.

From Fig.6 shown below, it is found that the turning drift angle is proportional to rudder angle and influenced by the wind speed to ship speed ratio, but not by ship speed even if the speed is dead slow. So we found that wind disturbance will be treated by rudder angle and the wind speed to ship speed ratio.

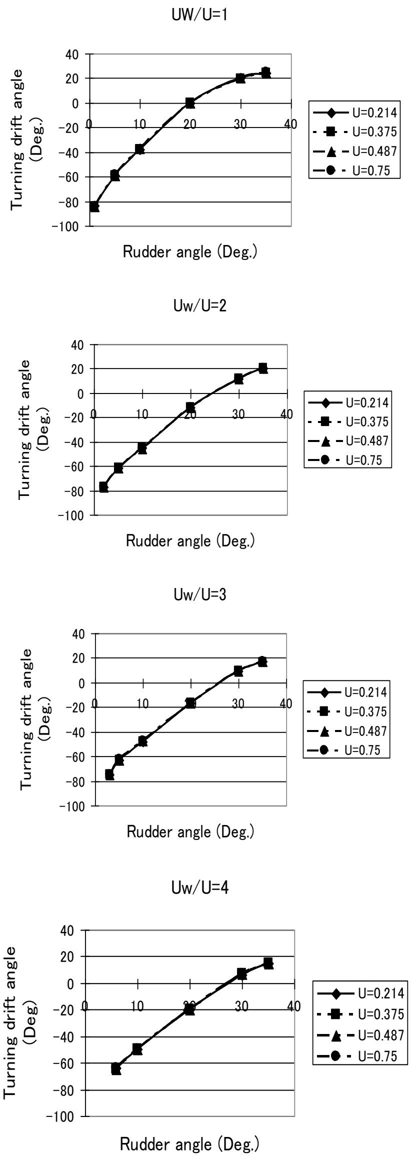


Figure 6. Turning drift angle resulted by different rudder angle

8. Course keeping controller

After we ran simulation several times to tune the constants we found that the optimal constants for the controllers are Kp = 2.5, Td = 650, and Ki = 50. The controller was tested for course keeping under wind with wind gust added. It was very successful as shown in Fig.7. It can be seen that the ship can maintain its straight trajectory.

For course keeping maneuver under steady wind, there are already established method to give maximum allowance wind speed [5]. However, here the problem is not such a case. Course keeping maneuver under steady wind is the equilibrium condition of rudder, heading angle and drift angle.

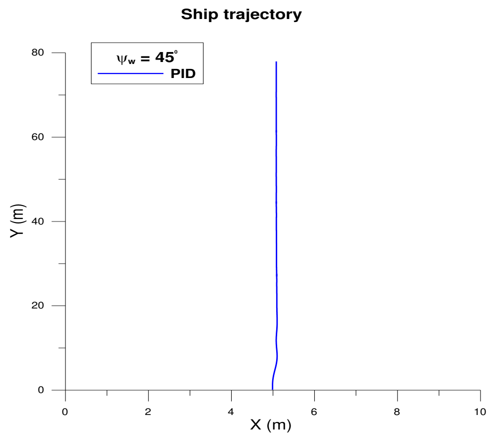


Figure 7. Ship course keeping trajectory

9. New proposed algorithm

New proposed algorithm consists of three things. First, when starting course change, the reference trajectory line is changed from approaching line into berthing line. This strategy is really helping the controller in avoiding overshoots since the distance correction term in the controller starting to work in minimizing error in distance. While in the previous algorithm, during course changing the controller was switch from PD based into "bang bang" controller, this contributes the ineffectiveness of the course changing controller under wind influence. There are two weaknesses in using the "bang bang" controller. First, it is open loop so it does not know if the output is not met the goal. There is no feedback into the controller for the output. Second, distance correction is not used since it is part of the PD controller. These factors contribute to the failure of "bang bang" controller under wind influence. Fig.8 shown below is depicting the first strategy.

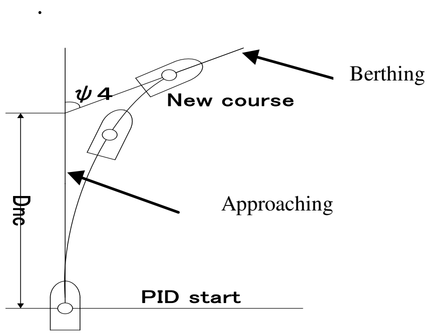


Figure 8. New course changing procedure

Second, since PD basically is used also in course changing controller, we do not need to find ψ_2. The controller will automatically determine when the rudder starting to take reverse rudder angle and how much rudder angle should be taken. So we just need to use the same Dnc equation as in the previous algorithm to determine when we need to start to change course. However, the Dnc equation has to be modified to work under wind influence.

Standard course alteration that was used in the previous algorithm is described by Fig. 8 shown. There are three parameters that should be determined to accomplish the course change in this algorithm. The first is Dnc. Dnc stands for *distance to new course*. Dnc is where the captain takes the first rudder action. Dnc is derived from two equations, i.e., Nomoto equation and first order speed equation

Third, this is the most important thing in this new algorithm, the basic idea is that we want the yaw rate of the ship in wind case closely resembles the yaw rate of no wind case. In the cases that only PD controller was used without modification, the yaw rate of the ship was too slow. It is shown in the Fig. 9 that the solid line is yaw rate of the ship when using unmodified PD controller. We can see that the rate is too slow compared with that of no wind case, in the dash-dot line. While the present method, which was represented by the dash line, has almost the same yaw rate as that of no wind case.

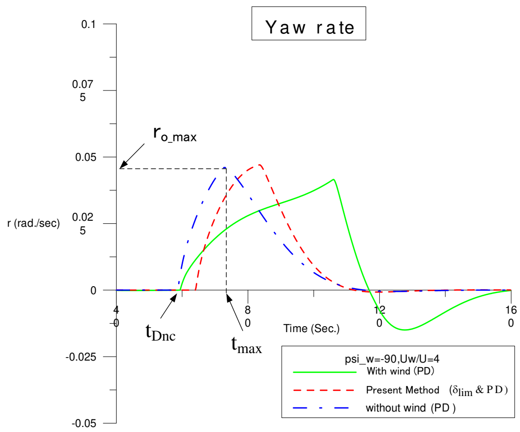


Figure 9. New proposed algorithm

Therefore, we need to increase the yaw rate when it is too slow by increasing the rudder command to the ship. It is described by the following equations shown below.

$$\delta(t)=\begin{cases}\delta_{\lim} & (a)\\ \delta_0+c\left(r_{0\_\max}-r(t)\right) & (b)\\ 10^0 & (c)\\ 20^0 & (d)\\ \delta_{pd} & (e)\end{cases} \qquad (6)$$

Where ,

(a) $\delta_{pd} > 10^0$, $10^0 < \delta_{lim} < 20^0$, and $t_{Dnc} < t < t_{max}$

(b) $\delta_{pd} > 10^0$, $10^0 < \delta_{lim} < 20^0$, and $t > t_{max}$

(c) $\delta_{pd} > 10^0$ and $\delta_{lim} < 20^0$

(d) $\delta_{pd} > 20^0$ and $\delta_{lim} < 20^0$

(e) $\delta_{pd} < 10^0$

$\delta_{lim} = \delta_0 + c\left(r_0(t) - r(t)\right)$

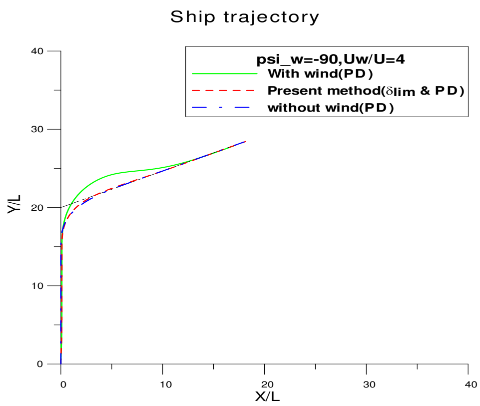
$\delta_{pd} = k_p\left(1+T_d s\right)\left(\psi_d - \psi\right) + k_i d$

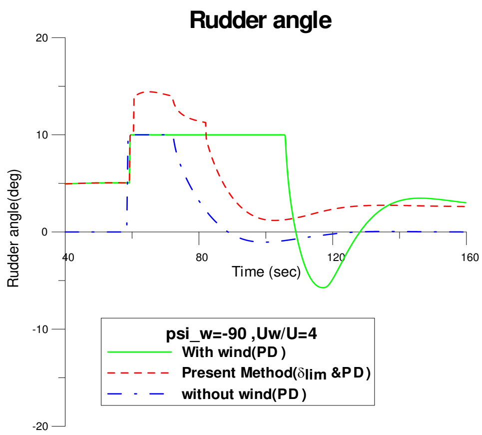
t_{Dnc} is the time for starting to turn

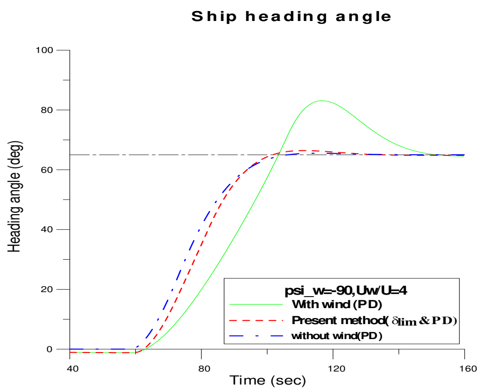
t_{max} is the time when yaw velocity reach maximum value

$r_{0\_\max}$ is the maximum value of yaw velocity

Several examples showing the comparison of different algorithms is shown in the following figures. It was found out that the wind affected badly for negative wind direction. It can be seen in Fig. 10 that for unmodified PD algorithm (solid line) under wind the ship overshoots its planned trajectory. While for the present method, the ship traveled along its planned trajectory. To achieve this result, it can be seen that rudder angle for present method (dash line) was increased to increase the yaw rate.







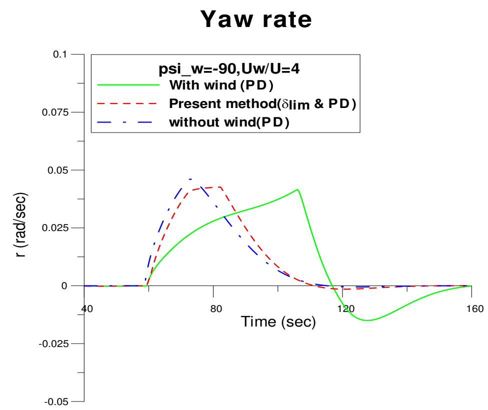


Figure 10. Simulation results for wind angle of -60 degree for all algorithms

10. Conclusion

There are several things that can be concluded from this research. In turning test, the wind causes ship to drift in certain drift angle. Ratio of Uw/U determines the effect of wind on ship. Using the new proposed algorithm for course keeping and course changing, the ship can maintain its trajectory under wind for all direction. Even adding wind gust to the simulation, the ship can maintain its trajectory.

However, almost all of the numerical simulations were done when the ship is in low speed when testing for all controller types is done. It will be necessary to investigate for the case of slow to dead slow speed such as during berthing procedure.

11. References

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