A Comparative Study on Guidance Systems for Ship’s Track-Keeping

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Abstract: This paper deals with ship’s track keeping methods which is crucial part of automatic navigation control systems. In this paper, we mainly discuss the performance of different guidance methods including way point guidance, enclosure-based steering guidance and lookahead-based steering guidance system. As a controller, a PID control system is employed to control ship’s rudder angle during track-keeping. Finally, the performance of three methods are discussed through some simulation results.

Key words: marine vehicle, PID control, guidance system

1. Introduction

Guidance systems of marine vehicle aims to produce control commands for a series of desired heading angle. Thus, the guidance system plays an important role in the ship’s track keeping. To study the control performance of guidance systems, this paper employs and evaluates three guidance methods containing way-point guidance, enclosure-based steering, and lookahead-based steering methods. All the methods are evaluated through a series of track–keeping simulations.

2. Ship model and control system

Ship dynamics equations is obtained by applying Newton’s laws. They can be written as[1]

\[ \begin{align*}
\text{surge:} \quad m\ddot{u} &= X, \\
\text{sway:} \quad m(\dot{v} + u\dot{x} + x\dot{\theta}) &= Y, \\
\text{yaw:} \quad I\ddot{\theta} + mx\dot{\theta}(\dot{v} + u\dot{x}) &= N,
\end{align*} \]

where \( m \) is mass of the ship, \( u \) and \( v \) are surge and sway velocities. The transformation matrix which is used to transfer the dynamic ship’s equation from body-fix reference to earth-fix reference is expressed as

\[ \eta = \begin{bmatrix}
\cos(\theta) & 0 & u \\
0 & \sin(\theta) & 0 \\
0 & 0 & 1
\end{bmatrix} \]

where the \( \eta \) is vector with kinematics coefficients at earth-fix reference.

The common form of the PID controller is expressed as[2]

\[ \delta = K_p\dot{\theta} + K_d\dot{\theta} + K_i\int \dot{\theta} dt \]

where \( \delta \) is rudder angle. Here, the control gain \( K_p \), \( K_d \), and \( K_i \) are required to be positive. Substituting PID
control equation into the first order Nomoto model, assuming $K_i = 0$ we have

$$T \Psi_d + K_d \dot{\Psi}_d + K_p \ddot{\Psi}_d = 0$$

(6)

where $\dot{\Psi}_d$ is the desired heading angle and $\ddot{\Psi}_d = (\Psi_d - \Psi)$.

4.2 LOS steering law

The heading angle command is written as

$$\Psi_d = \chi_d - \beta$$

where $\beta = \arcsin \left(\frac{U}{\sqrt{u^2 + v^2}}\right)$

(16)

where $U = \sqrt{u^2 + v^2}$ is total speed, is the sway speed. The heading angle command of the Lookahead–based steering method can be expressed as

$$\chi_d = \chi_p + \chi_s(\epsilon)$$

(17)

where $\chi_s(\epsilon) = \arctan(-K_p\epsilon(t))$. The heading angle command becomes

$$\Psi_d = \chi_d - \beta = \chi_p + \chi_s - \beta.$$  

(18)

4. Simulation studies

In this paper, we set the two points to present $p_1$ (100, 100) and $p_2$ (520, 600). The initial position of ship was set to be (100, 100). Fig. 1 depicts the simulation results.

4.1 Way point method

Let the path of vessel be planned by a set of way points $[x_d(k), y_d(k)]$ for $k = 1, \ldots, N$, we can define a desired heading angle as (Healey and Lienaid 1993)

$$\Psi_d(t) = \tan^{-1}\left(\frac{y_d(k) - y(t)}{x_d(k) - x(t)}\right)$$

(8)

The next way point can be selected if the condition as (9) is satisfied.

$$[x_d(k) - x(t)]^2 + [y_d(k) - y(t)]^2 \leq \rho_0^2$$

(9)

4.2 LOS steering law

After the explanation of way point method, the principle of proposed method can be described by

$$\alpha_k = \arctan\left(\frac{y_{k+1} - y_k}{x_{k+1} - x_k}\right),$$

(10)

$$s(t) = [x(t) - x_k]\cos(\alpha_k) + [y(t) - y_k]\sin(\alpha_k),$$

(11)

$$e(t) = -[x(t) - x_k]\sin(\alpha_k) + [y(t) - y_k]\cos(\alpha_k),$$

(12)

where $s(t)$ is alongtrack distance (tangential to path), $e(t)$ cross-track error (normal to path). For path following purposes, only the cross-track error is relevant since $e(t) = 0$ means that the ship has converged to the straight line. Associated control objective for straight line path following becomes $\lim_{t \to \infty} e(t) = 0$.

The heading angle command is written as

$$\Psi_d = \chi_d - \beta$$

where $\beta = \arcsin \left(\frac{U}{\sqrt{u^2 + v^2}}\right)$

(16)

where $U = \sqrt{u^2 + v^2}$ is total speed, is the sway speed. The heading angle command of the Lookahead–based steering method can be expressed as

$$\chi_d = \chi_p + \chi_s(\epsilon)$$

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$$\Psi_d = \chi_d - \beta = \chi_p + \chi_s - \beta.$$  

(18)

4.5 Conclusion

In this paper, three guidance methods have been evaluated. Through the simulation, we found that the lookahead–based steering guidance method has a better performance.

Reference