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선박의 항로추종 유도기법에 관한 비교 연구

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

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요 약 : 본 논문은 선박의 자동항법 시스템에서 주요한 부분인 항로추종 유도 기법을 다루고 있다. 특히, 웨이포인트(way-point)기반, 인클로져(enclosure)기반, 룩어헤드(lookahead)기반의 항로추종 유도기법의 성능에 관해 살펴본다. 아울러 본 논문에서는 항로추종 시 선박의 조타 제어를 위해 PID제어 시스템이 적용된다. 최종적으로 3가지 유도기법의 성능은 시뮬레이션 결과를 통해 평가된다.

핵심용어 : 선박, PID제어, 유도 시스템

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]

$$\text{surge}: \quad m\dot{u} = X, \tag{1}$$

$$\text{sway}: \quad m(\dot{v} + u_0 r + x_G \dot{r}) = Y\,, \tag{2}$$

$$\text{yaw}: \quad I_z \dot{r} + m x_G (\dot{v} + u_0 r) = N, \tag{3}$$

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

$$\dot{\eta} = \begin{bmatrix} \cos(\Psi) & 0 & 0 \\ 0 & \sin(\Psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ u \\ r \end{bmatrix} \tag{4}$$

where the η is vector with kinematics coefficients at earth-fix reference.

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

$$\delta = K_p \tilde{\Psi} + K_d \dot{\Psi} + K_i \int_0^t \tilde{\Psi} dt \tag{5}$$

where δ is rudder angle. Here, the control gain K_p, K_d, and K_i are required to be positive. Substituting PID

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control equation into the first order Nomoto model, assuming $K_i = 0$ we have

$$T\ddot{\Psi}+KK_d\dot{\Psi}+KK_p\tilde{\Psi}=0 \quad (6)$$

where Ψ_d is the desired heading angle and $\tilde{\Psi}=(\Psi_d-\Psi)$. The w_n is the nature frequency and ζ is the damping coefficient. The pole placement suggests the control gains as

$$K_p=\frac{w_n^2 T}{K},\quad K_d=\frac{2\zeta w_n T-1}{K},\quad K_i=\frac{w_n^3 T}{10K} \quad (7)$$

3. Guidance Systems

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⋯..N). we can define a desired heading angle as (Healey and Lienaid 1993)

$$\Psi_d(t)=\tan^{-1}\left(\frac{y_d(k)-y(t)}{x_d(k)-x(t)}\right) \quad (8)$$

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

$$[x_d(k)-x(t)]^2+[y_d(k)-y(t)]^2 \le \rho_0^2 \quad (9)$$

4.2 LOS steering law

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

$$\alpha_k = atan2(y_{k+1}-y_k, x_{k+1}-x_k), \quad (10)$$

$$s(t)=[x(t)-x_k]\cos(\alpha_k)+[y(t)-y_k]\sin(\alpha_k), \quad (11)$$

$$e(t)=-[x(t)-x_k]\sin(\alpha_k)+[y(t)-y_k]\cos(\alpha_k), \quad (12)$$

where $s(t)$ is along-track 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 $\lim_{t\to\infty} e(t)=0$. In order to ensure that $e(t)\to 0$, heading angle commands should be selected properly. Applying enclosure-based steering, the desired course angle can be described in

$$\chi_d(t)=atan2(y_{los}-y(t), x_{los}-x(t)) \quad (13)$$

where $p=[x_{los}, y_{los}]$ is the intersection point, and it can be computed as

$$[x_{los}-x(t)]^2+[y_{los}-y(t)]^2=R^2, \quad (14)$$

$$\tan(\alpha_k)=\frac{y_{k+1}-y_k}{x_{k+1}-x_k}=\frac{y_{los}-y_k}{x_{los}-x_k}. \quad (15)$$

The heading angle command is written as

$$\Psi_d=\chi_d-\beta \text{ where } \beta=\arcsin\left(\frac{v}{U}\right) \quad (16)$$

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

$$\chi_d=\chi_p+\chi_r(e) \quad (17)$$

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

$$\Psi_d=\chi_d-\beta=\chi_p+\chi_r-\beta. \quad (18)$$

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.

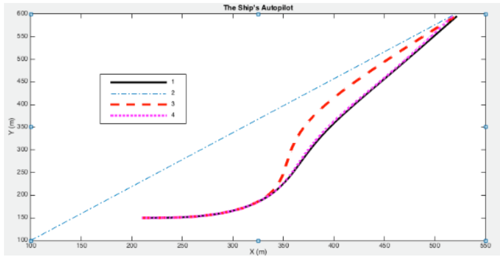

Fig. 4 Simulation results: the numbers 1, 2, 3, and 4 indicate enclosure-based, lookahead-based, way-point based, and desired course, respectively.

Here, we can find that three guidance systems are able to guide our ship to arrive at the desired point. However the paths with LOS vector law applied are paralleled with the desired course. While the path with way point method applied is not. It indicates the LOS vector law can make velocity vector point toward the destination point. In addition among methods based on the LOS vector law, the Lookahead-based steering has a better performance.

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

[1] Fossen,T.I. (1994) :"Guidance and control of Ocean vehicles"Wiley, New York