Design of Ship Course Controller based on Improved ADRC

Chunhao Yang[1, a], Yonghua Zhou[1]
[1]*College of electrical engineering, Guangxi University, Nanning 533000, China*

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Abstract: There are many interference factors when ships are sailing at sea. Therefore, the ship's course control is very important for its safe navigation. To solve this problem, a ship course controller with improved ADRC is designed. The controller uses TD to extract the desired course signal. Real time estimation and compensation of disturbance factors by ESO. Then the control law of the system is designed by using the backstepping sliding mode variable structure control. Finally, the simulation experiment of the controller is carried out with the simulation software of the real ship, the simulation results show the effectiveness of the controller.

1 INTRODUCTION

Course control is one of the most basic control problems in ship navigation. However, due to the large inertia and non-linear characteristics of the ship itself, many challenges have been brought to the study of the ship's course control method. Therefore, how to eliminate the uncertain factors and control the course quickly and accurately has become a research hotspot (Li An, et,al, 2020).

In this paper, a ship course controller based on improved ADRC is designed. The controller uses TD (Tracking differentiator) to extract the desired course signal. Real time estimation and compensation of disturbance factors by ESO (Extended state observer). Then, based on the traditional backstepping method and sliding mode variable structure control, the control law of ship course controller is designed. The controller combines the advantages of backstepping, sliding mode control and ADRC (Mathematics, 2020). Therefore, it has fast response speed and strong robustness.

2 SHIP NONLINEAR CONTROL MODEL

In the presence of external interference, the nonlinear operation model of the ship is as follows:

$$\begin{cases} \dot{\psi} = r \\ \dot{r} = f(r) + bu + w \end{cases} \tag{1}$$

In formula (1): ψ is the ship's course angle.r Is the rotating head angular velocity of the ship.u is rudder angle. f(r)is the internal interference caused by the rotating head angular velocity. In addition, the steering of the ship is completed by the steering gear. Using inertia link to express the characteristics of the steering gear, The expression of the inertia link of the steering gear is as follows:

$$T_E\dot{\delta} + \delta = K_E\delta_E \tag{2}$$

In formula (2): KE is the gain coefficient of the steering gear, TE is the time constant.

3 DESIGN OF CONTROLLER

Ship course controller based on improved ADRC technology consists of three parts. The following is a detailed order of the three parts of the controller.

3.1 Design of TD

The main function of TD is to extract the desired course signal and the differential value of the input signal. For the above control system. According to reference (Guo Siyu, et.al, 2020), the mathematical expression of the tracking differentiator is as follows:

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$$\begin{cases}\psi_{d1}(k+1)=\psi_{d1}(k)+p\psi_{d2}(k)\\ \psi_{d2}(k+1)=\psi_{d2}(k)+pfhan(\psi_{d1}-\psi_{d}(k),\psi_{d2},v,p)\end{cases} \quad (3)$$

In formula (3): p is the integration step,v is the velocity factor, ψ_d is the reference input signal, ψ_{d1} is an over signal of ψ_d, ψ_{d2} is the differential signal of ψ_d. fhan is the fastest comprehensive function. By choosing appropriate integration step and velocity factor, the tracking differentiator will be able to keep up with the expected signal and the differential value of the expected signal.

3.2 Design of ESO

ESO is the core of ADRC, it can estimate and compensate the internal and external interference of the whole system in real time. According to reference (Yuanqing Wang, et.al, 2020), the following expressions of linear extended state observer can be obtained:

$$\begin{cases}\dot{z}_1=z_2-l_1e\\ \dot{z}_2=z_3-l_2e+bu\\ \dot{z}_3=-l_3e\\ e=z_1-\psi\end{cases} \quad (4)$$

In formula (4): z= $[z_1\ z_2\ z_3]^T$ is the estimated value of the state variable ψ, r, h of the course control system. L= $[l_1\ l_2\ l_3]^T$ is the gain parameter of the ESO. The estimation and compensation of system disturbance can be realized by selecting the appropriate L (Yuanqing Wang, et.al, 2020).

3.3 Design of Backstepping Sliding Mode Controller

The expression of the error equation defining the system is as follows:

$$\begin{cases}e_1=\psi-\psi_d\\ e_2=r-r_d\end{cases} \quad (5)$$

In formula (5): r_d is the virtual control quantity of rotating head angular velocity. The mathematical expression of r_d is as follows:

$$r_d=-c_1e_1+\dot{\psi}_d \quad (6)$$

Take Lyapunov function as:

$$V_1=\frac{1}{2}e_1^2+\frac{1}{2}L^2 \quad (7)$$

In formula (7): $\dot{L}=-\dfrac{L}{\tau}+\dot{r}_d$, τ is the filter coefficient of the filter [3]. Derivative formula (7), the expression is as follows:

$$\dot{V}_1=e_1\dot{e}_1+L\dot{L}=e_1(-c_1e_1+e_2)+L\dot{L}\le -c_1e_1^2+e_1e_2 \quad (8)$$

In order to make e_2 approach zero, sliding mode control is introduced. The mathematical expression of sliding mode surface is as follows:

$$s=e_2+\gamma\dot{e}_2^h \quad (9)$$

Take Lyapunov function as:

$$V_2=\frac{1}{2}s^2 \quad (10)$$

Derivative formula (12), the expression is as follows:

$$\dot{V}_2=s\dot{s}=s(\dot{e}_2+\gamma h\dot{e}_2^{h-1}\ddot{e}_2)=s\gamma h\dot{e}_2^{h-1}(\ddot{e}_2+\frac{1}{\gamma h}\dot{e}_2^{2-h}) \quad (11)$$

With the Lyapunov stability theory, the control law of the system is obtained. The expression of the control law is as follows:

$$u=-\frac{1}{b}(\int_0^t\left[\frac{1}{\gamma h}\dot{e}_2^{2-h}+(\rho_1+\rho_2)\mathrm{sgn}(s)+\rho_3 s\right]d\tau+-\frac{1}{b}(z_3-\dot{r}_d) \quad (12)$$

4 SIMULATION EXPERIMENT

Taking the Yulong ship as the simulation object, The parameters of ships are introduced in reference (Guo Siyu, et.al, 2020). The selected controller parameters are as follows: p=0.1, v=50, c_1=0.05, h=1.25. The simulation experiment is set as follows: the simulation experiment duration is 200s, the expected course signal is 30 degrees, the external interference factor is wind force level 6, and the water flow rate is 1.3m/s. The simulation results are shown in Fig 1.

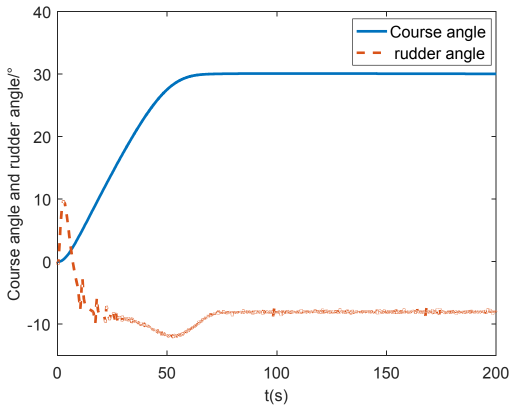

Figure 1: curve of ship course angle and rudder angle.

As can be seen from Fig 1, The system converges in 70 seconds, no any overshoot. The curve change of rudder angle is smooth. Finally stable at - 7 degrees to resist the interference of external environmental factors. The simulation results show the effectiveness of the controller.

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