ISSN 2616-5775 Vol. 6, Issue 9: 87-92, DOI: 10.25236/AJCIS.2023.060913

Ship course change control based on humanoid intelligent control

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Abstract: *A ship heading intelligent control algorithm is designed in this paper. First, ship heading control objective is proposed by input of control rudder angle and output of ship heading; Then, according to the deviation trend of ship heading output and its ideal trajectory, information about course deviation and its rate is extracted; Finally, to achieve ship heading control, rudder angle control strategy is enactmented under specific state by adopting human thinking, reasoning and control strategy. The simulation is executed with MATLAB software, and the results show that the controllerwhich is stability has strong robustness.*

Keywords: *Humanoid intelligent control, Control strategy, Ship motion, Heading control, Simulation*

1. Introduction

The ship is a typical pure hysteresis, non-linearity, time-varying uncertainty system, and the traditional digital PID control can no longer accurately control the ship's heading. The sliding mode variable structure control theory [1] provides an effective solution for the nonlinear and uncertain control of ship motion, but this method has the problem of severe chattering of the control input, which is not conducive to the engineering implementation. Adaptive control based on adaptive control rate [2] achieves remarkable results in non-linearity and uncertainty, but its disadvantage lies in relying on the mathematical model of the controlled object. Therefore, seeking an effective and easy-to-engineer control algorithm is the main content of future research.

Humanoid intelligent control [3-4] is based on human thinking mode and reasoning-control strategy, does not rely on the controlled object model, and makes decisions and controls the characteristic state (system deviation and deviation speed) of the controlled object, so as to complete the set goal. At present, humanoid intelligent control is widely used in nonlinear time-varying uncertain systems, such as vehicle parking control [5], servo system electro-hydraulic position automatic control [6], large time lag hot processing line temperature automatic control [7] and robot path planning control [8].

Therefore, this paper uses the humanoid intelligent control algorithm to directly control the characteristic state to achieve fast, stable and accurate control of the ship's course.

2. Responsive model of ship motion

In the 50s of the 20th century, Japanese scholar Kensaku Nomoto [9] proposed a responsive mathematical model of ship maneuvering motion based on rudder angle input and heading output from the perspective of control theory. Bech [9] developed a mathematical model of ship maneuvering motion that is suitable for large-scale course change maneuvering and can explain nonlinear phenomena such as course instability on the basis of the second-order Nomoto model, and consider external interference and ship system parameter perturbation. Its mathematical expression is,

$$T_1T_2\ddot{\varphi} + (T_1 + T_2)\dot{\varphi} + KH(\dot{\varphi}) = K(T_3\dot{\varphi} + d) + \Delta \tag{1}$$

Where $H(\dot{\varphi}) = \alpha_0 + \alpha_1\dot{\varphi} + \alpha_2\dot{\varphi}^2 + \alpha_3\dot{\varphi}^3$, Δ is uncertainty.

So, the goal of this paper is to seek a law of control δ, which makes ship course φ asymptotic

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tracking heading expectations φ_r, that is: if $t \to \infty$, then $e = y - \varphi_r \to 0$.

3. Ship heading humanoid intelligent control strategy

3.1. Humanoid intelligent control ideas

The humanoid intelligent control algorithm was first proposed in 1979 by professors Bai Jianguo and Zhou Qijian [4] of Chongqing University, taking the intelligent behavior of the controlled object such as measurement observation, memory, discrimination, and decision-making as the research basis, and using the hierarchical hierarchical structure method to simulate human experience skills and control, reasoning logic, intuitive detection and other knowledge and experience.

The design process of the intelligent controller algorithm [10-11] is to establish the relationship between multi-modal control rate and characteristic state on the basis of obtaining system input and deviation information. The control algorithm can be described in the form of a generative rule “IF < Condition > THEN< Results >”, provided that the characteristics are the result of the control decision.

3.2. Intelligent control strategy for ship heading humanoids

(1) Ship heading humanoid control concept

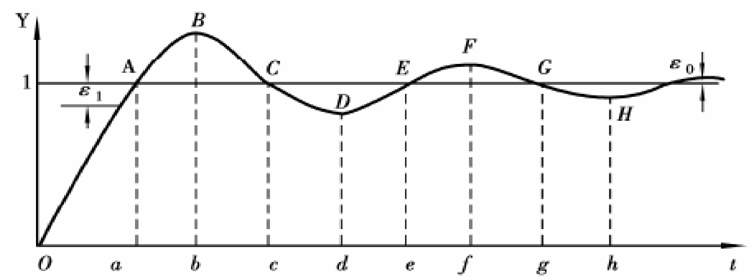

Figure 1: Ship heading step response curve

According to the deviation trend between the ship's heading output and the ideal trajectory, as shown in Figure 1, the heading deviation information and deviation change information are extracted, and the control strategy in a specific state is set by using the human thinking mode, reasoning and control strategy to achieve the ship's heading control, and the control system diagram is shown in Figure 2.

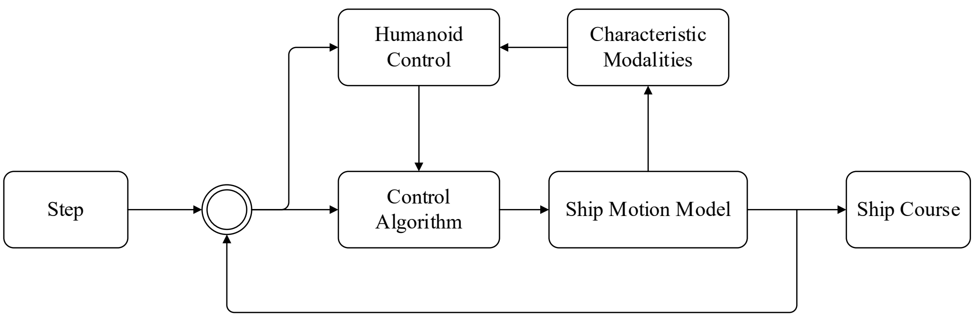

Figure 2: Ships heading humanoid intelligent control system diagram

(2) Ship heading humanoid control strategy

According to the position of the target trajectory on the error phase plane ($e - \dot{e}$), as shown in Figure 3, the difference between the system motion state and the ideal trajectory when it is in a feature state in the feature model, as well as the motion trend of the ideal trajectory, imitate the human control decision-making behavior, design the control or correction mode, and design the specific parameters in the mode [8].

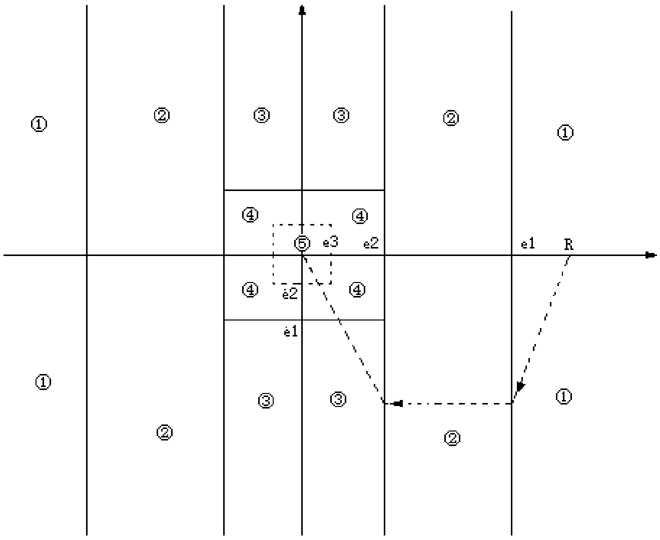

Figure 3: Ideal target trajectory of error

In order to make the actual error trajectory as consistent as possible with the ideal error target trajectory, the following control strategy of simulating human is adopted:

First, in the area (1), when the deviation is large, the largest possible control effect is adopted, such as pound-pound control, that is,

$$\text{IF: } |e_n| > e_1 \quad \text{Then: } u_n = \text{sgn}(e_n) \cdot U_{\max} \tag{2}$$

Second, in the area (5), the deviation and the rate of change of deviation are very small, in order to eliminate the error, PID control can be used, that is,

$$\text{IF: } |e_n| < e_3 \cap |\dot{e}_n| < |\dot{e}_2| \quad \text{Then: } u_n = k_{p5} \cdot e + k_{d5} \cdot \dot{e} + k_{i5} \int e dt \tag{3}$$

Third, in the region (2), if the deviation is large, proportional mode control is adopted, and in order to ensure that the deviation change rate is not too large, weak differential mode control is introduced on this basis, that is,

$$\text{IF: } |e_n| < e_1 \cap |e_n| > e_2 \quad \text{Then: } u_n = k_{p2} \cdot e + k_{d2} \cdot \dot{e} \tag{4}$$

Fourth, in the region (4), in the process of deviation reduction, if the deviation change speed is lower than or equal to the predetermined speed, proportional mode plus differential mode control can be used, that is,

$$\text{IF: } A \cap B \cap C \quad \text{Then: } u_n = k_{p4} \cdot e + k_{d4} \cdot \dot{e} \tag{5}$$

Where
$$A: |e_n| < e_2$$
$$B: |\dot{e}_n| < |\dot{e}_1|$$
$$C: |e_n| < e_3 \cap |\dot{e}_n| < |\dot{e}_2|$$
.

Fifth, in the region (3), in the process of deviation reduction, if the deviation change speed is greater than the predetermined speed, on the basis of proportional mode, strong differential control is introduced to reduce the deviation change rate as quickly as possible, that is,

$$\text{IF: } |e_n| < e_2 \cap |\dot{e}_n| \geq |\dot{e}_1| \quad \text{Then: } u_n = k_{p3} \cdot e + k_{d3} \cdot \dot{e} \tag{6}$$

(3) Ship heading humanoid control input limit

According to the principle of ship heading control, the control input is given by the servo equipped by the ship. To do this, the servo characteristics must be taken into account, i.e., the rudder speed of the servo is limited.

$$T_E \dot{\delta} = \delta_E - \delta \tag{7}$$

Where T_E is the servo characteristic index, δ_E is rudder angle and $|\delta_E| \le 35^0$, $\dot{\delta}$ is the speed of rudder and $|\dot{\delta}| = 3\ ^\circ/_S$.

4. Simulation experiments

Taking the teaching practice ship "Yulong" of Dalian Maritime University and COSCO ROTTERDAM container ship of COSCO Group as examples, Matlab/Simulink is used to design the ship heading humanoid control simulation platform, as shown in Figure 4.

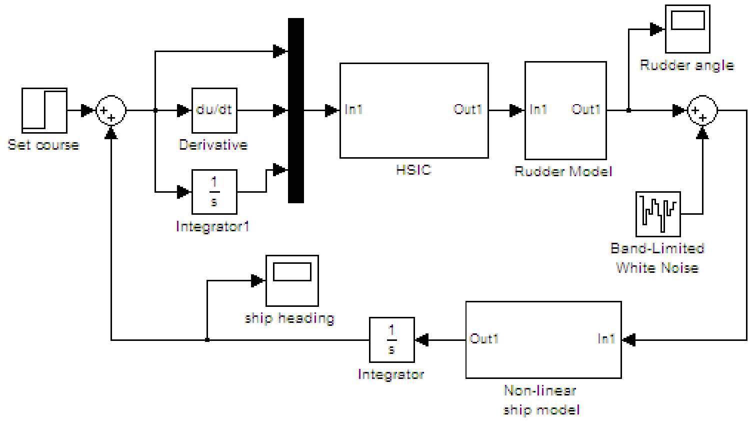

Figure 4: MATLAB simulation platform

4.1. Course change experiment based on humanoid control

The course change control experiment was carried out on the "Yulong" ship and COSCO ROTTERDAM container ship, the heading was set to 20°, and after adding random interference from the outside world, the ship's heading output and control rudder angle input were shown in Figure 5 and Figure 6. It can be seen from Figure 5 and Figure 6 that the ship's heading output is fast and stable, no overshoot, insensitive to external interference, and the rudder angle output is smooth and reasonable.

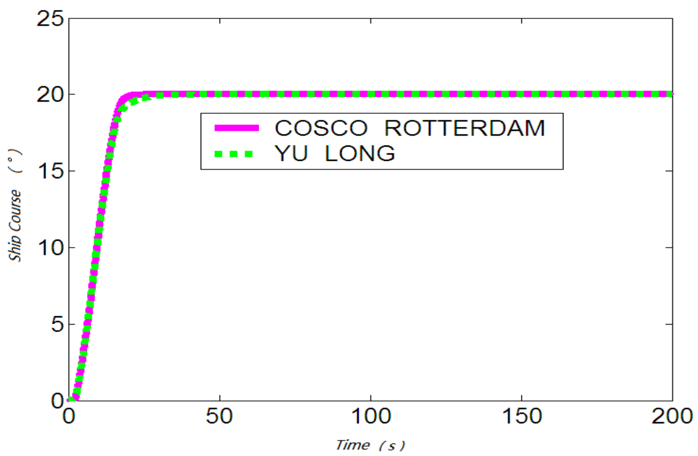

Figure 5: Output of ship heading

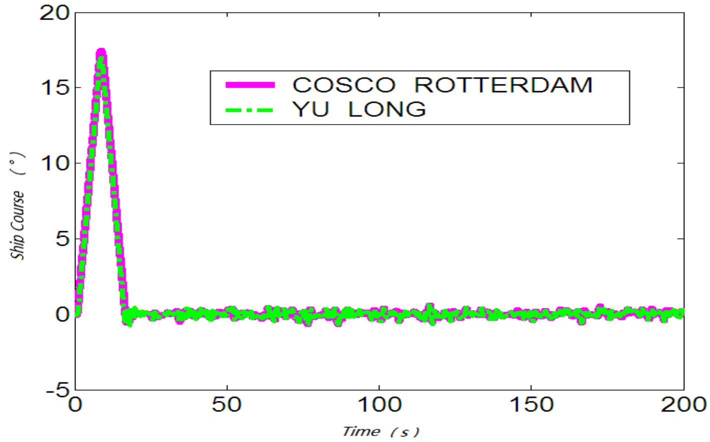

Figure 6: Input of rudder control

4.2. Comparative experiment on course-changing control

Simulation comparison experiments are carried out with ordinary PID and adaptive control algorithms. The heading is set to 20°, after adding random interference from the outside world, the ship's heading output is shown in figure 7 (comparative simulation experiment on the "Yu Long" ship) and figure 8 (comparative simulation experiment on the “COSCO Rotterdam” container ship). As can be seen from Figures 7 and 8, the ship's heading output is fast and stable, with no overshoot and no jitter.

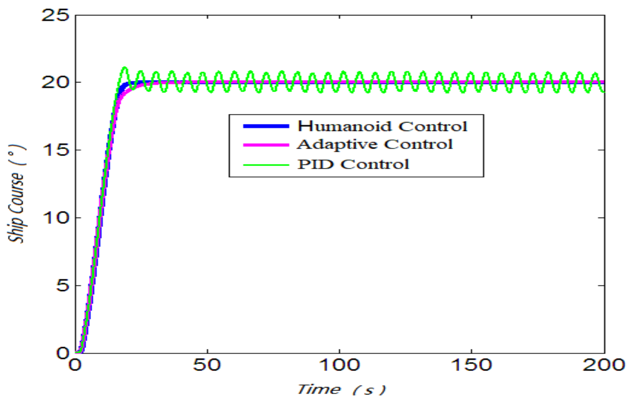

Figure 7: Ship heading output of “YU LONG”

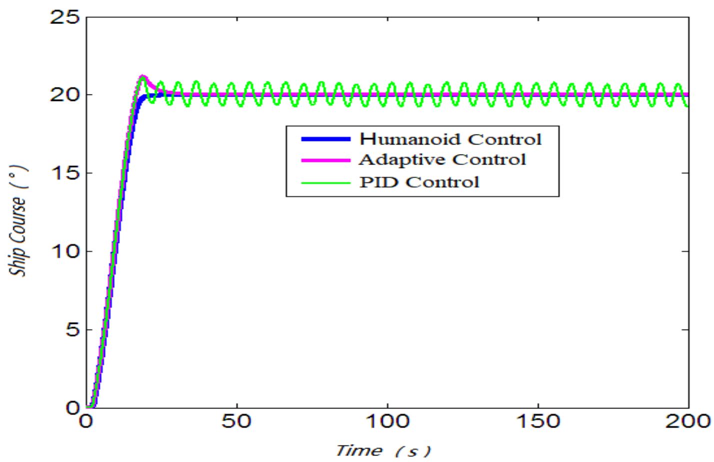

Figure 8: Ship heading output of “ROTTERDAM”

ISSN 2616-5775 Vol. 6, Issue 9: 87-92, DOI: 10.25236/AJCIS.2023.060913

In summary, the controller designed in this paper has superior control performance and strong robustness.

5. Conclusions

On the basis of the ship's rudder angle input and heading output, drawing on the idea of humanoid control, the rudder angle control mode is established based on the heading output error and its change situation, so as to realize the multi-modal control of the ship's course. Its control does not depend on the ship model, and the control is flexible and effective.

Acknowledgments

This work was supported by the Scientific research project of Jiangsu Maritime Institute under Grant 2022zkZD02, 2022zkZD03 and 2022kjcx-02, and supported by the Basic Science (Natural Science) Research Project of Universities in Jiangsu Province under Grant 21KJB580009, and the Jiangsu Province "Blue Project" outstanding young backbone teacher talent project in 2021.

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