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Research on Motion Control of Towed Target Based on Pan-boolean PID

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Abstract

The towed underwater target is an important tool for weapon assessment. The motion effect of the towed underwater target has a direct impact on the assessment result of the weapon's tracking ability, but the existing control methods all have certain defects. In this paper, the motion of the towed target's streamer and target support is analyzed, the transfer function is deduced, and the depth-fixing motion control model is established. The traditional PID is combined with the pan-Boolean algorithm to control the depth-fixing motion of the towed underwater target. Realize the deep control simulation of pan-Boolean PID control and traditional PID control in the Simulink simulation environment. The simulation results show that the pan-Boolean PID control method is better than the traditional PID control for the depth control of the towed underwater target.

Keywords

Towed target; Traditional PID; Pan-Boolean PID; Control method.

1. INTRODUCTION

For a long time, countries around the world have had the need to assess the power of weapons. The underwater target mainly shows its functions from the following aspects. First, the underwater target can be similar to the real target submarine, producing a specific "sensing", which is used for the test and identification of underwater weapons and the exercise and training of the fleet. Secondly, the underwater target is used to assess the important performance of underwater weapons or weapon systems to capture and attack targets, such as assessing the capture distance and guidance accuracy of the torpedo self-guided system; assessing the target capture capability of the wire-guided weapon system; the role of the fuze Radius; the overall function of the torpedo to track and strike the target. In addition, the underwater target also needs to cooperate with other related equipment to evaluate the torpedo's interference countermeasure ability[1][2]. Underwater targets include self-propelled targets and towed targets. This article refers to towed underwater targets.

Traditional PID control is a control technology commonly used for towed underwater targets. The PID controller is simple in design and has good performance. However, due to the external interference factors such as ocean currents and waves in the movement of towed underwater targets, when the interference factors are severe, traditional PID control effect is poor. Sliding mode control is simple in modeling, strong in robustness, fast in response and superior in performance, but the problem of chattering has always existed. Fuzzy control is often used in systems where precise mathematical models are not available, but fuzzy rules are sometimes difficult to formulate. Active disturbance rejection control has many parameters, and the adjustment is cumbersome. Therefore, since there are certain problems in the control effect of

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a single control method, a strategy combining different control methods can be applied to the motion control of the towed underwater target. In order to realize the problem that the depth is difficult to achieve fast and precise control, this paper designs a depth motion controller that combines the pan-Boolean algorithm [3] and the traditional PID.

2. MOTION MODEL OF TOWED TARGET

The towed underwater target system has three parts: tugboat, towed cable and underwater target support[4]. The system structure is shown in Figure 1. When the system is working, the towing vessel drags the underwater target through the towing cable, and a propeller is installed at the tail of the underwater target support body to provide thrust. By issuing control commands at the towing ship control terminal, the position of the underwater target support body is controlled to rotate the motor shaft of the wing, and the wing of the support body is rotated to change the water cutting angle of attack, so as to achieve the purpose of changing the navigation depth. As a moving carrier, the towed underwater target can be equipped with various sensors, underwater detectors and other devices to cooperate with other equipment to complete the requirements of weapon assessment.

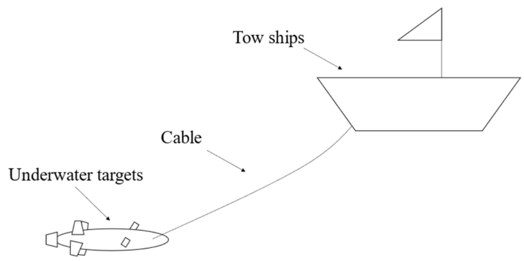

Figure 1. Towed target system

2.1. Analysis of Streamer Motion Model

In this paper, a simple analysis of the streamer is carried out, and the modeling refers to the motion equation proposed by Ablow and Schechter[5], without considering the tensile deformation and torsion, the motion balance equation of any node on the cable is.

$$\frac{\partial}{\partial s}\boldsymbol{T}+\boldsymbol{W}+\boldsymbol{F}+\boldsymbol{B}=0 \tag{1}$$

In the formula: S is the arc length of the towing cable after being stretched by tension; T is the tension on the node of the towing cable; W is the difference between the heavy buoyancy forces of the cable per unit length in water; F is the fluid water received by the towing cable per unit length Power; B is the inertial hydrodynamic force of the streamer per unit length.

2.2. Analysis of Dragging Target Motion Model

The target can be driven by the pulling force of the streamer. In this study, a thruster is also installed at the tail of the target to provide thrust. In this paper, the target is set to provide thrust by the tail thruster, and the mathematical model of motion is determined with reference to the submarine model. To study the vertical depth motion of the target, when making a fixed depth motion in the water, the target mainly bears the effects of gravity, buoyancy, the vertical component of the thrust generated by the thruster and the hydrodynamic force of the fluid. It is the basis for the research and design of the depth-fixing motion control algorithm of the towed underwater target [3]. The space motion equation can represent the depth-fixing motion state

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of the towed underwater target. According to the momentum theorem [6], the motion expression of the towed underwater target along the oz axis in the carrier coordinate system is:

$$Z = m[\dot{w} - uq + vp - z_G(p^2 + q^2) + x_G(rp - \dot{q}) + y_G(rq + \dot{p})] \tag{2}$$

In the formula: Z is the resultant external force on the oz axis of towed underwater target; m is the mass of the towed underwater target; u, v, w are the speeds of the towed underwater target along the ox, oy, and oz axes; p, q, r are the angular velocities of the towed underwater target along the ox, oy, and oz axes; xG, yG, zG are the center of gravity of the towed underwater target.

In the direction of depth-fixing motion, the expression of the resultant external force for dragging the target:

$$Z = G + B + Z_{\mathrm{T}} + Z_{\mathrm{F}} \tag{3}$$

In the formula: G is gravity; B is buoyancy; ZT is the thrust generated in the vertical direction of the propeller; ZF is the hydrodynamic force. Substitute equation (3) into the left side of equation (2), and assume that the center of gravity of the towed underwater target holder is located at the origin of the carrier coordinate system, its lateral velocity and acceleration v = v̇ = 0, and the angular velocity of heel and yaw and angular acceleration p = r = ṗ = ṙ = 0, the equation of motion for depth determination is derived as:

$$Z_{\mathrm{T}} = (m - Z_{\dot{w}})\dot{w} - (m + Z_q)uq - Z_{\dot{q}}\dot{q} - Z_w uw - Z_* u^2 - Z_{w|q|}w|q| - Z_{|w|}u|w| - Z_{w|w|}(w|w| + w^2) - (G - B)\cos\theta \tag{4}$$

Where: Zẇ, Zq is the dimensioned hydrodynamic coefficient; θ is the trim angle.

2.3. Motion Control Model of Towed Target Depth Determination

Due to the coupling relationship between the target depth-fixing motion and the motion of other degrees of freedom, and the existence of nonlinear hydrodynamic terms, in order to facilitate the establishment of the depth-fixing control model, this paper will linearize and simplify the depth-fixing control model.

During the depth-fixing movement, it is assumed that the forward speed of the target is constant, that is, u̇ = 0, and u=1 m/s; Acceleration q = q̇ = 0, pitch angle θ = 0°; ignoring nonlinear hydrodynamic terms. Therefore, Equation (4) can be simplified, and the simplified motion equation of depth determination is:

$$Z_{\mathrm{T}} = (m - Z_{\dot{w}})\dot{w} - Z_w w \tag{5}$$

At this time, it can be considered that in the fixed system, the depth of the towed underwater target is $\dot{\zeta}_o$= w, $\ddot{\zeta}_o$= ẇ , then the transmission between the depth $\zeta_o$and the vertical component force ZT of the thruster output thrust can be obtained from formula (5). function, the transfer function is as follows:

$$G_D(s) = \frac{\zeta_o(s)}{Z_{\mathrm{T}}(s)} = \frac{1}{(m - Z_{\dot{i}})s^2 - Z_w s} \tag{6}$$

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Bringing in the parameters, the specific transfer function of the towed underwater target depth-fixing motion control model is:

$$G_D(s) = \frac{1}{439.13s^2+310.53s} \tag{7}$$

3. PAN-BOOLEAN PID DEPTH CONTROLLER

Based on the traditional PID control algorithm, the pan-Boolean PID algorithm establishes a pan-Boolean control strategy. The independent variable of its control is similar to that of PID control, which is composed of deviation, deviation differential and deviation integral, but the pan-Boolean PID control adopts a brand-new logic control system, and the control parameters analyzed by the pan-logic diagram [7] greatly improve the control of the system. efficiency.

Referring to the pan-Boolean theoretical system, combined with the traditional PID control method, the pan-Boolean PID control principle is established as shown below:

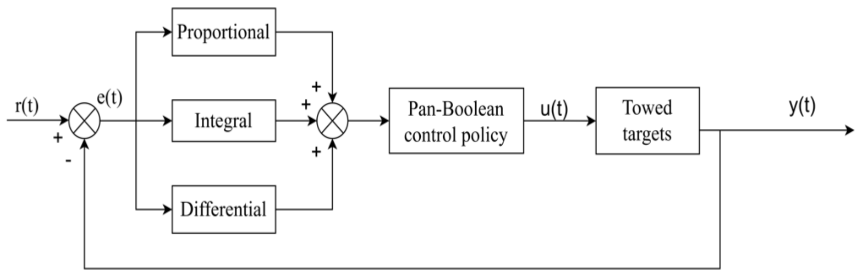

Figure 2. Pan-Boolean PID control principle of towed underwater target

The Pan-Boolean PID control system has three factors: deviation e(t)=r(t)-y(t), deviation integral $\int e(t)\,dt$, and deviation differentiation $\frac{de(t)}{dt}$, respectively represented by X1, X2, X3. $\pm\varepsilon$ represents the allowable deviation of the system, $\pm e$ represents the allowable deviation integral of the system, $\pm\delta$ represents the allowable deviation differential of the system. There are three state variables set for each factor, that is, the deviation factor consists of three state variables $e(t) > +\varepsilon$, $e(t) \leq |\varepsilon|$, $e(t) < -\varepsilon$,represented by X_1^1, X_1^2, X_1^3.The deviation integral factor consists of $\int e(t)dt > +e$, $\int e(t)dt \leq |e|$, $\int e(t)dt < -e$ three state variables X_2^1、X_2^2、X_2^3 means .The deviation differential factor consists of $\frac{de(t)}{dt} > +\delta$, $\frac{de(t)}{dt} < |\delta|$, $\frac{de(t)}{dt} < -\delta$ three state variables, which are respectively represented by X_3^1, X_3^2, X_3^3.Combining the above three factors with each other, a total of 27 situations are generated. Let Y4+, Y3+, Y2+, Y1+, Y0, Y1-, Y2-, Y3-, Y4- represent 9 kinds of increase, increase slightly, increase weakly, increase slightly, maintain, decrease slightly, decrease slightly, decrease slightly, and decrease more The 27 combinations are divided into 9 control strategies by using the pan-Boolean operation rules [8]. According to the established pan-Boolean PID control rules, the strategy is determined through the combination of factors and variables, and then the output energy is increased or decreased. A control system with good control effect must have a certain stability, which requires not only fast response speed, but also stable operation. This requires better parameter settings, that is, to adjust the nine output control parameters of the pan-Boolean PID control system.

In the pan-Boolean nine-point control theory [3]: Y4+ directly affects the maximum negative overshoot, Y3+ acts to start the system and obtain a certain initial speed, Y2+ directly affects the rise time, and indirectly affects the overshoot, and Y1+ affects the maximum negative

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overshoot. The adjustment has an impact, Y0 ensures that the steady-state error does not exceed the error limit, Y1- has an impact on the maximum positive overshoot, and has an impact on the error rate of change in the steady-state region, Y2- affects the downward trend after positive overshoot, Y3- ensures that the system does not exceed the upper boundary line of the allowable deviation. As Y3- enhances the upper boundary line of the allowable deviation, the upper boundary line is more reliable, and Y4- affects the maximum positive overshoot.

Table 1. Pan-Boolean PID control strategy table

X_1	X_3	X_2^1	X_2^2	X_2^3
	X_3^1	Y2+	Y2+	Y3+
X_1^1	X_3^2	Y4+	Y3+	Y2+
	X_3^3	Y3+	Y4+	Y4+
	X_3^1	Y2-	Y1-	Y1-
X_1^2	X_3^2	Y1+	Y0	Y1-
	X_3^2	Y1+	Y1+	Y2+
	X_3^1	Y4-	Y4-	Y3-
X_1^3	X_3^2	Y2-	Y3-	Y4-
	X_3^3	Y3-	Y2-	Y2-

4. SIMULATION RESULTS AND ANALYSIS

If In the deep motion control simulation of the pan-Boolean PID controller, the PID control parameters Kp=300, Ki=0.05, Kd=30 were determined after several simulations. A step signal with a depth change of 1m is added at 1s, and the simulation tracking responses of the two control algorithms to the step signal are shown in the figure.

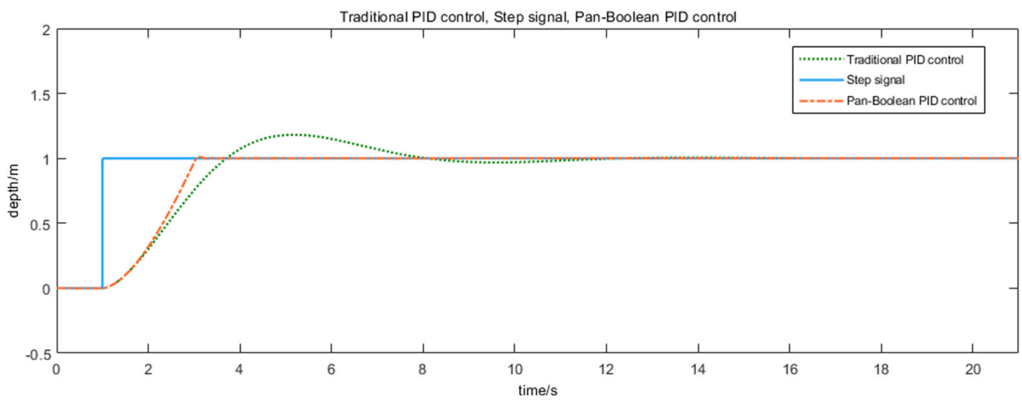

Figure 3. Controller response graph

From the simulation tracking response curve in the figure, it can be found that the pan-Boolean PID control has obvious advantages in dynamic performance compared with the traditional PID control. When the heading of the towed underwater target remains unchanged and the depth changes by 1m, the pan-Boolean PID can reach the set depth faster in the depth determination stage, and the set depth is reached for the first time in 3.045s, while the traditional PID control is in 3.7065s Only reached the set depth for the first time. In the deep adjustment stage, the pan-Boolean PID control has short transition time, small overshoot, small fluctuation and more stable. This shows that the pan-Boolean PID control has better dynamic

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performance in the motion control of the towed underwater target, which makes the system more stable.

5. CONCLUSION

This This paper mainly studies the depth control problem of towed underwater target motion control. Aiming at the towed underwater target motion system, a towed underwater target motion control system based on pan-Boolean PID is designed and applied to depth control. By simulating the depth motion in Simulink environment, it is verified that the pan-Boolean PID controller has better depth control effect on the towed underwater target.

In the future, in terms of the depth of the towed underwater target controller, the pan-Boolean PID controller can continue to be simulated at different depths; in terms of the motion control of the underwater controller, the attitude control can be simulated and further developed. Research.

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