Research on ROV Control Method based on Fuzzy PID

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Abstract

In order to ensure the stability of ROV, a corresponding control method must be adopted to realize the stable control of ROV. According to the joint action of multiple parameters, a bow motion control method based on multiple parameters is proposed, and the method is simulated and studied; the transfer function is derived. Then, using the theoretical study of PID control and fuzzy PID control, a fuzzy PID controller was constructed in the MATLAB Simulink library and simulated and tested, and the control effects of the PID controller and the fuzzy PID controller were compared, and it can be seen from the results of the simulation and test that the fuzzy PID control is better than the PID control under bow motion control and the overshoot of adjustment is less. The adjustment time is shorter, and the longitudinal control in the horizontal direction shows good stability and anti-interference.

Keywords

ROV; PID; Fuzzy PID; Bow Motion.

1. Introduction

Accompanied by the increasing human exploration of marine resources, cable-operated remotely operated underwater robots (ROV) have been more and more used [1]. Effective control of motion attitude is an important guarantee for ROV to carry out underwater operation and observation. The ROV motion control system is characterized by two features [2]: uncertainty of the working environment and nonlinearity of the control object. Bow direction control is the core technology for ROV to keep the predetermined heading and carry out stable operation, and simple and effective bow direction control can greatly improve the operation efficiency of ROV. The bow direction maneuvering device has to change its maneuvering performance with the change of underwater vehicle working conditions due to the change of underwater vehicle working conditions, and the disturbance of sea currents, which makes the maneuvering of underwater vehicle has great uncertainty [3].

Aiming at the characteristics of ROV such as uncertainty and nonlinearity, scholars at home and abroad have studied a variety of control methods for underwater vehicles. By adjusting the bow direction of ROV, fuzzy controller is used to correct the error of ROV model. However, in complex systems with a large number of variable parameters, it is difficult to accurately characterize their dynamics with a fuzzy controller. For this reason, a PID-based fuzzy controller is used in the thesis to ensure the stable operation of the ROV.

2. ROV Motion Modeling

Since ROV move underwater in a complex environment, it is necessary to gain a deeper understanding of the movement mechanism of ROV so as to provide a corresponding theoretical basis for the design of their control systems. On this basis, six different types of robots are modeled in motion and dynamics, so as to analyze the later transfer function.

2.1. Selection of the Coordinate System

In this paper, the coordinate system and nomenclature are selected according to the relevant standards of the International Pool Conference, and we choose two coordinate systems in the process of establishing the kinematic model, the fixed coordinate system E-ξηζ for calculating the kinematic characteristics of the ROV, and the kinematic coordinate system O-xyz for expressing the attitude characteristics of the ROV [4].

On this basis, we analyze the motion of the ROV with the ground as the reference. Setting E as the coordinate origin, we set the Eξ axis as the horizontal axis, whose positive direction is the main heading of the ROV; the Eξ and Eη axes form a horizontal plane and are perpendicular to each other; the Eζ axis points to the center of the Earth and is perpendicular to the horizontal plane [5].

Construct the ROV kinematic coordinate system by setting the coordinate origin O at the center of gravity G of the structure, and setting the Ox axis in the longitudinal mid-section, parallel to the waterline plane and pointing toward the bow of the ROV. The Oy axes are perpendicular to the longitudinal plane, parallel to each other in the horizontal plane and pointing to the right of the ROV's direction of advancement. The Oz axes are located in the mid-longitudinal plane, pointing toward the bottom end of the ROV and are perpendicular to the horizontal plane [6].

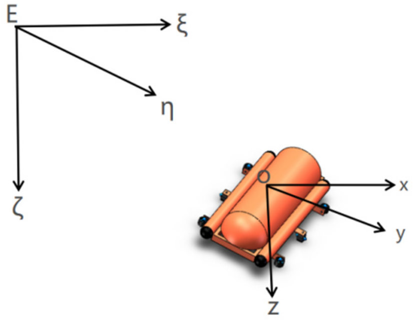

Figure 1. ROV Earth coordinate system and vehicle coordinate system

Table 1. Main symbols in the coordinate system

			Name	Parameters			
longitudinal displacement	x		Vertical movement speed	u		vertical force	X
transverse displacement	y		Lateral Movement Speed	v		transverse force	Y
vertical displacement	z		Vertical travel speed	w		Vertical force	Z
roll angle	φ		Transverse Tilt Velocity	p		oscillating torque	K
tilt	θ		Longitudinal angular velocity	q		pitching moment	M
heading angle	ψ		yaw angular velocity	r		Slewing orque	N

The ITTC recommended coordinate system is used to describe the ROV six-degree-of-freedom motion. The Euler angle method is used to describe the ROV attitude angle [7], and the ROV position and attitude vectors are expressed as:

$$\eta=[\eta_1^T,\eta_2^T]^T,\eta_1=[x,y,z]^T,\eta_2=[\varphi,\theta,\psi]^T \tag{1}$$

Vehicle velocity and angular velocity vectors

$$\mathrm{v}=[\mathrm{v}_1^{\mathrm{T}},\mathrm{v}_2^{\mathrm{T}}],\mathrm{v}_1=[u,v,w]^{\mathrm{T}},v_2=[p,q,r]^{\mathrm{T}} \tag{2}$$

2.2. ROV Thrust Distribution

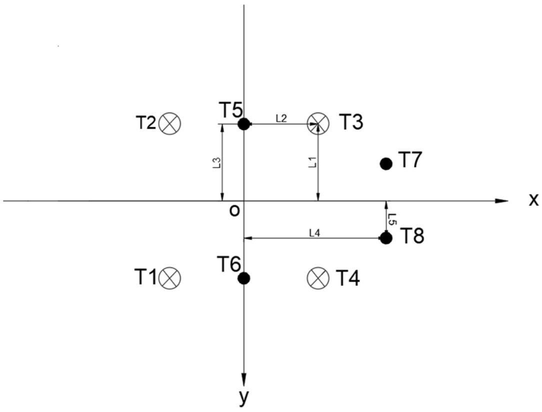

Figure 2. Thrust Distribution

Four underwater thrusters T1, T2, T3 and T4 are arranged on the horizontal plane of the follower coordinate system, the four thrusters are horizontally perpendicular to the xoy plane, and the four thrusters are symmetrical to the x and y axes, respectively; two propellers are arranged on the y-axis, propellers T5 and T6, and the two propellers are symmetrical about the x-axis. Thrusters T7, T8 are arranged in the same plane in the tail section and are also symmetrical about the x-axis.

This paper investigates the ROV parameters:

L1=L3=240mm, L2=250mm,L4=480mm,L5=120mm

Therefore, the ROV underwater thruster thrust and its resulting moment term matrix are expressed as.

$$\tau=\begin{bmatrix}X\\Y\\Z\\K\\M\\N\end{bmatrix}=\begin{bmatrix}T7+T8\\T5+T6\\T1+T2+T3+T4\\L4T7+L4T8\\-L3T5+L3T6\\-L2T1-L2T2+L2T3+L2T4\end{bmatrix} \tag{3}$$

2.3. ROV Motion Modeling

The ROV kinematic model requires a relationship between the stationary and kinematic coordinate systems, which is transformed according to the literature [8]:

$$J_1(\eta)=\begin{bmatrix}\cos\theta\cos\psi & \cos\psi\sin\theta\sin\varphi-\sin\psi\cos\varphi & \cos\psi\sin\theta\cos\varphi+\sin\psi\sin\varphi\\ \sin\psi\cos\theta & \sin\psi\sin\theta\sin\varphi+\cos\psi\cos\varphi & \sin\psi\sin\theta\cos\varphi-\cos\psi\sin\varphi\\ -\sin\theta & \cos\theta\sin\varphi & \cos\theta\cos\varphi\end{bmatrix} \tag{4}$$

$$J_2(\eta)=\begin{bmatrix}1 & \tan\theta\sin\varphi & \tan\theta\cos\varphi\\ 0 & \cos\varphi & -\sin\varphi\\ 0 & \sin\varphi\sec\theta & \cos\varphi\cos\theta\end{bmatrix} \tag{5}$$

$$\dot{\eta}=\begin{bmatrix}J_1(\eta) & 0_{3\times3}\\ 0_{3\times3} & J_2(\eta)\end{bmatrix} \tag{6}$$

Typically, the ROV six-degree-of-freedom equations consist of three translational and three rotational equations of motion, and according to Newton's second law, the translational equations of motion of the ROV can be obtained as:

$$F_{\Sigma}=\left[\frac{dv}{dt}+\Omega\times \mathrm{v}+\frac{d\Omega}{dt}\times Rg+\Omega\times(\Omega\times Rg)\right] \tag{7}$$

In the formula: Rg is the distance from the origin of the follower coordinate system to the center of gravity g.

The rotation of the ROV satisfies the Euler equation for:

$$M_{\Sigma}=I\frac{d\Omega}{dt}+\Omega\times(I\Omega)+mR\mathrm{g}\times(\frac{dv}{dt}+\Omega\times v) \tag{8}$$

Substituting the above two equations into the kinematic and rotational formulas respectively yields the ROV six degree of freedom equations in the follower coordinate system as:

$$\begin{cases} m\left[(\dot{u}-vr+wq)-xG(q^2+r^2)+yG(pq-\dot{r})+zG(pr+\dot{q})\right]=X \\ m\left[(\dot{v}-wp+ur)-yG(r^2+p^2)+zG(qr-\dot{p})+xG(qp+\dot{r})\right]=Y \\ m\left[(\dot{u}-uq+pv)-xG(p^2+q^2)+xG(rp-\dot{q})+yG(pr+\dot{q})\right]=Z \\ I_{xx}\dot{p}+(I_{zz}-I_{yy})qr-I_{xz}(\dot{r}+pq)+I_{yz}(r^2-q^2)+I_{xy}(pr-\dot{q})+m[yG(\dot{w}+pv-qu)-zG(\dot{v}+ru-pw)]=K \\ I_{yy}\dot{q}+(I_{xx}-I_{zz})rp-I_{xz}(\dot{p}+qr)+I_{xz}(p^2-r^2)+I_{yz}(qp-\dot{r})+m[zG(\dot{u}+qw-rv)-xG(\dot{w}+pv-qu)]=M \\ I_{zz}\dot{p}+(I_{yy}-I_{xx})pq-I_{yz}(\dot{q}+rp)+I_{yx}(q^2-p^2)+I_{zx}(pr-\dot{p})+m[xG(\dot{v}+ru-pw)-yG(\dot{u}+qw-rv)]=N \end{cases} \tag{9}$$

Style:

m is the mass of the ROV;

xG, yG, zG are the coordinates of the center of gravity of the ROV;

Ixx, Iyy, Izz, Ixy, Iyz, Izx are the moment of inertia of the ROV.

In this paper, we consider that the follower coordinate system coincides with the inertial main axis of the ROV and the origin of the follower coordinate system coincides with the center of gravity of the ROV, so that Ixx, Iyy, Izz, Ixy, Iyz, Izx=0 and xG, yG, zG=0 can be obtained from the simplified equations of motion:

$$\begin{cases} m(\dot{u}-vr+wq)=X \\ m(\dot{v}-wp+ur)=Y \\ m(\dot{w}-uq+vp)=Z \\ I_{xx}\dot{p}+(I_{zz}-I_{yy})qr=K \\ I_{yy}\dot{q}+(I_{xx}-I_{zz})rp=M \\ I_{zz}\dot{p}+(I_{yy}-I_{xx})pq=N \end{cases} \tag{10}$$

2.4. ROV Dynamics Modeling

The following assumptions are made before modeling ROV dynamics.

(1) Treat the ROV as a rigid body with a constant mass and do not consider changes in temperature, pressure, etc. in the water;

(2) The positions of the ROV center of gravity and center of buoyancy remain constant throughout the motion.

In the kinematic coordinate system, the six-degree-of-freedom model is represented as [9]:

$$M\dot{v} + C(v)v + D(v)v + g(\eta) = \tau \tag{11}$$

$$\dot{\eta} = J(\eta)v \tag{12}$$

M is the mass and its inertia matrix, C(v) the underwater robot Kurtosis and centripetal force matrix, D(V) the fluid drag matrix, g(η) the gravity and buoyancy matrix, and τ the thrust provided by the ROV underwater.

2.5. Propulsion System Transfer Function

In motion control studies, it is often possible to simplify the ROV thruster motor's to an inertial link [10], with a transfer function of

$$G_K(S) = \frac{K_M}{(1 + T_M s)} \tag{13}$$

where KM is the motor transfer coefficient and TM is the motor mechanical time constant. Since ROVs are typically nonlinear systems, they need to be linearized for subsequent modeling and simulation [11].

The thrust expression equation is:

$$T = Cn \tag{14}$$

$$C = 2K_T \rho D^4 n_0 \tag{15}$$

where KT is the thruster thrust coefficient; n0 is the rated speed of the motor. Therefore, the thruster transfer function can be derived as:

$$Gp(S) = C \tag{16}$$

The values of the parameters related to the motor and thruster can be determined by measuring, estimating and consulting relevant information as.

$$K_M = 2, T_M = 1.86, C = 0.2$$

The transfer function of the thruster is:

$$G_M(s) = \frac{2}{(1 + 1.86s)} \tag{17}$$

$$G_p(s) = 0.2 \tag{18}$$

2.6. Motion System Transfer Function

When the ROV does only bow motion, assuming that its motion in the plane does not consider the submerged motion, i.e., only the bow motion is considered, its main velocity vector is related to the parameters v and $\dot{v}$, i.e., it completes the fixed-point steering motion in the horizontal plane, with the position of the center of gravity unchanged, and does not involve the inward and outward and transverse motions, $u = v = 0$,at this time, its equations of motion for the turning of the bow is as follows.

$$(Iz - N_{\dot{r}})\dot{r} = Nr + Np \tag{19}$$

By using Solidworks software simulation and referring to related information, the following data were obtained

$$m = 20.4kg, L = 0.495m$$
$$Z'\dot{w} = -0.045,\quad Z'w = -0.027$$
$$I_z = 1.219$$
$$N_r = 6.68, N_{\dot{r}} = 0.024$$

Style:

$m -$ ROV quality.

$L -$ ROV height.

$Z'\dot{w}$、$Z'w -$ Dimensionless hydrodynamic coefficient

By utilizing the correspondence between the uncaused hydrodynamic coefficients, it can be obtained that

$$Z\dot{w} = \frac{1}{2}\rho L^3 Z'\dot{w} = -2.73$$
$$Zw = \frac{1}{2}\rho L^4 Z'w = -0.81 \tag{20}$$

The transfer function between the transverse roll angle and the thrust applied to the ROV when it is in transverse rocking motion can be obtained by pull-type integral transformation:

$$G_{\psi Z_T}(s) = \frac{\psi(s)}{Z_T(s)} = \frac{1}{(I_Z - N_{\dot{r}})s^2 - N_r s} \tag{21}$$

By combining the ROV motion transfer function with the motor transfer function, the open-loop transfer function of the ROV system can be obtained, where the bow motion control system transfer function is:

$$G_{\psi}(s) = G_M(s) \cdot G_P(s) \cdot G_{\psi Z_T}(s) = \frac{0.4}{2.22s^3 + 13.62s^2 + 6.69s} \tag{22}$$

3. Simulation Results and Analysis

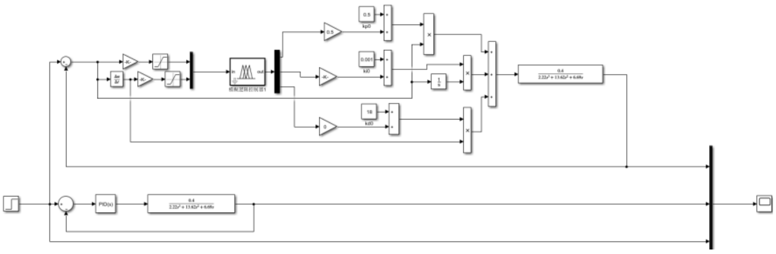

Figure 3. Simulation of ROV bow control

In order to verify the effectiveness of the fuzzy PID control system, Matlab Simulink is used to construct the fuzzy PID control system model and compare it with the conventional PID control system, and the fuzzy PID system simulation model is shown in Fig. 3. After a large number of adjustments and calculations, the fuzzy PID control parameters are determined as Kp = 0.5, Ki = 0.001, Kd = 18. The simulation conditions are set to dive to a depth of 10 m, and the simulation time is 200 s. The simulation results of the control system are shown in Fig. 3.

From Fig. 4, it can be seen that the fuzzy PID control time is significantly shorter than the conventional PID control on the ROV attitude control. The conventional single-loop PID tends to stabilize at 155s, and the fuzzy PID system tends to stabilize at 67s. Through the data analysis can be obtained by the conventional PID overshooting amount, reached 3.737%, while the improved fuzzy PID overshooting amount of 0.498%. This shows that the fuzzy PID has better steady state performance in the step response, and the control performance of the fuzzy PID is significantly better than the control performance of the conventional PID.

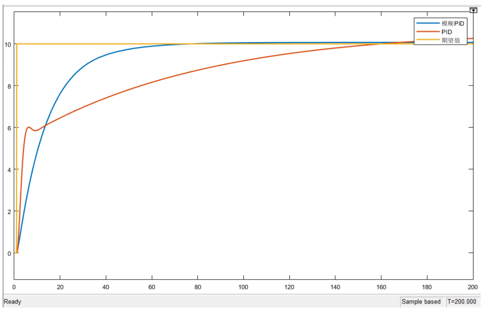

Figure 4. Step response curve

4. Conclusion

In this paper, a fuzzy PID-based ROV motion control system is designed with ROV as the object, considering its nonlinear, time-varying, and strongly coupled characteristics. Simulation is carried out using Matlab Simulink, and it is verified that the fuzzy PID controller is more effective than the conventional ROV control. The results show that the method can effectively improve the attitude regulation characteristics of the ROV during the bow motion of the ROV and has higher accuracy, which can effectively improve the motion control efficiency.

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