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Research on the Control of Underwater Stirring Robot based on PID Control

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Abstract

In the process of sewage treatment, it is necessary to control the oxygen content in the sewage according to the process requirements to achieve the effect of biochemical treatment. When the oxygen content is too high, it is necessary to stop the oxygen injection to the treatment tank, but the sludge containing biochemical components will be deposited at this time, affecting the biochemical effect. The purpose of this project is to design an underwater mixing robot and control system to solve the above problems. The fuselage structure is equipped with a multi-blade windlass design to achieve uniform mixing of the sludge in the gas explosion tank, optimize PID control, and improve mixing by optimizing software and hardware. The operating efficiency of the system under different sewage conditions.

Keywords

Underwater Robot; Mechanical Model; PID Control.

1. Introduction

With the rapid development of industrial technology and the continuous improvement of people's living standards, the amount of sewage treatment such as agricultural sewage, urban sewage, and industrial sewage is also increasing, so the problem of sewage treatment cannot be underestimated. In the field of sewage treatment in my country, the activated sludge method occupies a dominant position [1]. The activated sludge method is a treatment method with activated sludge (microorganism) as the main component. By stirring and mixing activated sludge and wastewater, the air is continuously aerated to decompose the organic pollutants in the wastewater, and at the same time, the biological solids are removed from the wastewater. It is separated from wastewater to achieve the purpose of sewage treatment [2].

At present, the mainstream research direction of activated sludge method at home and abroad is the improvement of the purification efficiency of the mixed components of sludge and sewage and the ventilation rate and method of the aeration tank. Whether the sewage and activated sludge are fully mixed is directly related to the effect of sewage treatment. At the same time, when reviewing literature and searching for information, it is found that most sewage treatment plants in my country do not invest in underwater robots to assist sewage treatment operations. Therefore, this paper proposes and designs an underwater robot device that can monitor the situation of sludge mixing in real time to improve the degree of sludge mixing, thereby improving the efficiency of sewage treatment, enhancing the importance of sewage treatment plants in my country, and improving the economic benefits of sewage treatment.

Figure 1 is the preliminary design of the shape of the underwater robot. On this basis, this paper will realize the design of the underwater mixing robot with the organic combination of the robot body mechanism and the underwater mixer through 3D modeling, mechanical structure design, and control algorithm design. On the basis of dynamic analysis and fluid mechanics analysis, the design of the

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stirring impeller structure is completed; the stirring rate control of the stirring robot in the aeration tank and the control of the robot's posture balance are realized by nonlinear PID control.

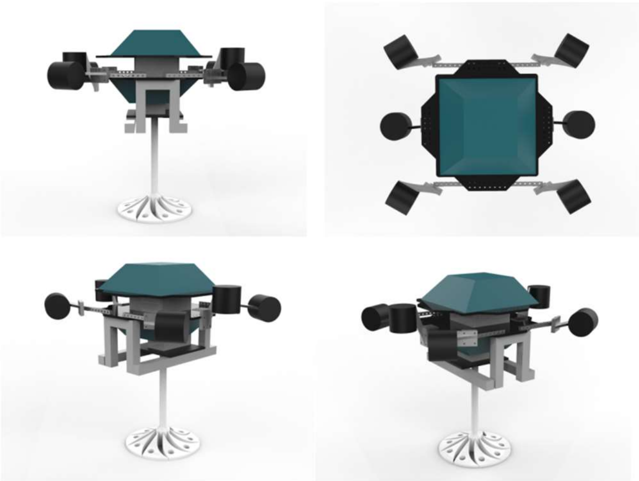

Figure 1. Outline of the underwater robot

2. Model Establishment

Combining the fluid mechanics model and the rigid body mechanics model to establish a mathematical model of the force of the sewage machine robot in the working process, this mathematical model is the control basis of the robot. Since the control of the sewage robot is a very complex system, it is very important to establish an accurate mathematical model. Difficulty, this paper makes the following assumptions:

1) Consider the underwater robot as a completely rigid body and completely symmetrical;

2) The coordinate origin of the robot is completely coincident with the center of mass of the robot;

3) The propeller of the robot is a completely rigid body, and its deformation and elastic structure are not considered;

4) Assume that the ground coordinate system O is an inertial coordinate system.

Under the above assumptions, in order to facilitate modeling, a fixed-depth state is selected for dynamic and kinematic force analysis. The analysis structure is shown in Figure 2 below:

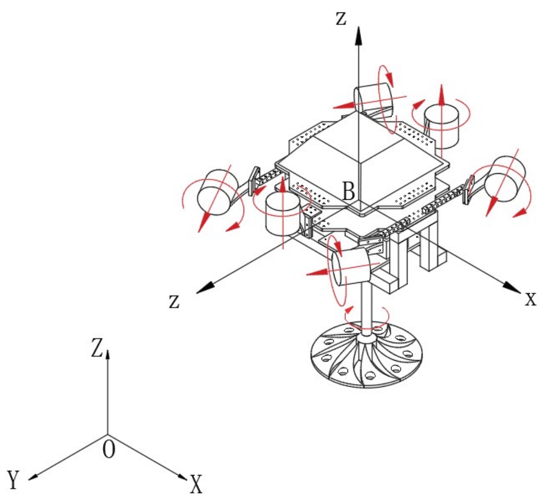

Figure 2. Mechanical model analysis structure

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Combined with the knowledge of fluid mechanics, it can be known that the propeller propulsion force T, the fluid resistance f, the resistance torque τ, the torque M of the propeller thruster and the torque N of the stirring disc are respectively expressed as follows

$$\begin{cases} \mathrm{T} = \mathrm{K_T}\Omega^2 \\ \mathrm{f} = \mathrm{K_f}\dot{s} \\ \mathrm{M} = \mathrm{K_M}\Omega^2 \\ \mathrm{N} = \mathrm{K_N}\varphi^2 \\ \tau = \mathrm{K_\tau}\dot{\theta} \end{cases} \tag{1}$$

Through the knowledge of rigid body mechanics and its force analysis, it can be known that in the body coordinate system, the overall propulsion force of the robot is:

$$\begin{cases} \mathrm{F_B} = [F_x \quad F_y \quad F_z]^T = [U_1 \quad U_2 \quad U_3]^T \\ U_1 = \sum_{i=1}^{4} \mathrm{K_T}\Omega_\mathrm{i}^2 \cos 45° \\ U_2 = \sum_{i=1}^{2} \mathrm{K_T}\Omega_\mathrm{i}^2 \cos 45° - \sum_{i=3}^{4} \mathrm{K_T}\Omega_\mathrm{i}^2 \cos 45° \\ U_3 = \sum_{i=5}^{6} \mathrm{K_T}\Omega_\mathrm{i}^2 \end{cases} \tag{2}$$

where is the thrust coefficient of the propeller, is the resistance coefficient, is the torque coefficient of the propeller, is the torque coefficient of the stirring plate, is the resistance torque coefficient of the fluid, Ω is the rotating speed of the propeller, φ is the rotating speed of the stirring plate, is the linear velocity and is the angular velocity.

According to the principle of coordinate transformation, it can be known that the transformation of the ground coordinate system and the body coordinate system is [3]:

$$R = \begin{bmatrix} cos\alpha cos\gamma & sin\beta sin\alpha cos\gamma - cos\beta sin\gamma & cos\beta sin\alpha cos\gamma + sin\beta sin\gamma \\ cos\alpha cos\gamma & sin\beta sin\alpha cos\gamma + cos\beta sin\gamma & cos\beta sin\alpha sin\gamma - sin\beta cos\gamma \\ -sin\alpha & sin\beta cos\alpha & cos\beta cos\alpha \end{bmatrix} \tag{3}$$

Among them: α, β and γ represent the pitch angle in the ground coordinate system (the angle between the Byz plane and the horizontal plane OXY in the body coordinate system), the roll angle (the angle between the Bxz plane and the horizontal plane OXY in the body coordinate system) and the yaw. Angle (the angle between the Bxy plane and the horizontal plane OXY in the body coordinate system).

Using the principle of coordinate transformation, the body coordinate system is transformed into the ground coordinate system:

$$\mathrm{F_O}| = [F_X \quad F_Y \quad F_Z]^T = R \cdot \mathrm{F_B} = \begin{bmatrix} cos\alpha cos\gamma U_1 + (sin\beta sin\alpha cos\gamma - cos\beta sin\gamma)U_2 + (cos\beta sin\alpha cos\gamma + sin\beta sin\gamma)U_3 \\ cos\alpha cos\gamma U_1 + (sin\beta sin\alpha cos\gamma + cos\beta sin\gamma)U_2 + (cos\beta sin\alpha cos\gamma - sin\beta sin\gamma)U_3 \\ -sin\alpha U_1 + (sin\beta cos\alpha)U_2 + (cos\beta cos\alpha)U_3 \end{bmatrix} \tag{4}$$

The resistance of the underwater robot in the ground coordinate system is as follows:

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$$\mathrm{f_O} = [f_X \quad f_Y \quad f_Z]^T = [\mathrm{K_{fx}}\dot{x} \quad \mathrm{K_{fy}}\dot{y} \quad \mathrm{K_{fz}}\dot{z}]^T \tag{5}$$

Taking the fixed-depth suspension state of the robot as the working state, we can know that the equivalent gravity of the robot is:

$$\mathrm{G_O} = [0 \quad 0 \quad mg - F_1]^T \tag{6}$$

In the ground coordinate system, Newton's second law F=ma combined with equations (5) and (6) can be known:

$$m[\ddot{x} \quad \ddot{y} \quad \ddot{z}]^T = \mathrm{F_O} - \mathrm{f_O} - \mathrm{G_O} \tag{7}$$

Due to the relatively small radius and mass of the thruster, the moment of inertia of the thruster can be approximately considered to be zero. The mechanical structure of the underwater robot is completely symmetrical, it can be known that are all zero. According to the force analysis diagram, the equilibrium equations around the three axes can be obtained [4] as follows:

$$\begin{cases} I_x\dot{p} = (I_y - I_z)qr - \tau_x \\ I_y\dot{q} = U_4L + (I_z - I_x)pr - \tau_y \\ I_z\dot{r} = U_5L + (I_x - I_y)pq - \tau_z \end{cases} \tag{8}$$

Among them, represent the moment of inertia of the robot around the three axes, respectively, represent the rotation angle of the robot relative to the body coordinate system, respectively, and respectively represent the fluid environment to the robot. The resistance torque in three directions.

$$\begin{cases} U_4 = (T_5 - T_6)L \\ U_5 = K_M(\Omega_1^2 + \Omega_3^2 - \Omega_2^2 - \Omega_4^2) - K_N\varphi^2 \end{cases} \tag{9}$$

L represents the distance from the propeller to the center of gravity of the fuselage.

3. Simplification of Mathematical Models

For the convenience of control and simulation, the linear model is simplified.

Since the working process of the underwater robot is a small rotation can be approximated as:

$$[p \quad q \quad r]^T = [\dot{\alpha} \quad \dot{\beta} \quad \dot{\gamma}]^T \tag{10}$$

Therefore, the angular acceleration of the robot in the ground coordinate system OXY is expressed as:

$$\begin{cases} \ddot{\alpha} = [(I_y - I_z)\dot{\beta}\dot{\gamma} - K_\tau\dot{\alpha}]/I_x \\ \ddot{\beta} = [U_4 + (I_z - I_x)\dot{\alpha}\dot{\gamma} - K_\tau\dot{\beta}]/I_y \\ \ddot{\gamma} = [U_5 + (I_x - I_y)\dot{\alpha}\dot{\beta} - K_\tau\dot{\gamma}]/I_z \end{cases} \tag{11}$$

Finally, the mathematical model of the system is obtained as:

$$\begin{cases} \ddot{x} = [cos\alpha cos\gamma U_1 + (sin\beta sin\alpha cos\gamma - cos\beta sin\gamma)U_2 + (cos\beta sin\alpha cos\gamma + sin\beta sin\gamma)U_3 - K_{fx}\dot{x}]/m \\ \ddot{y} = [cos\alpha cos\gamma U_1 + (sin\beta sin\alpha cos\gamma + cos\beta sin\gamma)U_2 + (cos\beta sin\alpha cos\gamma - sin\beta sin\gamma)U_3 - K_{fy}\dot{y}]/m \\ \ddot{z} = [-sin\alpha U_1 + (sin\beta cos\alpha)U_2 + (cos\beta cos\alpha)U_3 - K_{fz}\dot{z} - mg + F_1]/m \\ \ddot{\alpha} = [(I_y - I_z)\dot{\beta}\dot{\gamma} - K_\tau\dot{\alpha}]/I_x \\ \ddot{\beta} = [U_4 + (I_z - I_x)\dot{\alpha}\dot{\gamma} - K_\tau\dot{\beta}]/I_y \\ \ddot{\gamma} = [U_5 + (I_x - I_y)\dot{\alpha}\dot{\beta} - K_\tau\dot{\gamma}]/I_z \end{cases} \tag{12}$$

4. Matlab/Simlink Simulation of Underwater Robot

Matlab has powerful simulation function, this paper uses Simlink to simulate the above mathematical model.

The underwater robot is a strongly coupled mathematical model, and it is difficult to control it directly. In order to reduce the difficulty, the mathematical model is decoupled. The control of the robot is decomposed into three independent control of roll angle, pitch angle and yaw angle[5].

There are many disturbance factors in the actual work process. Other disturbance factors are ignored in the modeling process. The fluid resistance is proportional to the velocity is an important disturbance factor. Only considering the fluid resistance factor can make the model closer to reality. The fluid resistance proportional to the velocity is a linear disturbance, so the above-mentioned nonlinear model of the robot can be approximated as a nonlinear model with linear disturbance. According to the relevant knowledge of state space, the state equation [6-7] can be obtained as follows:

$$\begin{cases} \dot{X} = AX + BU \\ Y = CX + DU \end{cases}$$
$$X = (\dot{x}, \dot{y}, \dot{z}, \dot{\alpha}, \dot{\beta}, \dot{\gamma}, x, y, z, \alpha, \beta, \gamma); \tag{13}$$
$$Y = (\beta, \gamma);$$
$$U = (U_1, U_2, U_3, U_4, U_5).$$

According to the above state space equation and space transfer function, the calculated transfer function to the state is as follows:

$$\begin{cases} G_\beta(s) = \dfrac{1}{I_y s(s+K_{\tau y})} \\ G_\gamma(s) = \dfrac{1}{I_z s(s+K_{\tau z})} \end{cases} \tag{14}$$

PID control has a simple structure. By adjusting the relationship between the proportion and the differential integral, the stability of the system can achieve the desired effect. In this paper, combined with the established underwater robot mechanical model, PID control is used to control the fixed-depth suspension state of the model. The block diagram of the control system is shown in Figure 3.

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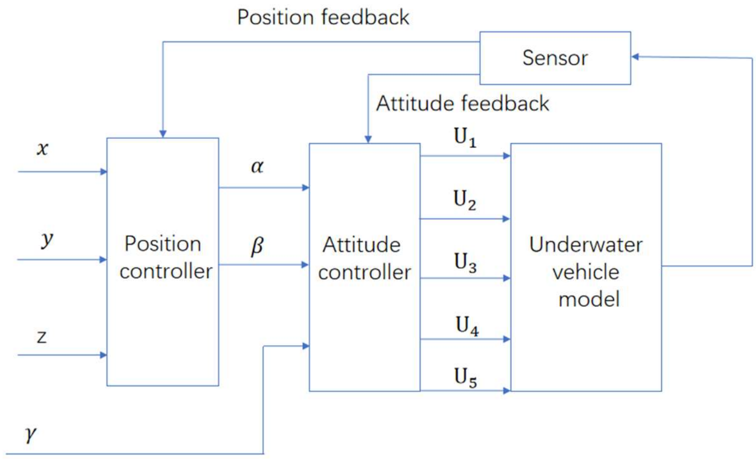

Figure 3. PID control system block diagram

In the simulation process, the relevant parameters of the underwater robot designed by the author's laboratory are shown in Table 1.

Table 1. Relevant parameters of the underwater mixing robot

parameter	unit	Numerical value
m	kg	0.75
g	m/s^2	9.81
L	m	0.258
K_T	$N/rad/s$	3.179×10^{-5}
K_M	$N \cdot m/rad/s$	7.932×10^{-7}
K_N	$N \cdot m/rad/s$	8.635×10^{-3}
I_x	$N \cdot m/rad/s^2$	1.9688×10^{-2}
I_y	$N \cdot m/rad/s^2$	1.9688×10^{-2}
I_z	$N \cdot m/rad/s^2$	3.9388×10^{-2}
K_{fx}	$N/m/s$	0.056
K_{fy}	$N/m/s$	0.056
K_{fz}	$N/m/s$	0.078
K_{tx}	$N \cdot m/rad/s$	0.0059
K_{ty}	$N \cdot m/rad/s$	0.0059
K_{tz}	$N \cdot m/rad/s$	0.0228

The simulation model is built in Matlab/Simlink, and the PID parameters are adjusted by the experimental rounding method. First proportional, then differentiate, and then integrate, repeat debugging, and collect the experimental results. The PID parameters are shown in Table 2.

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Table 2. PID parameters of the underwater mixing robot

attitude	Proportion (P)	Points (I)	Differential (D)
Pitch angle	1.5	0.1	1
yaw angle	0.9	0.03	0.1

The unit step response curves of its pitch angle and roll angle are shown in Figure 4 and Figure 5:

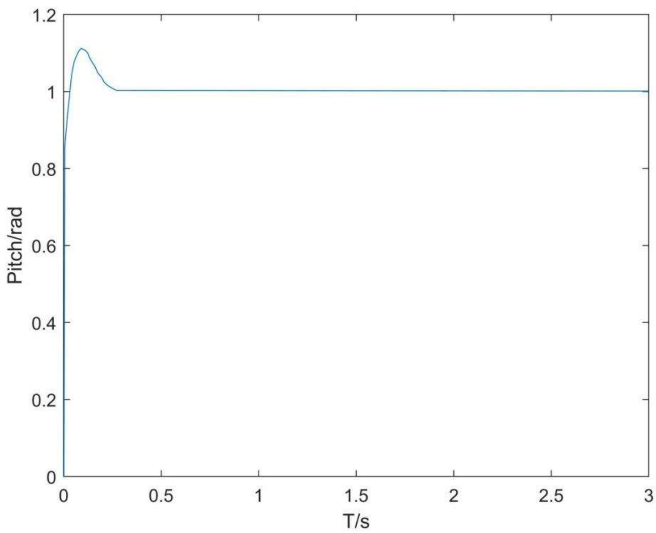

Figure 4. Pitch angle

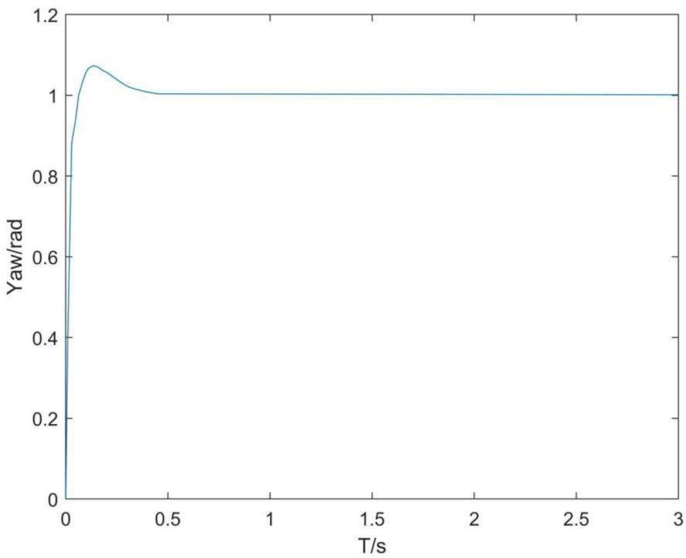

Figure 5. Yaw angle

It can be seen from the above figure that the overshoot is controlled within the range of 0.2, the attitude angle is stabilized faster, and the robot can be restored to the predetermined position within 0.3 seconds with a small deviation. The simulation results show that the PID controller can realize the pitch angle and yaw angle control of the robot.

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5. Conclusion

In this paper, for the underwater stirring robot, the kinematics and dynamics are modeled under certain assumptions, and a nonlinear mathematical model is established. The Matlab/Simlink simulation platform is used to simulate the PID decoupling control of the attitude. The simulation results show that it can meet the control requirements of the underwater mixing robot. Since the model is an idealized model, there are still some unstable factors that have not been considered. At the same time, the control of this paper also has some instability problems. It is necessary to continue research on this basis, and use superior control methods to make it reach a stable state faster in the future.

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