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# The Analysis of the Design of the System of Pitch Adjusting for Remote Operated Vehicle

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**Abstract:** ROV (Remotely Operated Vehicle) is applied widely currently which is an important tool for detecting in the water, salving on the ocean floor and resources surveying in the ocean. However it is common for ROV that is affected by surging and altering barycenter in the practice, and it is easy for pitching usually, and then ROV is low efficiency. Aiming at the problem, we designed a system of pitch adjusting for ROV including the design of mechanism and motion analysis, and use the AFSM control strategy. The simulation result shows that it has the good tracking feature and robustness. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** ROV, Surging, Pitching, AFSM.

## 1. Introduction

With the development of technology, ROV is applied in the field of detecting and resources surveying gradually that have produced benefits, especially in continental shelf and harbor. However ROV is driven by the thruster which uses the manipulator to work flexibly in the water. The altering barycenter of ROV is affected by the telescopic movement of the manipulator and surge which lead to pitching. Thus ROV can't keep balance and control the motion of manipulator accurately. It's necessary that the system of pitch adjusting should be installed on the ROV. In this article, a system of pitch adjusting was designed that can correct the change of pitching and keep itself balance according to data real-time fed back by attitude sensors including angle of pitch and angular velocity.

Otherwise, the classic control method can't meet control effect of ROV, and the theory of sliding mode control provide the system of ROV with a better method of robust control which protects the system dynamic quality from variation of the system model parameters or interference, eliminates the influence of nonlinearity or coupling, but chattering phenomena normally occurs. In this article, fuzzy logic was adopted to modulate the exponential reaching law of sliding mode controller. Not only the high frequency chattering was inhibited effectively, but also the method is better than the sliding mode controller according to the fixed exponential reaching law on the aspects of characteristics and robustness.

## 2. Mechanism Design and Kinematic Modeling

### 2.1. Mechanism Design of the System

In Fig. 1, the system of pitch adjusting for ROV is used to adjust the pitch angle of ROV. The system consists of support, precision ball screw, mass, moving bridge, synchronous belt and so on.

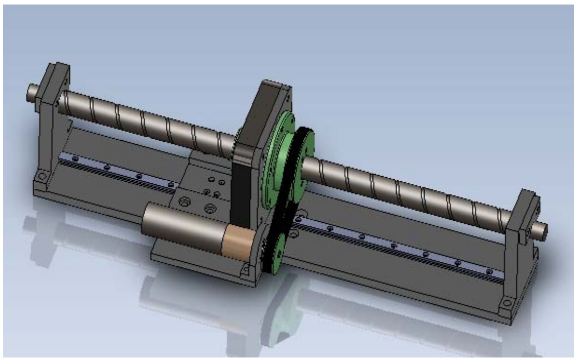

**Fig. 1.** The structure of the system of pitch adjusting.

The system stalled on the abdomen receive feedback information of the pitch angle during working, drive the servo motor which also drive synchronous belt and push the mass fixed on the moving bridge along the precision ball screw. Then Restore torque for pitch is provided to, modify the unstable phenomenon of pitch attitude. The key of t mechanism design of the system is velocity and accuracy. Thus Graphite brush servo motor is used to control the rotation of the motor accurately. In order to improve the accuracy of linear motion, the screw Lead of the precision ball screw chosen is 10 mm. Torque that the motor needs is given by

$$T = \frac{F' \bullet L}{2 \bullet \pi \bullet \mathrm{n}}, \tag{1}$$

$$F' = F + \mu mg, \tag{2}$$

where $F'$ is the axial load of the precision ball screw, $L$ is the screw lead, $n$ is the forward efficiency of the feed screw, $F$ is the axial cutting force of the precision ball screw, $\mu$ is the synthetically friction coefficient of guide part, $m$ is the total mass of the mass and platform.

The installation diagram of the system of pitch adjusting for ROV is shown in Fig.2.

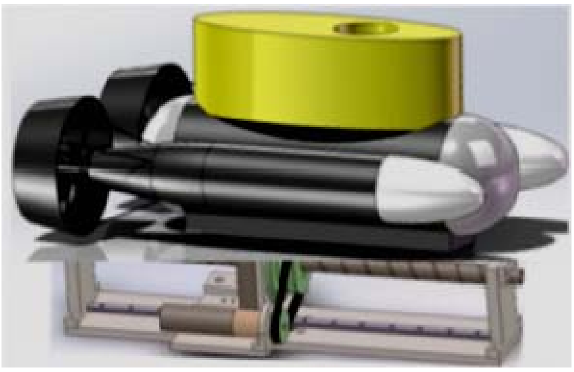

**Fig. 2.** The installation diagram of the system of pitch adjusting for ROV.

### 2.2. Equations of Motion

It's supposed that the mass of the system is $m$ and $J_y$ is the moment of inertia, when ROV is in the balance, centre-of-gravity position where the mass lie in is the origin of moving coordinate system. The linear motion of the mass along x-axis affects the variation of pitch angle $\varphi$ directly. This variation can be simplified as the ROV rotated around y-axis of the moving coordinate system, then the equation of pitch adjusting is as follows:

$$J_y \ddot{\varphi} = -M\dot{\varphi} + mx + f_0, \tag{3}$$

$$\ddot{\varphi} = -A\dot{\varphi} + B + f, \tag{4}$$

where $M$ is the hydrodynamic coefficients, $f_o$ is the total interference, $A=M/J_y$, $f=f_0/J_y$, $B=mx/J_y$.

## 3. AFSMC for the System of Pitch Adjusting

### 3.1. Question

From the theory of Sliding-mode control, Sliding-mode control which is not affected by the parameters of the controlled object and outside interference has good robustness.

In order to decrease buffeting for sliding mode control, AFSM based on linear feedback is used to keep the system stable. On the basis of the nonlinearity of pitching motion and sliding-mode control, the import of system is pitch angle $\varphi$. The longitudinal righting moment which is generated by the rectilinear motion of the mass is output $T=mgx$ for decreasing the pitch angle.

### 3.2. The Fuzzy System Based on Parameter Adjustment

The fuzzy system is defined that consists of 'IF-THEN' form of the rule of fuzzy control: $R^{(j)}$: if $x_1$ is $A_1^j$ and … and $x_n$ is $A_n^j$ then y is $B^j$.

Product inference engine, singleton fuzzifier and center average defuzzifier are adopted, then the output of the fuzzy system:

$$y(x) = \frac{\sum_{j=1}^{m} y^i \left( \prod_{i=1}^{n} \mu_{A_i^j}(x_i) \right)}{\sum_{j=1}^{m} \left( \prod_{i=1}^{n} \mu_{A_i^j}(x_j) \right)} \tag{5}$$

where $\mu_{A_i^j}(x_i)$ is the Gaussian membership functions of $x_i$. It's supposed that vector quantity $\delta$ and fuzzy vector $\alpha(x)$, where $\delta = [\overline{y_1}, .., \overline{y_m}]^T$, $\alpha(x) = [\alpha^1(x) \ldots \alpha^2(x)]^T$, then $y(x) = \delta^T \alpha(x)$.

### 3.3. The Design of AFSMC Based on Linearity Feedback Method

Equation (4) is adapted to $\ddot{\varphi} = f(x,t) + g(x,t)T + d(x,t)$, $g(x,t) = J_y^{-1}$, $f(x,t) = J_y^{-1}(-M\dot{\varphi})$. The bounded disturbance is $d(x,t) = J_y^{-1} f_0$. The state variable is $x = [\varphi \quad \dot{\varphi}]$, and the ideal state variable is $x_d$, then tracking error is $e = x - x_d = [e \quad \dot{e}]^T$.

The switching function of sliding mode control is as follows:

$$s(x,t) = c_1 e + \dot{e}, \tag{6}$$

Controller is design to be:

$$T = \frac{\ddot{x}_d - c_1 \dot{e} - \lambda S_\delta - f(x,t)}{g(x,t)}, \tag{7}$$

where $k > 0, S_\delta$ is saturation function, $f(x,t)$ and $g(x,t)$ are unknown and bounded disturbance is $d(x,t) \neq 0$, so the ideal controller is unachievable. Thus approximation result of fuzzy logic system $f^*(x,t)$ and $g^*(x,t)$ is used to approximate the two unknown function:

$$f^*(x,t) = \theta_1^{\mathrm{T}} \alpha(x,t), \tag{8}$$

$$g^*(x,t) = \theta_2^T \alpha(x,t), \tag{9}$$

Parameter vector $\theta_1^T$, $\theta_2^T$ are assumed to be linearly proportional to the adaptive law:

$$\dot{\theta}_1 = -\eta_1 s \alpha(x,t), \tag{10}$$

$$\dot{\theta}_2 = -\eta_2 s \alpha(x,t), \tag{11}$$

where $\eta_1 > 0$, $\eta_2 > 0$, $\eta_1$, $\eta_2$ are constant, and $\theta_1 \in Q_1$, $\theta_2 \in Q_2$. Optimized-weighted always exist for fuzzy system:

$$\theta_1^* = \arg\min_{\theta \in Q_1} [\sup_{x \in R^n} \left| f^*(x,t) - f(x,t) \right|], \tag{12}$$

$$\theta_2^* = \arg\min_{\theta \in Q_2} [\sup_{x \in R^n} \left| g^*(x,t) - g(x,t) \right|], \tag{13}$$

From the known theorem, if the input fields $U$ is fuzzy compact set of $R^n$, $g(x,t)$ is a continuous function of $U$, then, fuzzy system $y(x)$ meet relationship for arbitrary $\varepsilon > 0$:

$$\sup_{x \in U} \left| y(x) - g(x) \right| < \varepsilon, \tag{14}$$

The least approximate error is:

$$\varepsilon = f(x,t) - f^*(x,t) + \left[ g(x,t) - g^*(x,t) \right] T, \tag{15}$$

$\varsigma_1 = \theta_1^* - \theta_1$, $\varsigma_2 = \theta_2^* - \theta_2$, $\dot{\varsigma}_1 = -\dot{\theta}_1$, $\dot{\varsigma}_2 = -\dot{\theta}_2$, the stability of system is analyzed:

$$\dot{s} = c_1 \dot{e} + \ddot{e} = (\theta_1^{*T} - \theta_1^T)\alpha(x) + (\theta_2^{*T} - \theta_2^T)\alpha(x)T + \varepsilon - \lambda S_\delta \tag{16}$$

$$\dot{s} = \varsigma_1^T \alpha(x) + \varsigma_1^T \alpha(x) T + \varepsilon - \lambda S_\delta, \tag{17}$$

Lyapunov function is defined as follows:

$$V = \frac{1}{2} s^2 - \frac{1}{\eta_1} \varsigma_1^T \varsigma_1 - \frac{1}{\eta_2} \varsigma_2^T \varsigma_2, \tag{18}$$

$$\dot{V} = \frac{1}{\eta_1} \varsigma_1^T [\eta_1 s \alpha(x,t) + \dot{\theta}_1] + \frac{1}{\eta_2} \varsigma_2^T [\eta_2 s \alpha(x,t) T + \theta_2] + \dot{s}\varepsilon - \lambda S_\delta \tag{19}$$

Saturation function is $S_\delta = \frac{2}{|s| + \mu}$, where $\mu = \mu_0 + \mu_1 \| e \|$, $\mu_0 > 0$, $\mu_1 > 0$, then $\dot{V} \le 0$ and $\dot{V} = s\varepsilon - \lambda \frac{s^2}{|s| + \mu_0 + \mu_1 \| e \|} \le 0$ prove that the system is stable.

### 3.4. Simulation Result

The above-mentioned AFSM algorithm is simulated by MATLAB. The total mass of ROV and the system of pitch adjusting is 9 kg. In order to keep the ROV balance, it's supposed that the mass is 2 kg that move along the screw. The distance of the motion is between -90 and +90 mm. And the maximal restore torque is -1.76 Nm or 1.76 Nm.

Five kinds of membership function are selected. The number of fuzzy rules for approaching $f(x,t)$, $g(x,t)$ is 25. As is shown in Fig. 3 and Fig. 4, AFSM based on linear feedback is used to acquire good tracking feature and robustness.

## 4. Conclusions

Aiming at the pitching motion of ROV, in this article, the motion modeling is processed, a kind of mechanism of pitch adjusting for ROV is designed. AFSM based on linearity feedback algorithm is provided for decreasing the chattering of the system, and MATLAB is applied in simulation. According to the analysis result, the system has good tracking feature and robustness.

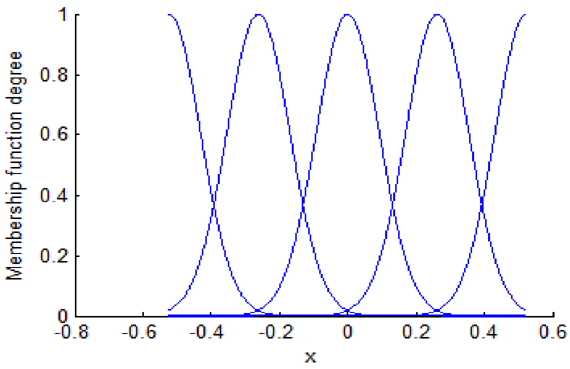


**Fig. 3.** The membership function of the fuzzy input $x_i$.

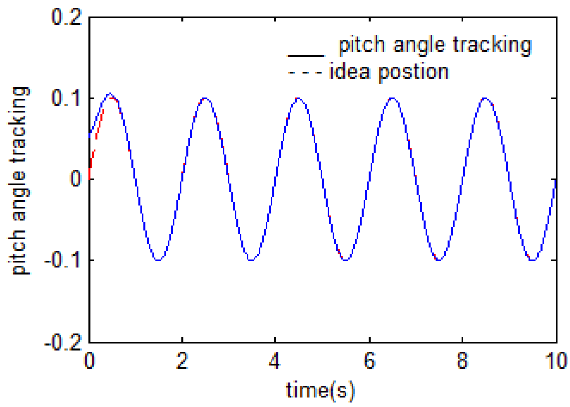


**Fig. 4.** The trajectory tracking for pitch adjustment.

When ROV is affected by the external interruption, not only it occurs pitching motion, but also it generates rolling motion. The Instability of ROV influenced by surge result from superposition of rolling motion and pitching motion. The most research of this article is pitching motion. In the future, the pitching motion combined with rolling motion should be taken into account for keeping working of ROV stable that is realistic significance.

## References


[1]. Wang Biao, Wu Chao and Ge Tong, Development of a remotely operated vehicle test-bed, *Sensors and Transducers*, Vol. 153, Issue 6, 2013, pp. 45-52.

[2]. Hwangbo Sea-Hee, Jeon Jun-Ho and Park Sung-Joon, Wireless underwater monitoring systems based on energy harvestings, *Sensors and Transducers*, Vol. 18, Special Issue 1, January 2013, pp. 113-119.

[3]. Lee Chien-Yi, Tung Pi-Cheng and Chu Wen-Hou, Adaptive fuzzy sliding mode control for an automatic arc welding system, *International Journal of Advanced Manufacturing Technology*, Vol. 29, Issue 5, 2006, pp. 481-489.

[4]. Wai Rong-Jong, Lin Chih-Min and Hsu Chun-Fei, Adaptive fuzzy sliding-mode control for electrical servo drive, *Fuzzy Sets and Systems*, Vol. 143, Issue 2, 2004, pp. 295-310.

[5]. Yu Jian-Cheng, Hang Ai-Qun, Direct adaptive control of underwater vehicles based on fuzzy neural networks, *Acta Aumatica Sinica*, Vol. 33, Issue 8, 2007, pp. 840-846.

[6]. N. Katte, N. R. Konduru, B. Pobbathi, P. Sidaraddi, Fuzzy logic applied to an oven temperature control system, *Sensors and Transducers*, Vol. 133, Issue 10, 2001, pp. 65-73.

[7]. Vishnu G. Nair, V. I. George, K. R. Prahlad, Lateral control of aircraft, considering the cross-coupling effect of yaw and roll on each-other using fuzzy logic, *Sensors and Transducers*, Vol. 142, Issue 7, July 2012, pp. 105-117.

[8]. Mohammad-Reza Moghanni-Bavil-Olyaei, Ghanbari Ahmad, Jafar Keighobadi, Intelligent robust nonlinear controller for MEMS angular rate sensor, *Sensors and Transducers*, Vol. 141, Issue 6, June 2012, pp. 92-105.