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Research Article

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Design of fuzzy rules switching-based fuzzy PID controller of underwater robots

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ABSTRACT

In order to precisely control move of underwater robots, the fuzzy PID dual-mode controller based on fuzzy rules switching is invented, combining the conventional fuzzy controller and the more precise PID controller. Fuzzy rules are switched on the basis of different moves of underwater robots. The new controller has been conducted simulation and field experiments on underwater synthetic explored robots. The experiments show that, with pragmatic design and good dynamic performance like traditional controllers, the new controller improves precision while reduces overshoot. It also has good robustness when dealing with uncertainty of the model and external disturbances. On the whole, it has higher pragmatic value.

Key words: Underwater robots, Move control, Fuzzy PID, Fuzzy rules switching

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INTRODUCTION

The main task of underwater robots is to find, identify and gather as much information of the target as possible. This requires precise move control of the robots. The power system of the underwater robots is nonlinear and time-varying due to complex marine environment and coupling effect of the robot, which means it is hard to precisely estimate and measure its hydrodynamic coefficient. Sometimes the robot is even required to support variable load to complete the given task. All these implicate that the conventional control solution based on the model cannot achieve the required control effects when applied to control underwater robots.

Based on human's knowledge of and experience on the system, the conventional fuzzy controller has a simple and pragmatic design and does not rely on precise mathematic model. It is apt to control effectively the uncertain and strongly nonlinear system and has been widely applied to control move of underwater robots. However, similar to PD controller, the fuzzy controller has good dynamic performance but its static performance is not good enough to eliminate steady state error. People have put forward many new control solutions, such as fuzzy self-adaptive control and fuzzy neural network control, but they failed to work well with underwater robots.

According to experience, the fuzzy controller can have good effects when system deviation value is large. When system deviation value is small, PID controller can accelerate convergence of the system response and reduce overshoot and steady state error. Therefore, this paper introduces fuzzy rules switching-based fuzzy PID dual-mode controller of underwater robots. Feasibility and superiority of the new controller on controlling move of underwater robots have been confirmed through simulation and field experiments on underwater synthetic explored robots.

2 DESIGN OF THE FUZZY PID DUAL-MODE CONTROLLER OF UNDERWATER ROBOTS

2.1 The Conventional Fuzzy Controller of Underwater Robots

The fuzzy control rule is composed by n if…then, among which the case of rule i is calculated as in Formula (1):

$$\text{IF } E \text{ is } \tilde{E}_i \text{ and } EC \text{ is } \tilde{E}\tilde{C}_j \text{ then } U \text{ is } \tilde{U}_k \quad (1)$$

In the formula, $\tilde{E}_i$, $\tilde{E}\tilde{C}_j$, and $\tilde{U}_k$ are linguistic values of error, error rate of change and control value. $\tilde{E}_i$ and $\tilde{E}\tilde{C}_j$ get value from the 13 grades, NB, NFB, NFM, NM, NFS, NS,ZE, PS, PFS,PM, PFM, PFB and PB. The membership function of error and error rate of change is set a triangular function as shown in Graph 1. Value of control output is set the fuzzy single point.

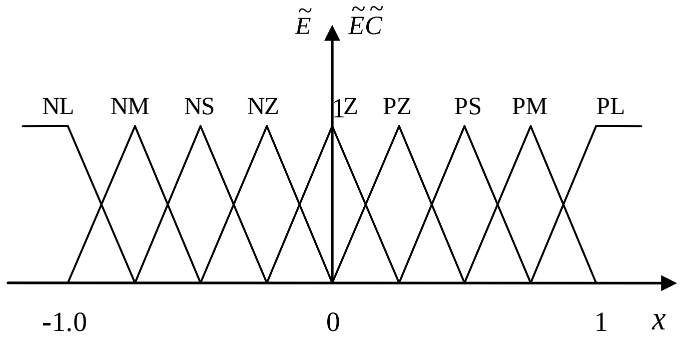

Figure 1 The Membership Function of Error and Error rate of change

2.2 The Fuzzy PID Dual-mode Controller of Underwater Robots

The fuzzy PID dual-mode controller of underwater robots is composed by the conventional fuzzy controller and fuzzy rules switching-based PID controller. The overall structure is shown in Graph 2. Value of input of the controller is position deviation e and deviation of the rate of change ec of the robot, while value of output is value of thrust and moment of force that relevant degree of freedom needs. Value of output is decided by position deviation and deviation of the rate of change. When the deviation value is large, value of output is decided mainly on the value of output of fuzzy control. When the system deviation value is small, value of output of the controller is decided mainly on value of output of PID controller.

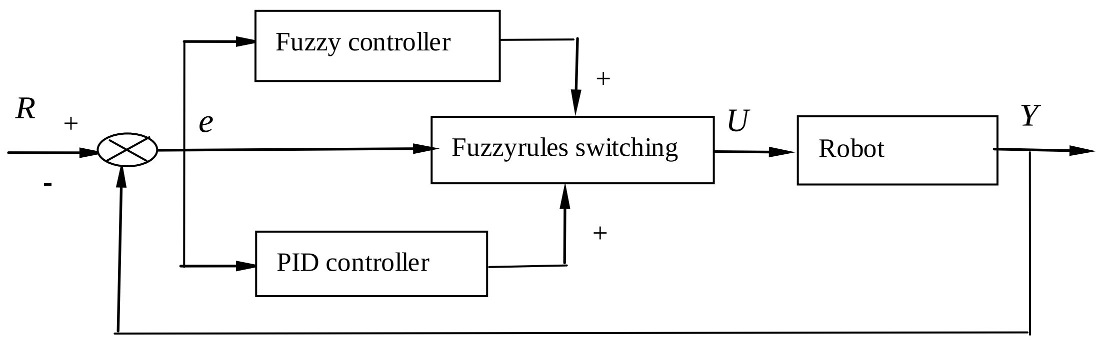

Figure 2 Overall Structure of the Fuzzy PID Dual-mode Controller

The main aim of adopting the switching method based on fuzzy rules is to realize the smooth transition from one control mode to another one. In order to maintain the rapidity of fuzzy control and the high accuracy of PID control, fuzzy control is used with the range of large deviation in transient state to carry out rapid response adjustment, and PID control is adopted in the range of small deviation in steady state to adjust the details. The weighted average produced by both the fuzzy controller and the PID controller is used only in transient process to ensure the steady transition.

Due to the responding retardation of underwater robot system and due to some problems of the transducer itself, the deviation rate of change caused by deviation difference is liable to vary. Since the double controller of fuzzy and PID realize switching controls according to different stages of system response, or, different deviation values of the system, here a switching fuzzy rules formulae is set as follows:

$$\text{IF } E \text{ is } X_1\text{, THEN } U \text{ is } U_{PID} \text{ ELSE } U \text{ is } U_{FUZZY} \qquad (2)$$

In this formulae, U_{PID} and U_{FUZZY} stand for the output of the PID controller and fuzzy controller respectively, X is the subordinate function of switching rules. Through changing its forms, different controlling intensity components could be obtained.

When the time deviation and the rate of deviation change are $e_{(k)}$ and $ec_{(k)}$ respectively, corresponding membership values m_1、m_2 can be figured out by using the subordinate function. When the output intensity coefficients of the PID controller and the fuzzy controller are set ω_{PID} and ω_{FUZZY}, then, the output intensity coefficient of the fuzzy controller is ω_{FUZZY} = 1- min (m_1, m_2).
At this time, the output is a mixture of both controllers and can be calculated with the help of the method of weighted average.

$$U = \frac{\omega_{PID} U_{PID} + \omega_{FUZZY} U_{FUZZY}}{\omega_{PID} + \omega_{FUZZY}} = \omega_{PID} U_{PID} + \omega_{FUZZY} U_{FUZZY} \quad (3)$$

3 EXPERIMENTAL VERIFICATION

Some underwater robot is designed to search quality problems, such as cracks, damages and possible dangers of various dams in rivers, lakes and seas. Because of the relatively low requirements of its speed and of the needs of carrying different equipment for different exploring tasks, it is designed into an open-shelf underwater robot. Due to its special outer structure which has no streamlined geometric shape, it is more difficult to control it more accurately. And this problem has not resolved yet. When the robot executes missions, it is moving at a relatively slow speed, and thus the coupling between various degrees of free movements is not bad. In order to facilitate the design of the motion control system of underwater robots, the coupling function between various degrees of free movements is neglected. And the robot's motion states are considered as independent from each other. Therefore, the motion control system of underwater robot is divided into multiple modules, such as, the heading control module, vertical control module, the longitudinal control module and lateral control module. And the controller's structure and calculating method for each module are the same.

3.1 Simulation experiment

Many simulation experiments have done in the simulating system, and here only the heading control is taken for an example. When the heading directional value is 90, the initial state of the system is 0, and the current velocity is o, the experiment got the following result as Figure 3 shows, and a comparison with the fuzzy controller is also made.

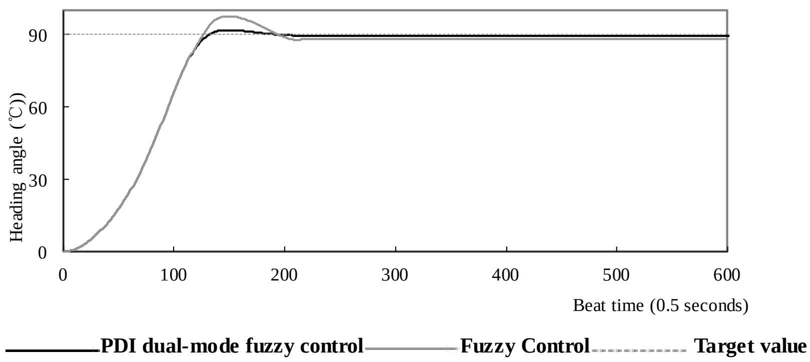

Figure 3 simulation experiment result

The simulation experiment result shows, the overstrike is reduced greatly and deviation in steady state dropped from its original 2% to 0.46%.

3.2 Field experiment

A field experiment is carried out in a sea area which includes automatic orientation and automatic depth setting. In this experiment, a double set of PID controller and fuzzy controller are used to realize the precise controls of the robot's movements. On the water, the robot is automatically orientated from 50 degree to minus 43 degree, and then it goes underwater to the automatically set depth of 6 meters, the results are as Figure 4 and Figure 5 show:

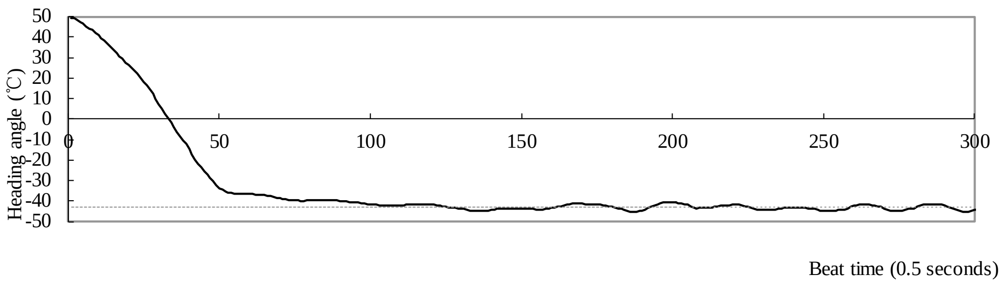

Figure 4 Directional experiment result

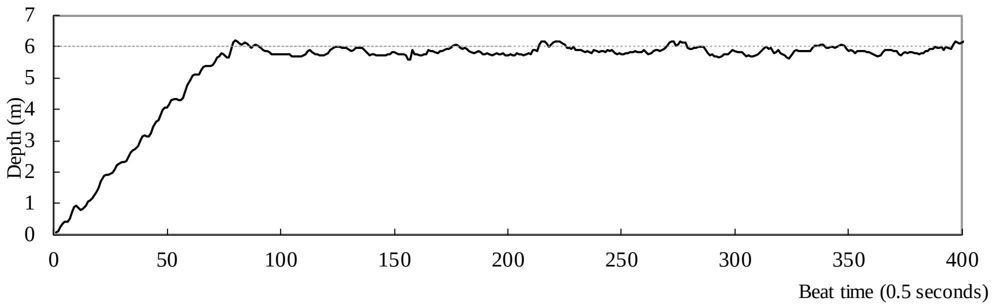

Figure 5 Depth-set experiment results

The field experiments' results show that the fuzzy PID dual-mode controller of underwater robotsbased on the fuzzy switch rules is workable because it can realize the precise control of the robot's movements and has a strong robustness against external disturbances. One point needs to be pointed out here is that the vibrating phenomenon in the depth-set experiment is mainly caused by the unsteadiness of the transducer.

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CONCLUSION

This paper mainly designs the fuzzy PID dual-mode controller of underwater robots by combining a regular fuzzy controller and PID controller. It also carries out experiments on an underwater exploring robot. The results show that this controller keeps the advantages of fuzzy controller, such as its simplicity, practicality and its good dynamic property, at the same time, it greatly improves the controlling accuracy, reduces the overstrike, strengthens its robustness against the instabilities of this model and external disturbances. Thus, it has very great practical values.

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