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Research of Submarine Hovering based on Fuzzy Control

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Abstract

The underwater hovering of submarine is to keep and alter depth at zero speed, which is a complex nonlinear process. Traditional control methods affect the effect because of lacking of adaptive capability, while fuzzy control can solve the problem well. Here the structure of fuzzy controller was set up based on the principle of fuzzy control. Then the rule for hovering control was carried out according to the classic step response. At last, the anti-jamming differentiator was set up by Simulink. The result of two basic working condition simulation showed that fuzzy controller was able to fix the submarine depth well, and had the advantage of fast and robust.

Keywords: *submarine, hovering, fuzzy control*

1. Introduction

So far, almost all of the submarines have installed automatic steering system. Unlike surface ships and submarines on the automatic steering system should not only control the course but also control the depth and trim[1-3]. Because most of submarine autopilot PID rudder, and the conventional PID autopilot is designed based on the mathematical model of submarine campaign, the more accurate model, the response is better. And submarine motion system is a complex system of big inertia, nonlinearity, environmental disturbance, difficult to use a precise mathematical model to describe. Even now the world's widely used for submarine simulation standard of six degrees of freedom motion equation, and the real movement of the submarine also exist certain differences, and hydrodynamic coefficients of the equation is very difficult to achieve. Fuzzy control is a particularly applicable to that are hard to use mathematical model to describe accurately the system mainly depends on artificial experience. At present, people have to apply fuzzy control to the surface ship maneuvering control, fuzzy control, but only limited to heading for submarine hovering control of the fuzzy controller are rarely involved. Will be according to the characteristics of the submarine hovering control, this paper puts forward fuzzy control method of submarine hovering movement, provides the automatic control of underwater hovering preliminary technical foundation.

2. Submarine Hovering Fuzzy Controller Design

2.1. The Submarine Underwater Hovering System Model of the Movement

However [4-6] is one of the important way of anchor of the submarine underwater, refers to the state of submarine underwater navigation after parking, the balanced accurately, using special note, drainage water ballast tank, submarine depth under zero speed control mode of boat handling. Strictly under the hovering submarine to the bottom of the sea is relatively static state of a movement, and usually say hover

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is refers to the general meaning, is refers to the submarine propeller stalling, keep and seawater relatively static, the main task is to keep hovering depth and dynamic balance. Submarines to hover submarine can effectively reduce the noise, and improve the concealment, increasing target detection range; to reduce power consumption and prolong the charging time interval, increase which time; hovering control when the submarine has good mobility.

Submarine underwater hovering movement model of the system is shown in figure 1, the model has three initial disturbance input, uneven respectively vessel compression, the initial measure and seawater density change, these interference on the hovering motion model, the motion model of the motion state changes, through the depth of the deviation and depth deviation rate input to hover fuzzy controller, get the corresponding control quantity, so as to start hovering note drainage water tank for operation, until the actual depth is consistent with the specified depth.

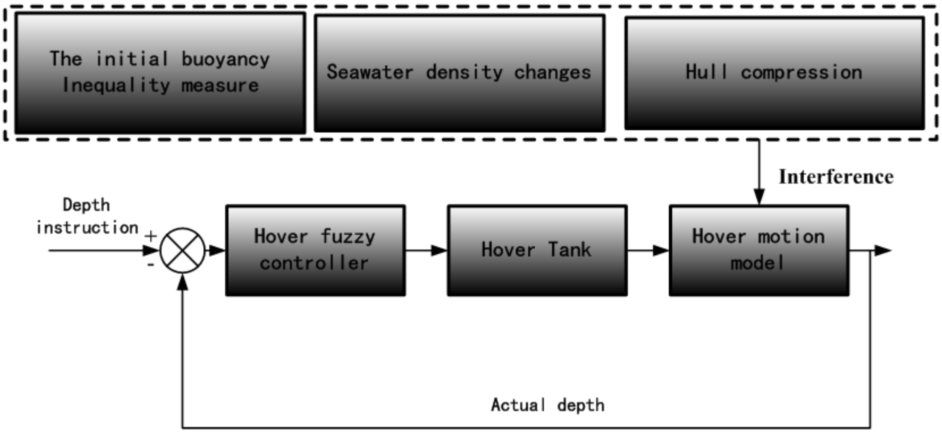

Figure 1. System Model of Submarine Hovering

2.2. Hover Over the Structure if Fuzzy Controller

The composition of fuzzy control [7-9] system with general computer control system, the only difference is the control by fuzzy controller. In general, the fuzzy controller is mainly composed of blur, knowledge base, fuzzy inference, the fuzzification of the four main function modules. Fuzzy controller structure is shown in Figure 2.

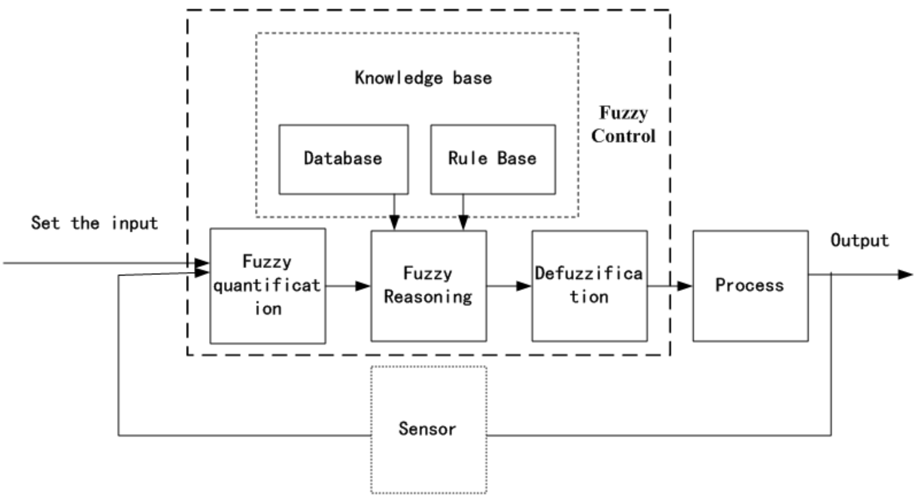

Figure 2. Fuzzy Controller Structure

Because the input and output of fuzzy controller are fuzzy, but based on the fuzzy language of its internal control, by the degree of condition is met with the size of the fuzzy reasoning with fuzzy output. Fuzzy reasoning of fuzzy quantity must be converted into fuzzy values, namely as the blur. As the output of fuzzy reasoning is a fuzzy value, must also convert the fuzzy output to the fuzzy set, namely the blur. The fuzzy controller of fuzzy, fuzzy reasoning and fuzzy set up on the basis of the knowledge base. The knowledge is based on the database and rule base of two parts. Database stores all the input and output variables of the membership degree of fuzzy subset vector values or membership functions. Rule base is based on expert knowledge or manual operation skilled personnel long-term accumulation of experience, it takes the language form of "if-then", said a fuzzy control rules. Fuzzy control rules and membership functions decides transfer characteristics of the fuzzy controller.

1. Blur

For an actual controlled process, the input fuzzy controller is always a maximum variation range, this range is called an external input on the field, and in the definition of fuzzy linguistic variables used reasoning (fuzzy sets), and also make provisions an internal input domain. Task fuzzy unit is to achieve the conversion of this domain, but also for the language variable assignment, namely blurred.

Submarine hovering motion blur controller, blurring the specific process is as follows:

(1) First submarine depth e and depth variation rate deviation change as input, will inject displacement as output. These inputs are then output as the input and output linguistic variables of fuzzy controller.

(2) When the submarine hovering motion, setting the depth deviation e basic domain is: [-5, 5], Unit: m; depth deviation rate of change of the basic domain: [-1,1], unit: m / s; Note displacement u basic domain [-2000, 2000], unit: l.

(3) Precise amount of input output has been become blurred, with the corresponding fuzzy sets to represent.

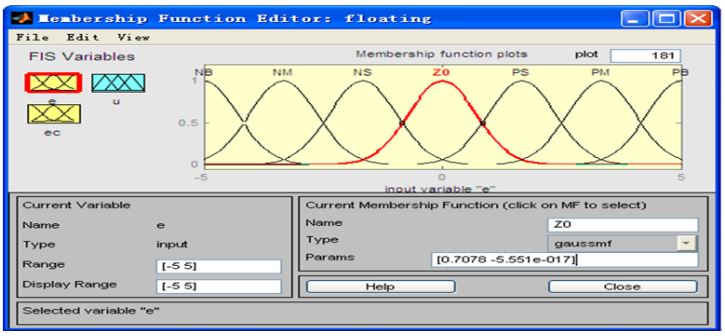

Figure 3. Membership Function of Input E

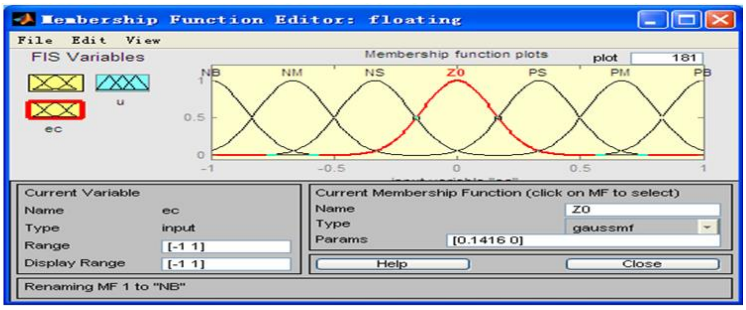

Figure 4. Membership Function of Input Ec

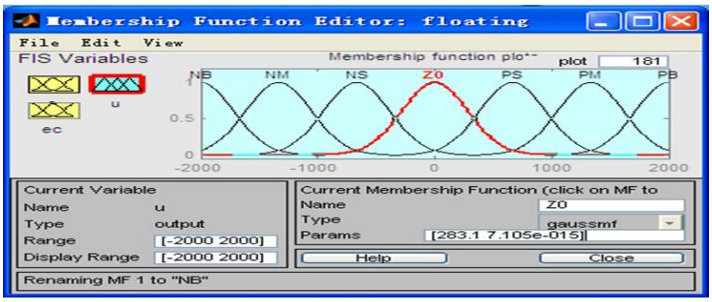

Figure 5. Membership Function of Output U

Membership function curve input and output as shown in Figure 3- 5. Submarine hovering motion blur control, language values of linguistic variables are taken as "negative big (NB)", "negative in (NM)", "negative small (NS)" and "zero (ZO)", "are small (PS) "" middle (PM) "," Chia (PB) "a total seven kinds. According to the principle of membership function selection Gaussian function, wide membership functions to reflect the characteristics of fuzzy sets has low resolution, low error control sensitivity, control features relatively flat, so we selected a wide membership functions. There is some overlap between adjacent membership functions, interval no cross bounds.

2. The Knowledge base

Knowledge Base contains specific control objectives in the field of knowledge and application requirements, which usually consists of a database and fuzzy control rule base in two parts. Database includes the membership function of each linguistic variables, scaling factor and the number of hierarchical fuzzy space and so on. Rules library includes a series of control rules represented by linguistic variables. They reflect the experience and knowledge control experts. Kept the entire rule base of fuzzy control rules, in the fuzzy logic control rules provide for the fuzzy inference engine. Fuzzy subsets will finer division of linguistic variables, the more the number of rules. If we can guarantee the accuracy of expert knowledge, so the more the number of rules, the accuracy of the rule base is higher.

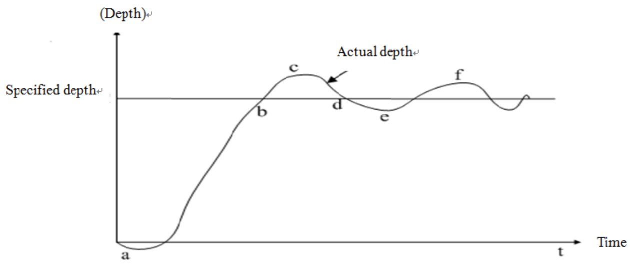

Figure 6. The Classic Step Response of Hovering Control

Table 1. Control Rule

E \ U \ EC	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	PS
NM	PB	PM	PM	PS	PS	PS	PS
NS	PM	PM	PS	PS	PS	PS	PS
ZO	PS	PS	PS	ZO	NS	NS	NS
PS	NS	NS	NS	NS	NS	NM	NM
PM	NS	NS	NS	NM	NM	NM	NM
PB	NS	NS	NM	NM	NM	NB	NB

3. Control Rules

Figure 6 illustrates a typical step response of the submarine hover process. In the beginning, that is, in a near point a the deviation e has a great depth, and the depth of the deviation rate of change EC is very small, then depth is mainly to eliminate bias, and therefore need to increase water injection to make the submarine quickly darken to reduce bias. Therefore, a point a close to the rule is: if the depth e and the deviation is ZO or are NS, then the injection displacement is NM.

Near the point b, the depth deviation e is very small, and relatively large deviation rate of change EC, this time to prevent the system overshoot or oscillation, and therefore requires a positive small control signal in order to avoid excessive overshoot the actual depth. Therefore, the point b is close to the rule: if the depth e is ZO and the deviation EC is NB, then the displacement of the injection is PS.

Respectively, to points a and b in the vicinity of the point c and d near the control behavior. With such ideas can be summed up fuzzy rules hover controller: When e is large, note should be taken to increase the displacement, in order to quickly eliminate the depth deviation, then the depth deviation e dominant in the controller. Such as the size of them, in order to prevent large overshoot, should be appropriately reduced in order to avoid the more displacement injection produces a large overshoot. When the e is small and EC is large, when the deviation is small and the main task is to prevent large overshoot or oscillation, then EC dominated, then the reverse should note drainage.

4. Fuzzy Reasoning

Fuzzy reasoning is the core of the fuzzy controller, which has the ability to simulate human reasoning based on fuzzy concepts. The reasoning is the implication fuzzy logic inference rules based on relationships and carried out. According to the calculation method of controlling the amount can be divided into two categories:

(1) The Online calculation method

This approach is measured by the amount of online process to calculate the amount of control response.

(2) Look-up table calculation

This method is calculated offline in advance in all cases of a set amount of process control amount according to the fuzzy control rules, the formation of fuzzy control table. Throughout the control process, the control amount is converted to a direct calculation of the measured process variable to find the control table.

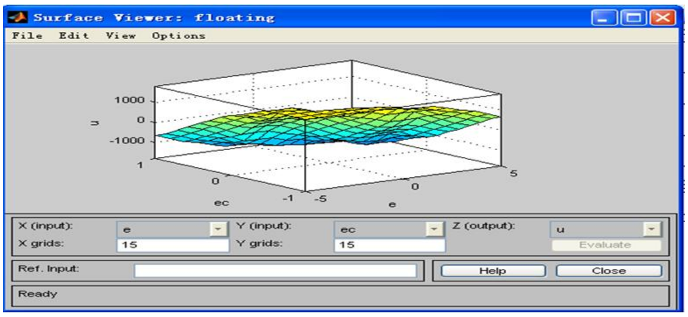

Figure7. Fuzzy Reasoning Curve of E,Ec and U

In hover controller, based on the input variables and depth of the depth variation rate deviation change, through the control rule table 1, an output variable discharge water injection is derived.

Using MATLAB fuzzy toolbox fuzzy inference can see each linguistic variables characteristic curve shown in Figure 7. As can be seen, e,EC and u the fuzzy inference output characteristic curve smooth transition, there is no mutation. From this, the controller of fuzzy control rules hover reasonable choice.

5. Defuzzification

Fuzzy reasoning includes the amount of blur, so you need to convert the amount of blur amount to a clear and clearly expressed by the scaling amount within the range of domain into practical the control amount. The fuzzy control amount is calculated by the clarity of the amount converted into clearly expressed in the domain-wide, there are usually several ways like this: maximum membership degree method, the median area of the central ruling Law and the Law.

These three methods have their advantages and disadvantages, the maximum membership degree method is simple, easy to use, real-time, but rarely use information; median judgment method using too much information, a lot of calculation; an area of central France only there are formulas to follow, using information more widely practical application, so this paper uses the fuzzy area of the center of decision-making method.

3. ADRC Tracking Differentiator Design

Hover fuzzy controller fuzzy controllers use two-dimensional, the controller has two inputs, the depth e and the depth of the deviation rate of change of the deviation EC. Depth deviation rate of change is a differential signal, while the rate of change in the depth of the submarine deviation is not obtained directly through the sensor, but by the depth of the digital differential bias was, so to get the micro-components also need to add a differentiator. In the classical theory of adjustment, it takes direct way to get a first-order differential micro component depth, and one of our usual approaches. But there will be a classic differentiator differential amplification random signal noise pollution contamination is so out of the differential signal glitches and jitter. We can get through mathematical derivation, the output signal $y(t)$ is superimposed on the differential signal amplified input signal $v(t)$ times the noise signal, and the time constant T is small, so the noise amplification is very serious, and sometimes completely submerged differential signal, so the classical differential part will produce severe noise amplification. Therefore, in the differential treatment process to avoid a state variable differential will generate another state of variables.

As can be seen from Figure 8, the classic differentiator out of the differential signal jitter is very obvious even distortion, steepest nonlinear tracking differentiator [10-11] out of the differential signal is very smooth, due to the above reasons, this article will use the steepest nonlinear tracking differentiator differential signal obtained depth, thereby enhancing the effect of the fuzzy controller to control a large extent.

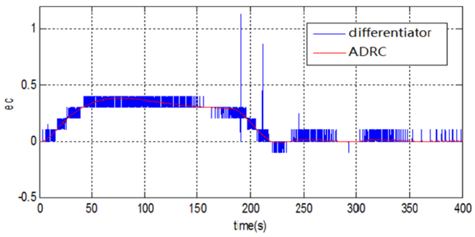

Figure 8. Signal Comparison of Two Differentiators

The most comprehensive speed control function $fhan(x_1, x_2, r, h)$, as shown in its expression as equation (1):

$$\begin{cases} d = rh^2, a_0 = hx_2 \\ y = x_1 + a_0 \\ a_1 = \sqrt{d(d+8|y|)} \\ a_2 = a_0 + \dfrac{sign(y)(a_1 - d)}{2} \\ s_y = \dfrac{sign(y+d) - sign(y-d)}{2} \\ a = (a_0 + y - a_2)s_y + a_2 \\ s_a = \dfrac{sign(a+d) - sign(a-d)}{2} \\ fthan = -r(\dfrac{a}{d} - sign(a))s_a - rsign(a) \end{cases} \quad (1)$$

Second-order discrete system is set up:

$$\begin{cases} v_1(k+1) = v_1(k) + hv_2(k) \\ v_2(k+1) = v_2(k) + hu \end{cases} \quad (2)$$

Steepest integrated function $fhan(x_1, x_2, r, h)$ creates discrete steepest feedback system:

$$\begin{cases} fh = fhan(v_1(k) - v(k), v_2(k), r, h) \\ v_1(k+1) = v_1(k) + hv_2(k) \\ v_2(k+1) = v_2(k) + hfh \end{cases} \quad (3)$$

System (3) is a good value differentiator, called "fast discrete tracking differentiator." The function $fhan(x_1, x_2, r, h)$ of the step h into step h_0 with the system independent parameters for signal processing it will have a lot of special features. Then the parameter r called "fast factor" and the parameter h_0 called "filter factor", then tracking differentiator becomes:

$$\begin{cases} fh = fhan(v_1 - v, v_2, r, h_0) \\ v_1 = v_1 + hv_2 \\ v_2 = v_2 + hfh \end{cases} \tag{4}$$

Its input signal is $v(t)$, $v_1(t)$ tracking the input signal, $v_2(t)$ is a differential signal of $v_1(t)$, as a differential input signal $v(t)$ approximation.

ADRC tracking differentiator is a signal processing chain, to achieve the extraction of the input signal transition arrangements and differential signals. ADRC tracking differentiator given the dynamic performance of a closed-loop system can be achieved, this object is given to the accused, it is no longer been a steady expectations, but a real-time tracking of the curve. Meanwhile, when the external disturbance, the role of ADRC tracking differentiator filter can also been achieved in the presence of an input signal.

4. System Simulation

Simulink Simulation module builds submarines deep set hover fuzzy system model.

Where ADRCTD modules completed by the second-order discrete tracking differentiator s function, Hover module function by submarine hovering s movement mathematical model is complete. System simulation is as shown in Figure 9.

Two typical operating conditions selected simulation proves the feasibility of fuzzy control theory. The simulation results are shown in Figures. 10 to 13.

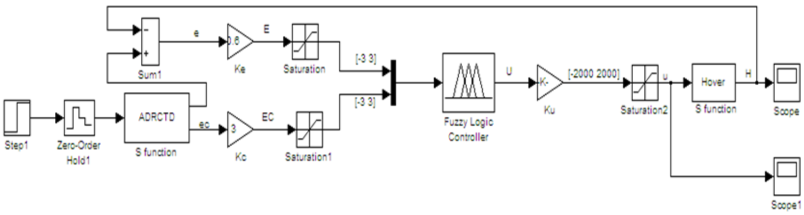

Figure 9. Simulation of Hovering

(1) Interference is positive gradient conditions, initial variation measure for boat weight 300 l, corresponding to the initial unbalanced torque shift quantity is 200 liters, an initial deviation of 2 m.

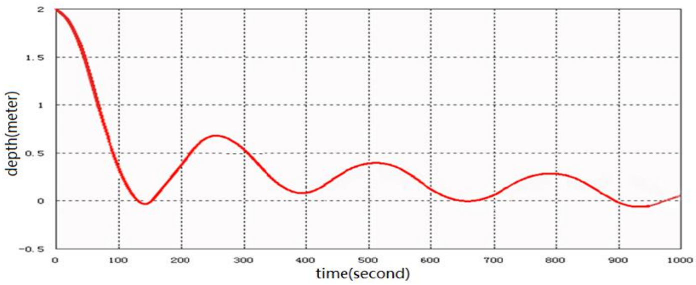

Figure 10. Curve of Depth Variation

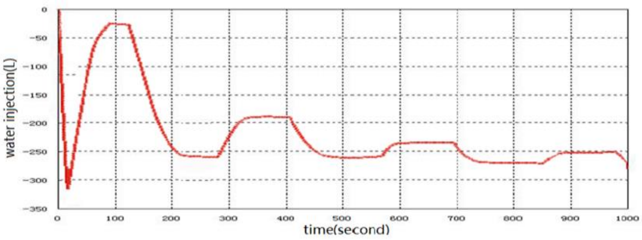

Figure 11. Curve of Drainage and Injection

(2) Interference is negative gradient conditions, a measure for the initial unevenness boat weight 300 l, corresponding to the initial unbalanced torque shift quantity is 200 liters, an initial deviation of 2 m.

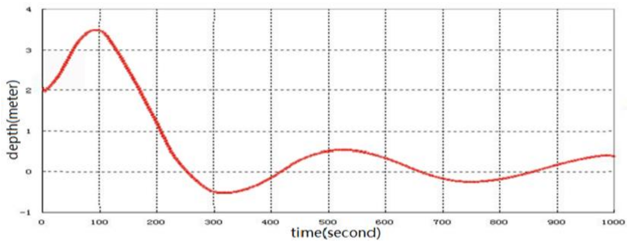

Figure 12. Curve of Depth Variation

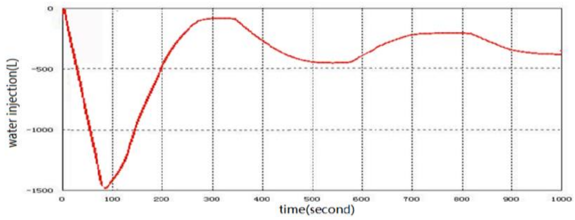

Figure 13. Curve of Drainage and Injection

5. Conclusion

By simulation that, given the deep submarine hovering fuzzy control, no more than four meters of depth, after the stabilization energy fluctuations in the vicinity of the

in fixed specified depth, consistent control requirements.

Seawater density gradient layers are relatively easy to manipulate hover, because the density changes caused by changes in buoyancy can balance the buoyancy of the hull compression caused by the change, the submarine can quickly reach a new equilibrium state, the number of small water injection during hover, note displacement is not. In seawater density gradient layer is negative, due to intensified submarine hull compression movement, so during hover manipulation, must increase the number of water injection, and stability control even during the depths of continuous water injection control, in order to counteract interference negative gradient force impact.

Using submarine depth hover fuzzy control method, hover pump discharge water can be automatically controlled, so that the water discharge curve showed a smooth curve, followed by increased sensitivity control can be changed in real time according to inject displacement hull attitude, but also reduced crew boat parade strength.

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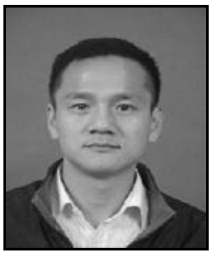

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