Research on improved single-neuron adaptive PID control algorithm in plasma discharge system

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***Abstract*—The large-area closed-loop RF discharge plasma system features multiple variables, significant lag, non-linearity, and strong coupling among its control loops. Based on the Hebb algorithm, fuzzy control rules have been incorporated, proposing an improved single-neuron adaptive control strategy. By constructing models and simulations of the aforementioned algorithms in Simulink, real-time control of the discharge chamber is maintained in the presence of external disturbances, theoretically providing support for plasma discharge chambers.**

Keywords-Adaptive PID control;Fuzzy rules ; improved single neurons; joint control; plasma discharge system;

I. INTRODUCTION

Based on the characteristics of plasma, it has the function of enabling aircraft to achieve stealth. To enhance the stealth function, it is necessary to conduct simulation of plasma discharge on the ground. A large-area closed-circuit radio-frequency plasma discharge chamber is a new type of plasma discharge system in plasma discharge research. This control system can provide experimental theory and technical support for future plasma discharge research [1]. During the generation of plasma, there will be intense chemical reactions, which will cause changes in the pressure of the discharge chamber. Therefore, to improve stability, designing corresponding control algorithms to ensure the stability of the gas pressure inside the chamber is particularly crucial. Due to the characteristics of this system such as multi-variable coupling, large lag, and strong nonlinearity [2]. Currently, the most widely used traditional control is still PID control. Traditional PID has a simple structure and is easy to implement, and still occupies a dominant position in industry. However, for the above system, using only the traditional PID control algorithm is difficult to improve the anti-interference ability of the gas pressure and intake volume [3].

Deng Jianjun et al.[4] An adaptive control algorithm was proposed for the control of electronic proportional control valves. Although it can approach the target value, the response time of the system is relatively long and real-time control of the system has not been achieved.Gao Lei et al.[5]An adaptive PID algorithm was proposed for the random system of anti-aircraft guns, which can effectively achieve the set target values and handle sudden increases in disturbances. However, the simulation only covered sudden additions of disturbances to the system, and did not cover long-term continuous disturbances.

Feng Zhengfu, Li Yongheng et al.[6],A fuzzy logic control algorithm was developed for the marine internal combustion engine system. The effectiveness of the control strategy was verified through simulation experiments, but no tests were conducted to add anti-disturbance capabilities to the internal combustion engine system.

To address the aforementioned issues, this paper incorporates fuzzy logic rules into the previous Hebb control algorithm. The controller parameters and gains are adjusted in real time using the supervised Hebb learning algorithm and fuzzy logic rules[7-8]. The improved adaptive PID control algorithm is used to control the pressure and intake volume, enabling real-time precise control of the pressure and intake volume in the plasma discharge chamber.

II. MATHEMATICAL MODEL ANALYSIS OF DISCHARGE CAVITY

The joint control system of air pressure and air intake volume is mainly composed of air pressure control loop and air inlet control loop. In order to achieve precise control more accurately, the coupling relationship between air pressure and air intake volume is mainly considered. The air pressure and air intake control system is approximated as a dual-input and dual-output system, and its single loop is composed of a first-order inertia delay link, and the transfer function of the discharge cavity is represented as shown in Eq. (1). where G(s) is the transfer function of the system in a single loop, K is the gain coefficient of the system, and T is the time inertia constant, which represents the delay time of the system. The control principle of the system is shown in Figure 2, where P and Q represent the air intake control loop and air pressure control loop of the system, respectively.

$$G = \frac{k}{Ts+1}e^{-\tau s} \qquad (1)$$

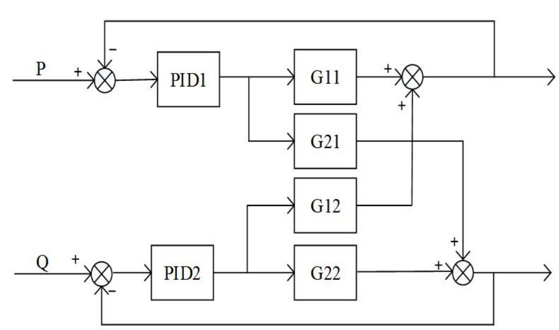

Figure 1. Block diagram of the plasma discharge cavity control system

The traditional PID controller has been widely applied in the control field, featuring simple implementation, strong adaptability and robustness. Its schematic diagram is shown in Figure 2. It mainly achieves feedback control of the controlled object through the linear combination of proportional adjustment of the error, integral accumulation and differential prediction. In the plasma emission chamber system, measurement elements are used to measure the gas pressure and intake volume in the loop, and the feedback value is fed back to the input end to form a closed loop.

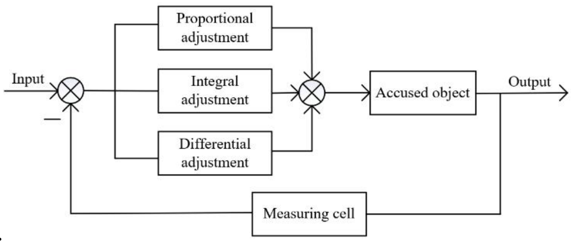

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Figure 2. Model of the traditional PID control system

The traditional PID control rules are as follows:

$$u(t) = k_p[e(t) + \frac{1}{k_i}\int_0^t e(t)dt + k_d\frac{de(t)}{dt} \quad (2)$$

where k_p, k_i, k_d is the output of the system t, are the scale coefficient, the integration coefficient and the differential time constant, respectively, and the incremental expression of the PID controller is:

$$\Delta u(t) = k_p[e(t) - e(t-1)] + k_i e(t) + k_d[e(t) - 2e(t-1) + e(t-2)] \quad (3)$$

From Equations (2) and (3), it can be seen that the output of the traditional PID controller is affected by the three parameters of proportion, integration, and differentiation. Once the parameters are determined, they cannot be changed online. Moreover, with the development of industry and modern technology, more precise requirements have been put forward for the controlled object and effect. Only relying on the traditional PID controller is difficult to meet the higher control requirements. In order to further improve the precise control of pressure and intake and the adaptive ability, by combining a single neuron with the traditional PID control strategy, and utilizing the nonlinear approximation and adaptive ability of the neural network, an improved single neuron adaptive PID control algorithm is proposed.

III. IMPROVED ADAPTIVE PID CONTROL ALGORITHM

In order to improve the real-time control of the plasma discharge cavity system, an adaptive PID control method based on improved single neuron is proposed, and the improved control block diagram is shown in Figure 3. The Hebb algorithm is combined with the fuzzy logic control method, and the fuzzy logic control is added to adjust the gain in the controller in real time while the Hebb algorithm adjusts the weight of the neural network connection, so as to realize the self-tuning of parameters and gain coefficients in the adaptive PID controller. Through this design connection, fuzzy control is used to flexibly cope with complex and nonlinear system behaviors, which is suitable for rapid response and processing of dynamic changes, and the advantages of traditional single-neuron PID control to improve control accuracy, eliminate steady-state errors, suppress oscillations, and ensure stable operation of the system, so as to achieve accurate and real-time control of the plasma discharge cavity system.

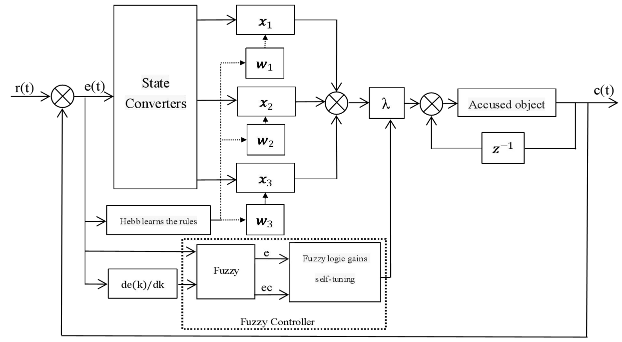

Figure 3. Block diagram of adaptive PID control based on improved single neuron

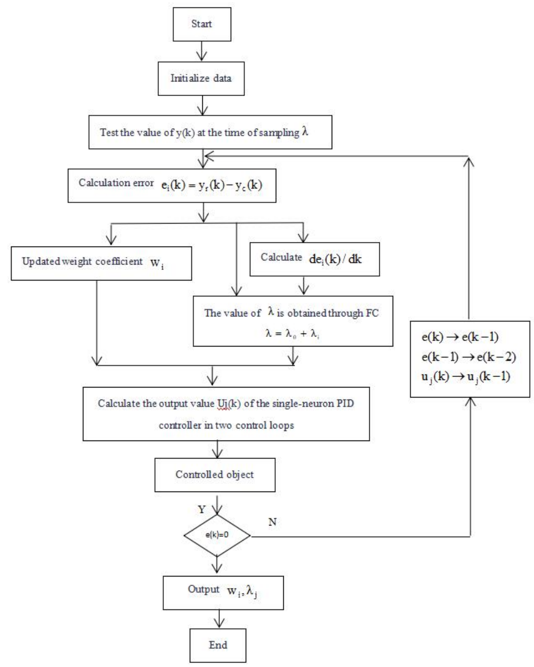

Figure 4. Flow diagram of improved neuronal adaptive algorithm

IV. IMPROVE THE CONSTRUCTION OF NEURON MODULES

In order to verify the effect of the single-neuron adaptive PID control algorithm in the plasma discharge system, the Adaptive PID Controller is obtained by encapsulating the above algorithm in Simulink, and the adaptive PID algorithm is encapsulated, and the encapsulated module is adaptive_pid. The adaptive PID controller is applied to the plasma discharge cavity system model, the simulation model is built in Simulink, and the random perturbation signal is added to verify the ability of the adaptive PID control algorithm to suppress interference, the internal structure of the encapsulated module is shown in Figure 5.

The S-Function module is used to implement custom control algorithms or logic. It is a functional extension in Simulink that allows you to write MATLAB code to implement specific functions.

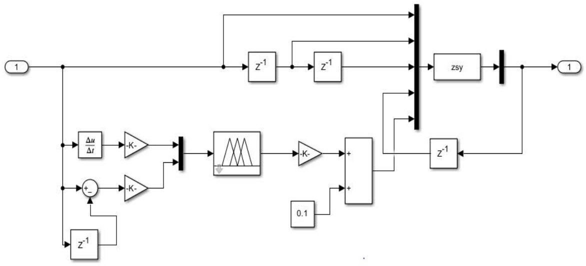

Figure 5. Improved single-neuron adaptive PID controller

The S-Function module is used to implement custom control algorithms or logic. It is a functional extension in Simulink that allows you to write MATLAB code to implement specific functions. The ZSY module represents a custom control strategy for further optimization of the control system. The feedback loop is the core component of the control system, ensuring that the system's outputs can influence the inputs and automatically adjust the control signal when errors occur. The system feeds the output signal back to the adder, calculates the new error, and then generates a control signal based on the error to achieve the target output. A control signal is then generated based on the error to achieve the target output. S-Function provides customization capabilities that enable the system to be scaled to meet specific needs. This hybrid control architecture is particularly suitable for systems that require precise control and involve uncertainties or complex dynamics.

In Matlab, the fuzzy control module is called to write fuzzy control rules, and the program interface is shown in Figures 6 and 7. The fuzzy domains of error e, error rate of change ec and gain k are both [-5,5].

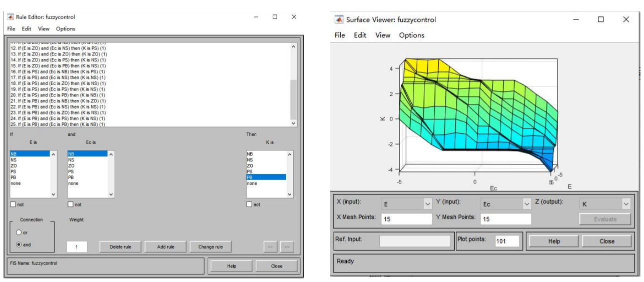

Figure 6. Fuzzy logic control rules

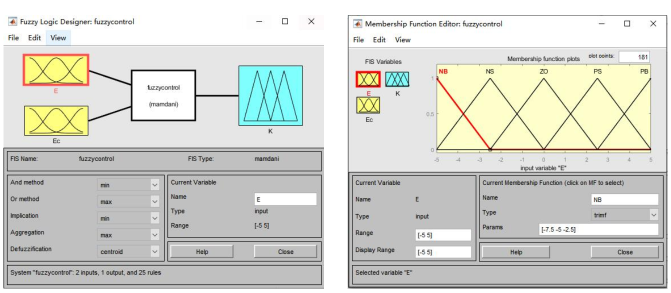

Figure 7. Fuzzy controller structure and membership function

TABLE I. FUZZY OPERATION RULES FOR GAIN

E \ EC	NB	NS	ZO	PS	PB
NB	PB	PB	PS	PS	ZO
NS	PB	PS	PS	ZO	NS
ZO	PS	PS	ZO	NS	NS
PS	PS	ZO	NS	NS	NB
PB	ZO	NS	NS	NS	NB

V. SIMULATION VERIFICATION

In order to verify the effect of the single-neuron adaptive PID control algorithm in the plasma discharge system, the Adaptive PID Controller is obtained by encapsulating the above algorithm in Simulink, and the adaptive PID algorithm is encapsulated, and the encapsulated module is adaptive_pid. The adaptive PID controller is applied to the plasma discharge cavity system model, the simulation model is built in Simulink, and the random perturbation signal is added to verify the ability of the adaptive PID control algorithm to suppress interference, the system simulation model is shown in Figure 8.

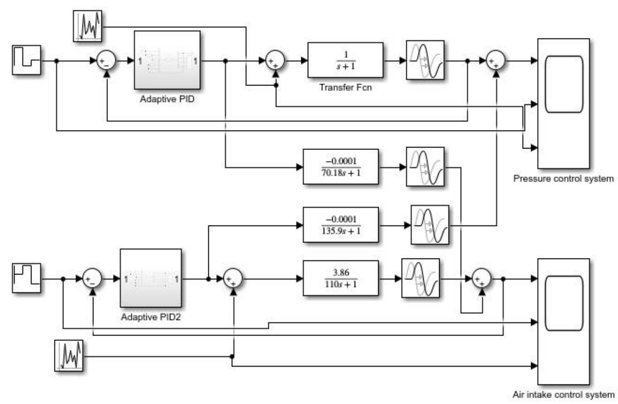

Figure 8. Simulation model of single-neuron adaptive PID Simulink

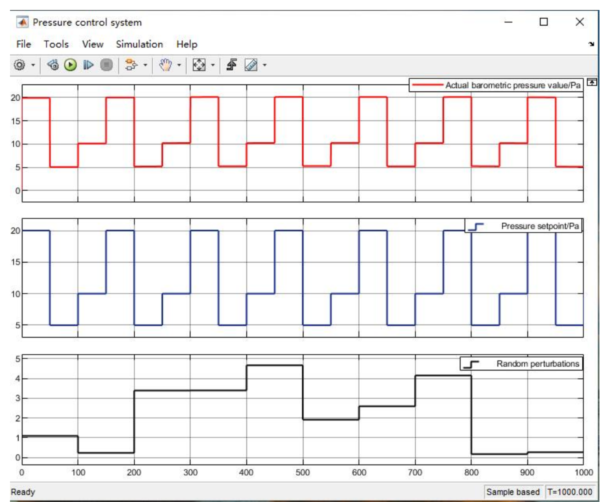

Figure 9. Simulation results of the pressure control system

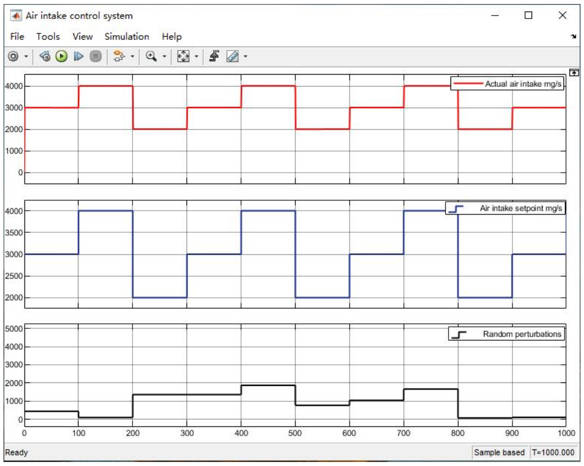

Figure 10. Simulation results of the intake control system

Figure 9 and Figure 10 are respectively the simulation results of the pressure control system and the simulation results of the air intake control system, it can be seen from the simulation results that in the pressure control system, the set values are 5Pa, 10Pa, 20Pa, and the random disturbance signal of 0~5Pa is added, and in the air intake control system, the set values are 2000mg/s, 3000mg/s, 4000mg/s, respectively, and the random perturbation signal of 0~2000mg/s is added, under the single-neuron adaptive PID control system, The response curve can quickly track changes in the setpoint and suppress disturbances.

VI. CONCLUSIONS

This paper presents a single-neuron adaptive control algorithm for pressure and intake volume in a two-parameter control system. By adjusting the weight coefficients online, it solves the problem that the parameters of the traditional PID controller cannot be set online. A simulation model was built in Simulink to verify the ability of single-neuron adaptive PID control to track the step response curve and its anti-interference ability in the presence of disturbances. Through the online real-time adjustment of control parameters, the preset value was quickly reached, verifying the effectiveness of the control algorithm.

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