An Intelligent Controller Based on Primary–Secondary Responding Mechanism of Immune System

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Abstract

Based on the primary–secondary responding mechanism of immune system, we present a novel immune intelligent controller (IIC). The IIC has the abilities of self-learning, memory, and evolution. It can produce the control antibody automatically during the period of eliminating control error. The control system has no control antibodies when the control error appears at the first time. The IIC can learn and produce the control antibody during the period of eliminating the error by using conventional control algorithm. When the control error appears again, the IIC can eliminate it rapidly and stably. Simulation results demonstrate that the control performance of the IIC is better than that of the conventional PID controller.

Keywords: immune system, self-learning, memory, evolution, intelligent controller.

1. Introduction

With the rapid development of the biocybernetics, intelligent control theory and biological technology have been combined more and more close. The immune system has excellent abilities of learning, memory, and recognition, and can remember every kind of antigen invaded and eliminate the antigen fast and stably when the antigen invades again [1].

Since the later 1990s, the artificial immune system (AIS) has been developed quickly. Currently, some intelligent controllers or algorithms based on immune mechanisms have been discussed. Several intelligent controllers based on the special feedback mechanism of the immune cell are introduced in [2-4]. And several methods of regulating PID parameters dynamically to improve the control effectiveness by using immune algorithm are presented in [5-6]. According to the current work, few researches of intelligent controller based on the primary–secondary responding mechanism of immune system have been reported. However, this mechanism has some special features of high efficiency, stability, and self-adaptation [1]. In this paper, we present a novel immune intelligent controller (IIC) based on the primary–secondary responding mechanism. The IIC has the abilities of self-learning and memory, and evolution.

In Section 2, the primary–secondary responding mechanism of immune system is briefly introduced. In Section 3, the design and implementation of the IIC are explained. In Section 4, the control performance of the IIC is examined through several computer simulations. In Section 5, we conclude the paper.

2. Primary–Secondary Responding Mechanism of Immune System

When the antigen (Ag) first invades the body, the immune system does not have the corresponding antibody to kill them. But the old antibodies in the immune system can produce a new one via evolution, stimulated by the invading antigen. Then the invading antigen is eliminated. This is the primary responding of the immune system, and is its learning process. After the antigen is eliminated, a certain number of antibodies in the body are always kept. When the foreign antigen invades body again, the antibodies in the immune system first make a match with the antigen, and then the matched antibody can propagate rapidly to eliminate the antigen. This is the secondary responding and self-adaptation of immune system [1]. The primary-secondary mechanism of immune system is as shown in Fig.1.

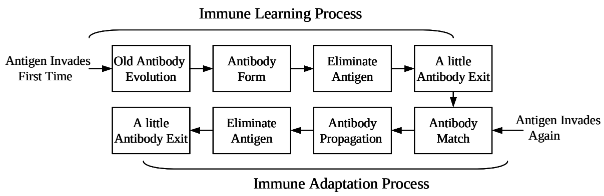


Fig.1: Primary-Secondary Responding Mechanism of immune system.

3. Design of Immune Intelligent Controller

We associate the control error $e(t)$ with the antigen, and the control strategy or process of eliminating $e(t)$ with the antibody. All the control antibodies in the control system constitute the antibody library, which is noted as $C_{Ab}(i)$ where i=1,2,…,n (n is the total number of all the control antibodies in the library). According to Fig.1, we design an intelligent controller based on the primary–secondary responding mechanism of immune system. And its learning and evolution process is as shown in Fig.2. In Fig, 2, CCA is the conventional control algorithm.

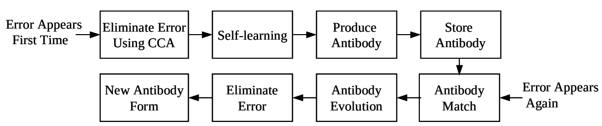


Fig.2: The Learning and Evolution Process of the IIC.

For the antibody $C_{Ab}(i)$, we define two concepts:

(1) Features: they are set-point value $sp_i(t_0)$ and control error $e_i(t_0)$ when the $C_{Ab}(i)$ begins to be produced;

(2) Control strategies: they are the difference value Δu_i:

$$\Delta u_i = u_i(t) - u_i(t_0)\,, \tag{1}$$

where $u_i(t)$ is the final output value of the IIC when the control error is eliminated, and $u_i(t_0)$ is the initial output value when the $C_{Ab}(i)$ begins to be produced.

3.1. Control-antibody working process

When the antigen appears at the first time, it is the primary responding of immune system, the IIC does not have the corresponding antibody. It learns and produces the corresponding control antibody. In other words, it uses its auxiliary conventional control algorithm to eliminate the control error. After the first control error is eliminated, the first control antibody has been produced.

When the control error appears again, the control antibody begins to take effect. The IIC first matches all the control antibodies in the library with the antigen. Then the most matched antibody is corrected. Finally, the IIC uses the corrected antibody to eliminate antigen. After the antigen is eliminated, the new antibody is produced. This is the process of control antibody memory, evolution, and propagation, and can be explained as follows (let the total number of antibodies in library is n).

(1) Record features. When the antigen appears (the control error exceeds the threshold ε_1), the antigen's features are recorded. The features include the process set-point value $sp(t)$, control error $e(t)$, and the IIC output value $u(t)$.

(2) Antibody match. The antigen's features are compared with those of every control antibody in the library. The matched factor ω_i (i=1,2…n) of every control antibody is calculated according to

$$\omega_i = \frac{1}{\alpha\left|sp(t) - sp_i(t_0)\right| + (1-\alpha)\left|e(t) - e_i(t_0)\right|}\,, \tag{2}$$

where 0< α <1.0, and we let α equal 0.5. Then the control antibody with maximum ω_i is the matched one, and it is noted as $C_{Ab}(k)$, where $k \le n$. This is the memory process of control antibody.

(3) Control antibody correction. Because $e(t)$ may not matched with $e_k(t_0)$ well. For example, the value or changing direction may be not uniform. So the changing output value $\Delta u_k(t)$ of antibody $C_{Ab}(k)$ is corrected, and then the changing output $\Delta u(t)$ of the middle-antibody $C'_{Ab}(n+1)$ is obtained according to liberalization theory and equation

$$\Delta u(t) = \Delta u_k(t)\frac{e(t)}{e_k(t_0)}\,, \tag{3}$$

where $e_k(t_0)$ is the feature of antibody $C_{Ab}(k)$.

(4) Eliminating antigen. The IIC uses middle-antibody $C'_{Ab}(n+1)$ to eliminate antigen, and its output value $u(t)$ is

$$u(t) = u(t_0) + \Delta u(t)\,, \tag{4}$$

where $u(t_0)$ is the initial controller output value to eliminate the control error, and $\Delta u(t)$ is the changing output value of middle-antibody $C'_{Ab}(n+1)$.

(5) Producing of the New control antibody. After the control error is eliminated, the factual changing output value $\Delta u_{n+1}(t)$ of middle-antibody $C'_{Ab}(n+1)$ is calculated based on Eq. (1) and the final IIC output value $u_{n+1}(t)$. Then the new control antibody $C_{Ab}(n+1)$ is produced , and is stored in data file. This is the propagation process of the control body. The detail process is as shown in Fig.3.

3.2. Antibody strategy and auxiliary PID

If only the antibody memory-strategy (4) is used, the control performance will be affected. The reasons are: (1) the low changing rate of the process variable can make the control system take longer time to be stable; (2) there is error between the changing output $\Delta u(t)$ of middle-antibody and the real final changing IIC output value.

To the first factor, a measure of combining the control antibody strategy and conventional P (proportion) control algorithm is taken. The IIC output $u(t)$ is

$$u(t) = u(t_0) + \Delta u(t) + K_{p0} e(t) , \qquad (5)$$

where K_{p0} is the proportion gain. The measure can make the output value $u(t)$ change fast and eliminate control error rapidly. When the control error is eliminated, the stable IIC output value $u(t)$ equals to $u(t_0)$ plus $\Delta u(t)$ (refer to Eq.(4)).

To the second factor, a measure of combining the above measure and the auxiliary PID control algorithm is taken. When control error $e(t)$ exceeds the threshold ε_2 (such as 1%), the method of the control antibody and P control algorithm is taken. Otherwise, it switches to the auxiliary PID control method to eliminate the control error further. The overall process is as shown in Fig. 4.

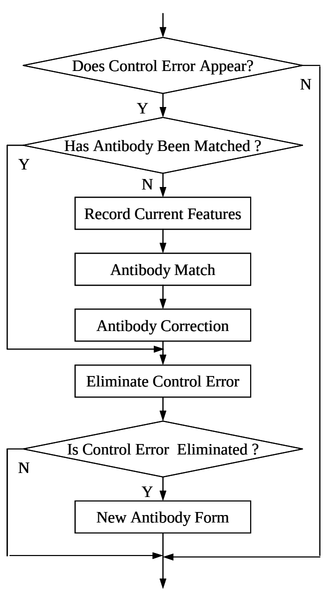
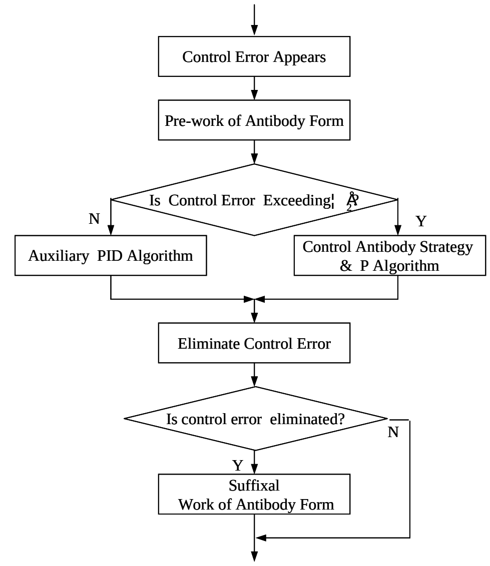


Fig.3: Working Process of Control Antibody.

Fig.4: The Overall Control Process.

4. Simulation Results



In order to examine the IIC's performance, the plant A (6) and B (7) are used for the simulation experiments. A is a second-order plant with a time delay in temperature control system, and B is a third-order plant in level control system. We compare its control performance with that of the conventional PID controller. Through the changing of set-point value, the IIC can produce control antibodies. In fact, this is the IIC's self-adaptation process. In the simulation, the IIC auxiliary PID control parameters are set as same as those of conventional PID controller.

$$G(s) = \frac{e^{-2s}}{(s+2)(s+3)} \qquad (6)$$

$$G(s) = \frac{1+2s}{(1+10s)(1+7s)(1+3s)} \qquad (7)$$

The IIC control parameters set is as shown in Table.1, where K_{p1}, T_{i1}, and T_{d1} are the control parameters of the auxiliary PID algorithm, ε_1 and ε_2 are the IIC control error threshold and the switching threshold, respectively. The produced control antibodies are as shown in Table.2. From the control performance in Fig. 5, 6, it can be found that the IIC can eliminate control error fast stably, and with no overshoot. While the conventional PID controller does that with great overshoot and violent oscillation.

Table.1: Control Parameters.

Name	K_{p0}	K_{p1}	T_{i1}	T_{d1}	ε_1	ε_2
Plant A	1.3	1.3	5.0	0.0	0.05	0.02
Plant B	0.08	5.0	80.0	0.0	0.05	0.02

Table.2: Produced Control Antibodies.

Name	**No.**	**Set-point**	**Control error**	**Changing output**
Plant A	1	1.0000	1.0000	0.9995
	2	1.5000	0.5000	-0.4995

	3	1.0000	-0.5000	-0.4995
Plant B	1	0.5000	0.5000	0.4996
	2	0.7000	0.2000	0.1996
	3	0.5000	-0.2000	-0.1996

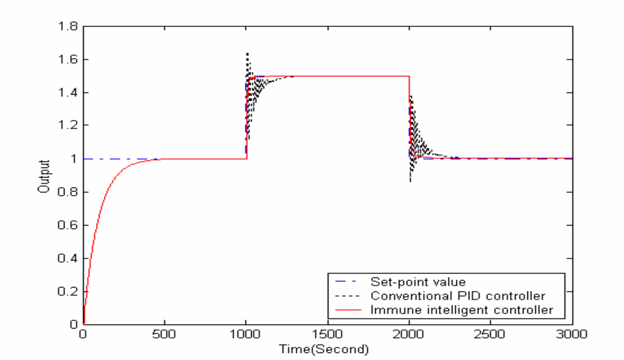


Fig.5: The Control Effectiveness of Plant A.

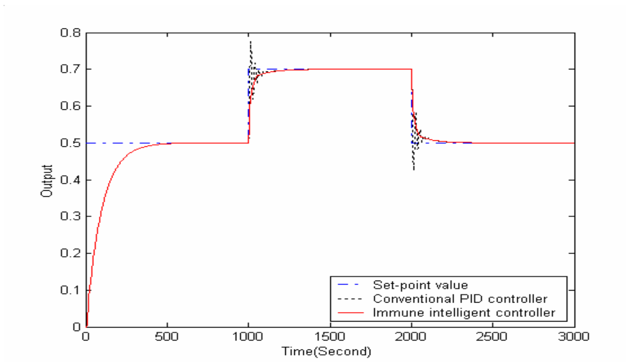


Fig.6: The Control Effectiveness of Plant B.

5. Conclusions

In this paper, we present a novel IIC based on the primary–secondary responding mechanism of immune system. The IIC can produce control antibodies automatically. When the control error appears, the controller can find the most matched antibody and correct it to produce middle-antibody. After the control error is eliminated, the new control antibody has been produced. The more times does the IIC eliminate the control error, the more antibodies are produced, and the better are the IIC control performance. Combined with auxiliary PID control algorithm, the IIC can eliminate control error fast, stably, with less overshoot. The simulation results demonstrate that the IIC's performance is superior to that of conventional PID controller.

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