A Quick Regulation Algorithm Based on Immune Feedback Principle

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Abstract

Based on analyzing the feedback principle of nature immune system, the immune process is imitated from the viewpoint of molecular dynamics and the nonlinear model of immune system is founded. Furthermore, a novel regulation algorithm based on immune feedback principle (IFRA) is designed. The results of simulation show that the IFR algorithm can make the system respond rapidly and stabilize quickly. Its performance is superior to that of the ordinary regulation methods. It also shows that the IFR algorithm suits for regulating the finance system which has large time-delay system especially.

Keywords: Immune, feedback, nonlinear, regulation algorithm.

1. Introduction

The information systems enlightened by the research on creature can be classified into brain-nervous system (NN, Neural Networks), genetic system (EC, Evolution Computation and GA, Genetic Algorithm), and immune system (AIS, Artificial Immune System). Now, NN and EC, GA have been wildly applied to various fields. Because of its complexity and deficiency of support by mathematical theory, the application and development of AIS is constricted. The current researches and applications enlightened by immune principle mostly adopt the fundamental idea of NN[1] and EC, GA[2,3]. The research based on the innate feedback principle of immune system is relatively few.

This paper first analyzes the feedback principle of nature immune system and then the immune process is imitated by virtue of nonlinear molecular dynamics. Then the mathematic model of immune system is founded. The model implicates two important processes in immune system. One is that antibodies (Ab) and killer T cells (T_{kill}) rapidly respond to the change of the number of antigens (Ag). Another is that suppressor T cells (T_{sup}) inhibit and adjust the number of Ab and T_{kill}. In this paper, foreign disturbances, input errors and measurement noises are regarded as Ag. The process in which creature presents immune response produces antibodies and removes antigens is regarded as the regulation process of eliminating disturbances and adjusting differences. So, we designed a novel regulation algorithm based on immune feedback principle (IFRA). In most financial problems, the mathematic models described by the equations with time delay and inertia are common and advantageous from the applied point of view[4]. The regulation process of finance system demonstrates the quality of tardiness and low efficiency. Applying the proposed algorithm to the financial problems, it will improve the adjusting ability and better the regulation effect. Some simulation experiments are performed accordingly.

2. Immune Feedback Principle

The natural immune process is shown in figure 1.

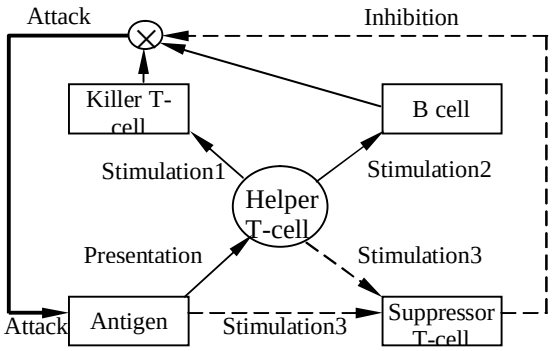

Fig 1. Scheme of the whole immunity Circle

When antigens such as virus, bacteria, etc. enter into the body of creature, they will first be recognized by the T-cell receptor (TCR) on the surface of helper T cells. Then antigen presentation cells (APCs) present them. APCs can transfer antigen information to helper T cells and stimulate them. Then, helper T cells become the chief adjustor in immune process. On the one hand, helper T cells stimulate and activate the killer T cells in blood (as stimulation 1 in Fig. 1)

according to the information presented by APCs, then make them effect cells. The effect cells can kill and remove antigens so as to perform the specific cell-mediated immunity. On the other hand, helper T cells also stimulate and activate the resting B cells (as stimulation 2 in Fig. 1). The activated B cells can reproduce and secrete antibodies. These antibodies will perform the nonspecific humrol immunity. Besides, helper T cells will complete another task: they will adapt the whole immune process according to the progress of natural immune. When helper T cells sense that the number of antigens is smaller than a threshold or the proportion between the number of antibodies and antigens is greater than a value, they will activate suppressor T cells in blood (as stimulation 3 in Fig. 1). Suppressor T cells will inhibit secretion and reproduction of B lymphocytes and killer T cells. So, they enhance the system to restore dynamic balance. Here, we view the process of antigen defending and removing by immune system as the main feedback process, and the process of balance restoration of the system by suppressor T cells as the inhibition feedback process. By interplay of main feedback and inhibition feedback, immune system can rapidly respond to foreign material and stabilize itself simultaneously.

3. Modeling of Immune Process

Kawvfuku[5] and Yongsheng Ding[6] etc. made great efforts on the modeling of the immune system. Distinguished from those works, this paper studies the immune process from the viewpoint of molecular dynamics. By this method, we founded the model of the immune system.

3.1. Antigen

One of important function of immune system is antigen removing. The obvious effect of antigen is to destroy the former balance of immune system and force immune system to respond. That is just like the environment disturbances, input deviations and measurement noises in engineering. The exterior disturbances, price fluctuation in finance regulation process have their own mathematic characteristics.

3.2. Helper T cell

After entering into the body of creature, antigens are recognized by TCR. Then APC presents the information of antigen to helper T cells. Stimulated by these biochemical signals, helper T cells will be activated and their concentration in blood is varied remarkably. By extensive investigation, Fishman, M.A. got the dynamic equations of this process. By the method of quasistatic approximation, we can get the following differential equation set to describe the nonlinear relation between helper T cells and antigens[7].

$$\begin{cases} \dfrac{ds}{dt} = \sigma(Ag - s) \\ \dfrac{dT}{dt} = \alpha + (\dfrac{s}{1+T} - 1)T \end{cases} \tag{1}$$

where, s is the overall number of the loci of APC that are able to conjoin with helper T cells; T is the number of helper T cells; α, σ are constants decided by dendritic cell or macrophage selected as APC. The value of α is small, so it is often neglected in computation.

Solving equation set (1), we can gain

$$\begin{cases} s = ag + e^{-\sigma t} \cdot C1 \\ t - \dfrac{1}{s-1}\log T + \dfrac{s}{s-1}\log(s - T - 1) + C2 = 0 \end{cases} \tag{2}$$

where C1, C2 are integral constants.

Equation set (2) further describes the nonlinear relation between helper T cells and antigens.

According to the proportion between helper T cell and killer T cell, we can calculate the number of killer T cells $T_{kill}(t)$ at t time.

$$T_{kill}(t) = k_c \cdot T(t) \tag{3}$$

where k_c is the proportion between helper T cells and killer T cells.

3.3. B cell

APCs present the information of antigens to helper T cells and activate them. Then helper T cells will activate the resting B cells and cause them to transform to plasma B cells (B_p). When modeling the antigen presentation process, M.Kanfman and J.Urbain applied Hill function H(Ag; θ_B) to describe the MHC's (Major Histocompatibility Complex) effects on B cell activation[8]. Considering the relation between the transformation velocity of B cells and the concentration of B cells and the needed helper T cells, the model of this process is as the following,

$$\begin{cases} \dfrac{dB}{dt} = k_1 - k_2 \cdot B \cdot T \cdot H(Ag;\theta_B) - d_1 \cdot B \\ \dfrac{dB_p}{dt} = k_2 \cdot B \cdot T \cdot H(Ag;\theta_B) - d_2 \cdot B_p \\ H(Ag;\theta_B) = \dfrac{Ag^2}{\theta_B{}^2 + Ag^2} \end{cases} \tag{4}$$

where, θ_B is a threshold which is the concentration of antigen when the activation degree is half; k_1 is the number of B cells entering into blood from marrow everyday; k_2 is the reproduction velocity constant of B cell; d_1, d_2 are the natural death rate of B and B_p respectively.

Solving the equation set (4), we will get the number of B_p. It is also known that one B_p can secrete 10^3-10^4 antibodies per second. Thus, we gain the number of antibody *Ab(t)* at t time,

$$Ab(t) = k_B \cdot B_p(t) \tag{5}$$

where, k_B is the rate of antibody production by B_p.

3.4. Suppressor T cell

Suppressor T cells can inhibit activities of all other cells, but the details of inhibition are not very clear. Considering an application to feedback regulation, this paper approximates this function as following,

$$T_{\sup}(t) = k_2 \left\{ \begin{matrix} [T_{kill}(t-d) + Ab(t-d)] \\ -[T_{kill}(t-d-1) + Ab(t-d-1)] \end{matrix} \right\}^2 \cdot Ag(t) \tag{6}$$

where, k_2 is the suppression factor, whose sign is positive. *d* is the starting time of inhibition. In equation (4), the squared term is introduced to account for the interaction between immune cells and antigens at the *(k-d)th* generation.

According to 3.1-3.4, the overall number of immune cells (attacking cells in figure 1) at t time is

$$attack(t) = T_{kill}(t) + Ab(t) - T_{\sup}(t) \tag{7}$$

Thus, equation (7) gives the immune feedback principle, which is a function about Ag and t. If we regard *Ag* as financial fluctuation, equation (7) describes a nonlinear feedback regulator.

4. Simulation Experiment

During the process of finance regulation, we expect the fluctuation is as small as possible and the regulation time is as soon as possible. When the whole finance system is in equipoise in the mass, we think the difference between totals in the debit and credit sides of an account is very small, even to zero. Some exterior factors can upset the balance and cause the economy behaviors into the fluctuating market. It is the unexpected phenomenon. If we want to recover the finance balance, we must introduce some regulation action to solve the fluctuation. The shorter the regulation time is, the fewer the economy loss is. Thus, it is very significant for us to develop a quick regulation mechanism to maintain the finance balance. According to the characteristic of economy behavior, we can describe the regulation process qualitatively as an inertia system with some time delay.

Using the proposed regulation algorithm, we can construct the artificial immune feedback regulation system showed in Fig. 2. Where, the process plant describes some a finance problem with time delay and inertia, e(k) denotes the differences from the ideal status, u(k) denotes the regulation actions.

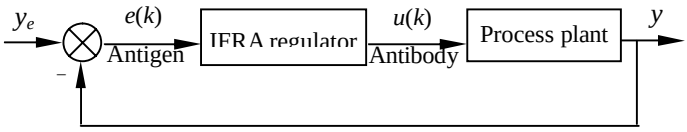

Fig. 2 Artificial immune feedback regulation system

The model of the regulation plant is described as equation (8) approximately.

$$P(s) = \frac{K_G}{s^2 + \tau_1 s + \tau_2} e^{-\tau_d s} \tag{8}$$

where, K_G is the gain of the model, τ_1 and τ_2 are inertia time constants, τ_d is the delay time of the model. During the computer simulations, the values of gain and inertia time constants of the model are: K_G=1, τ_1=3, τ_2=2. In order to demonstrate the effect of the delay time, τ_d is 10, 20, 50 in the simulation respectively. The simulation flowchart is shown in Fig. 3.

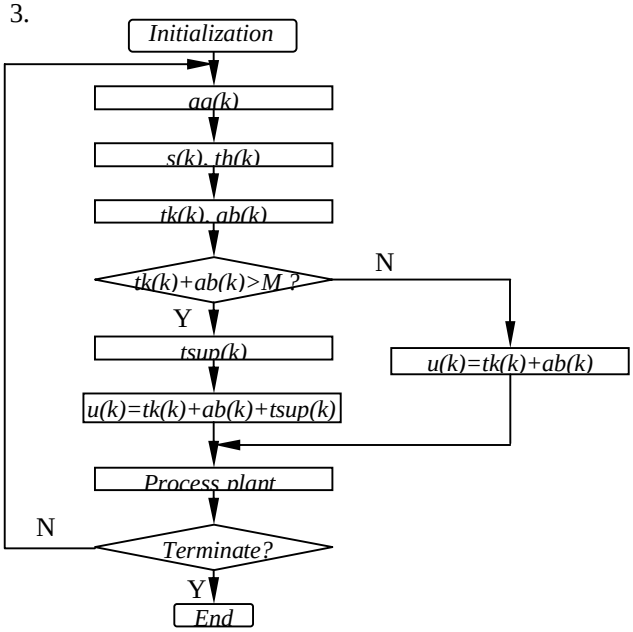

Fig. 3 The flowchart of IFR algorithm

Meanwhile, computer simulations are done to compare the performance between the immune feedback regulation algorithm and the corresponding ordinary PID regulation algorithm. The simulation results are as shown in Fig 4.

As Fig. 4 is shown, the rise time and settling time of IFRA is much shorter than that of PID. It confirms that the immune feedback regulation has the ability of rapid respond and quick stabilization. From the comparison of Fig 4 (a), (b) and (c), we also conclude that the IFR algorithm is fitter for regulating the

finance system which has larger time delay. It is important to ensure the real-time performance of the regulation system. Furthermore, as seen in Fig. 4(c), if we want to accelerate the respond speed of PID regulation process, the overshoot of the system will become so large (just like the PID1 curve in (c))and costs much more than the IFR algorithm. On the whole, the all-round property of the immune feedback regulator is superior to that of the ordinary PID regulator.

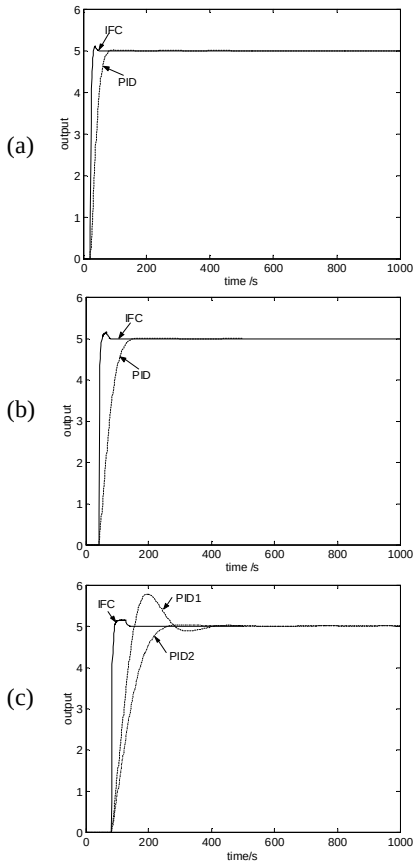

Fig. 4 The performance IFRA and PID with different delay time (a) τ_d=10, (b) τ_d=20, (c) τ_d=10

5. Conclusions

Starting with analyzing the feedback principle of nature immune system, the immune process is imitated from molecular dynamics and nonlinear model of the immune system is founded. Furthermore, a novel immune feedback regulation algorithm is designed. We apply the IFR algorithm to regulate a finance system. According to the results of simulation, we can draw the following conclusions:

1) The nonlinear modeling method from the view-point of molecular dynamics is feasible.
2) The feedback principle of nature immune system is able to be led into the domain of the finance regulation. The IFR algorithm also ensures the real-time performance of the regulation system.
3) The immune feedback regulation algorithm can make the system respond rapidly and stabilize quickly, which is just like the nature immune system. It improves the swiftness and stabilization of the system simultaneously. The all-round property of the immune feedback regulator is superior to that of the ordinary PID regulator.

There are many potential application areas in which immunity-based models appear to be very useful. They include finance planing, combination optimization, bankruptcy prediction, and so forth. So, further analysis and applications of immune principle should be done in our future research.

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