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# Research on CNC Machine Tool Fuzzy Immune PID Position Controller

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**Abstract**: CNC machine tool position controller connects control system with actuating mechanism and often adopts traditional PID control technology. But the traditional PID technology is hard to achieve rapid adjustment and lesser overshoot at the same time. Consequently, the CNC machine tool fuzzy immune PID position controller based on immunity feedback control theory is developed in the study. The experiment results show that the developed controller can achieve shorter adjust time, better rapidity and higher steady-state precision in contrast to traditional PID position controller.

**Keywords:** Adjust time, CNC machine tool, fuzzy immune PID, overshoot, position controller

## INTRODUCTION

The CNC machine tool position controller often adopts traditional Proportional Integral Differential (PID) control technology to compute controlled quantity. The strongpoint of the approach is simple and easy to implement (Hui-Gui and Hui, 2010). However, with the increasing requirement of practical manufacture speed, precision and stability, the traditional PID controller reveals its disadvantage gradually. For example, the poor adaptability and anti-jamming ability and the weakness that can't achieve rapid adjustment and lesser overshoot at the same time.

Aimed to the weakness of traditional PID controller, the researchers all over the world study how to enhance PID controller performance from two aspects mainly. For one thing, improve the classical PID control arithmetic. Hu Ligang devises the nonline-differential tracker to receive corresponding integral and differential signals and process the signals properly to build up nonlinear PID controller (Hu and Xu, 2010). Guo Yanqing analyzes each PID portion change trend with step input and develops a universal nonlinear PID contl model . K.Z. Tang combines the traditional PID and self-adaption nonlinear control and compensates the linear model warp with nonlinear model. Y.X. Su combines nonline-differential tracker and traditional PID controller in series and process signals with two nonline-differential trackers in order to improve anti-jamming ability.

For another thing, study PID control with intelligence approach. YiJie combines fuzzy control theory and traditional PID controller and regulates PID parameters with fuzzy reasoning (Yi, 2009). Ning Wang introduces the nonlinear PID control approach based on nerve cell network and carry out nonlinear control through nerve cell network parameters online adjustment. The simulation results show the approach can achieve high respond speed and satisfied robust performance.

In order to improve the traditional PID controller performance, the CNC machine tool fuzzy immune PID position controller based on immunity feedback control theory is developed in the study. The experiment results show that the developed controller can achieve shorter adjust time, better rapidity and higher steady-state precision than traditional PID position controller.

**Immunity feedback control mechanism:** As a pre-requisite recovery mechanism for biology, immunity system includes apparatus, organize, cell and immune effect moleculer with immune function. Immunity system can protect biology from pathogen and ensure natural life activities (Ye and Luo, 2011).

The lymphocyte in immunity system consists of B cell and T cell. In the whole life course, B cells are produced continuously from marrow, whose main function is to secrete blood serum antibody and carry out special body fluid immune adjustment function. T cell which is used to implement special cell immunity and immunity regulation, includes assistant T cell and restraint T cell. The assistant T cell play an important role on advancing B cell, while the restraint T cell play an important role on restraining B cell.

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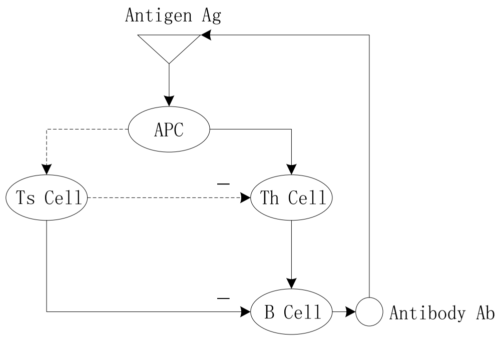


Fig. 1: The immunity feedback control mechanism

The immunity feedback control mechanism is shown in Fig. 1 (Li, 2011). Above all, Antigen Present Cell (APC) capture antigen and transfer antigen information to Th cell. Then Th cell activate B cell and Ts cell and make B cell produce antibody to remove antigen. With the process of immunity despondence, Ts cell excrete leucocyte to restrain immunoreactions and antibody production, when antigen is decreased even to removed gradually. Finally, the immunity system turns to balanceable and steady-going.

In immune reaction initial stage, antigen and Th cell are more, while Ts cell is less. So more and more B cells are produced. With the process of immunoreactions, antigen decrease gradually, while Ts cell increase. This will restrain Th cell and B cell production. After period of time, immunity system turns to balanceable.

## RESEARCH ON FUZZY IMMUNE PID CONTROLLER

**Immunity feedback rule:** Suppose the antigen amount be ε(k), suppose the Th cell output which receives APC activation be $T_h(k)$ and suppose the restrain action on B cell be $T_s(k)$ by Ts cell. Then all of the received activation of B cell can be obtained:

$$S(k) = T_h(k) - T_s(k) \tag{1}$$

$$T_h(k) = k_1 \cdot \varepsilon(k) \tag{2}$$

$$T_s(k) = k_2 \cdot f[\Delta S(k)] \cdot \varepsilon(k) \tag{3}$$

where, $k_1$ is Th cell advance coefficient, $k_2$ is Ts cell restrain coefficient and $\Delta S(k)$ is B cell total activation variable. $f(\bullet)$ is defined as a nonlinear function, which relates with B cell amount and describes the immunity result that B cell antibody and antigen act on each other.

With Eq. (1), (2) and (3), the total activation expression which B cell receive can be obtained:

Table 1: The variables corresponding connection between immunity system and CNC machine tool position controller

| Immunity system | CNC machine tool position controller |
|---|---|
| The k^th antibody and antigen multiplication | The k^th sampling period of CNC system |
| The k^th antigen concentration $\varepsilon(k)$ | Position error $e(k)$ on the k^th sampling period |
| B cell total activation $S(k)$ on the k^th period | The position controller output $u(k)$ on the k^th sampling period |

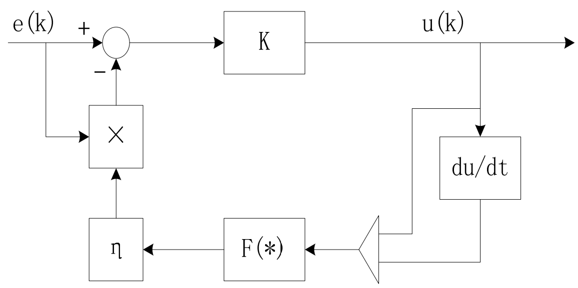


Fig. 2: The fuzzy immune controller

$$\begin{aligned} S(k) &= k_1 \cdot \varepsilon(k) - k_2 \cdot f[\Delta S(k)] \cdot \varepsilon(k) \\ &= K\{1 - \eta \cdot f[\Delta S(k)]\} \cdot \varepsilon(k) \end{aligned} \tag{4}$$

where, $K = k_1$, $\eta = k_2 / k_1$. Adjust K and n reasonably can achieve satisfied control effect.

Introduce the artificial immunity theory to the CNC machine tool position control to overcome the weakness of traditional PID controller. And the corresponding connection of parameter variable is shown in Table 1.

The traditional P controller arithmetic is:

$$u(k) = K_p \cdot e(k) \tag{5}$$

where, $K_p$ is proportional coefficient and e(k) is position error. Comparing Eq. (4) with (5), the CNC machine tool position control arithmetic based on immunity feedback mechanism is a nonlinear P controller essentially. Its proportional coefficient is:

$$K_p' = K \cdot \{1 - \eta f[\Delta S(k)]\} \tag{6}$$

The proportional coefficient changes adaptively along with the controller output change. The controller performance largely depends on k, n and $f(\bullet)$. Because the nonlinear function $f(\bullet)$ is difficult to design, fuzzy control reasoning arithmetic is introduced to approximate the $f(\bullet)$ function. The fuzzy immune controller based on the above-mentioned immunity feedback control arithmetic is shown in Fig. 2.

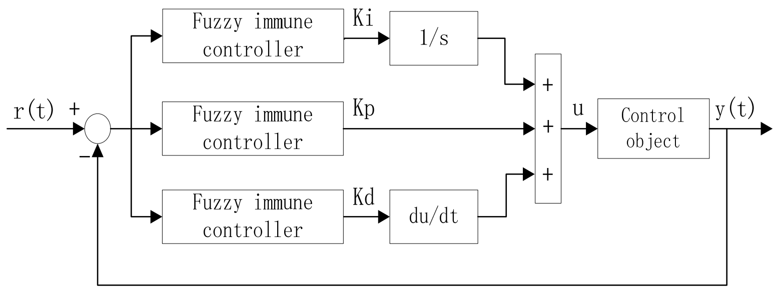


Fig. 3: The fuzzy immune PID position controller framework

**The fuzzy immune PID controller framework:** The fuzzy immune PID controller can be regarded as a nonlinear function, which adjusts the proportional coefficient, integral coefficient and differential coefficient. If k, n and f(●) are regulated reasonably, the developed CNC machine tool fuzzy immune PID position controller will achieve rapid self-adjustment, satisfied adaptability and robust performance like the artificial immunity system. According to the above principle, the fuzzy immune PID position controller is built up as shown in Fig. 3.

**The fuzzy controller design to achieve f(●):** The fuzzy reasoning arithmetic is introduced to compute f(●). In the fuzzy controller, the input of u(k) fuzzy subset is as follows:

$$u = \{NB, NS, ZO, PS, PB\}$$

The output of f(●) fuzzy subset is as follows:

$$f = \{NB, NM, NS, ZO, PS, PM, PB\}$$

Both the input subjection function and output subjection function adopt triangle subjection function. The immunoreactions course can be divided into four stages.

In the initial stage, the antigen thickness is higher and the antibody amount is hoped to increase quickly, so the Ts cell should be restrained to produce; in the sufficiently, so the antibody is hoped not to increase continually. In other words, the restrain action on Ts should decrease; In the third stage, most of the antigen have been removed, so Ts cell is hoped to increase quickly to restrain B cell and antibody production; In the last stage, all of the antigen have been removed, so antigen and antibody amount are hoped to keep stable till the immunoreactions course ends.

Table 2: The fuzzy control rule to achieve $f(\bullet)$

| F(u(k)) | F(Δu(k)) NB | F(Δu(k)) NS | F(Δu(k)) ZO | F(Δu(k) ) PS | F(Δu(k)) PB |
|---|---|---|---|---|---|
| NB | NB | NB | NM | NS | ZO |
| NS | NB | NM | NS | ZO | PS |
| ZO | NM | NS | ZO | PS | PM |
| PS | NS | ZO | PS | PM | PB |
| PB | ZO | PS | PM | PB | PB |

According to the above immunoreactions course, the fuzzy control rule is developed as shown in Table 2. Adopt mamdani fuzzy reasoning theory and area and gravity model approach to compute $f(\bullet)$.

## FUZZY IMMUNE PID POSITION CONTROLLER

**Simulation experiment:** The common medium CNC machine tool feeding system mathematic model is introduced (Xiong, 2009), the transfer function is as follows:

$$G(s) = \frac{10}{s^3 + 9s^2 + 23s + 15}$$

The servo system simulation modules are set up with MATLAB/Simulink to compare the traditional PID controller with the developed fuzzy immune PID position controller.

The traditional PID controller coefficients can be obtained with Z-N approach:

$$K_p = 11.52,\ T_i = 0.6575,\ T_d = 0.1644$$

The fuzzy immune PID position controller coefficients can be obtained after NCD toolbox optimization:

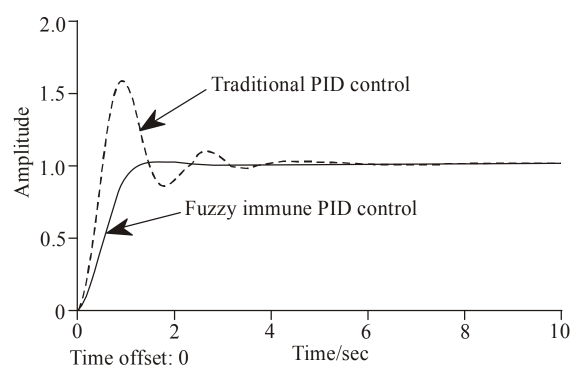


Fig. 4: The traditional PID controller step response curve and the developed fuzzy immune PID position controller step response curve

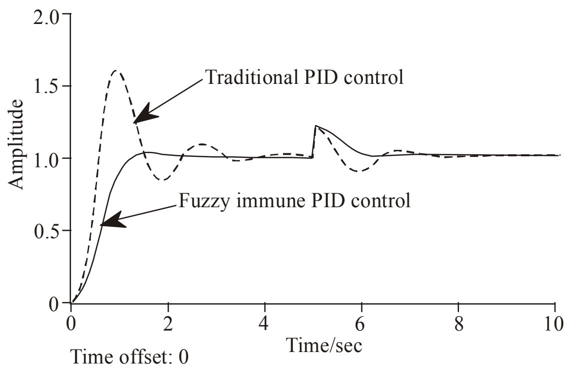


Fig. 5: The traditional PID controller step response curve and the developed fuzzy immune PID position controller step response curve with a step disturbance signal

$K_{p1} = 0.6363$, $K_{p2} = 5.2568$, $K_{i1} = 0.0491$,
$K_{i2} = 2.3567$, $K_{d1} = 0.2613$, $K_{d2} = 1.2363$

- Aimed to the unit step input signal, the traditional PID controller step response curve and the developed fuzzy immune PID position controller step response curve are shown in Fig. 4.
  From Fig. 4 it can be seen, in contrast to the traditional PID controller, the rise time with the developed fuzzy immune PID position controller increases from 0.33s to 0.74s; The adjust time decreases from 3.69s to 1.23s markedly; And the overshoot decreases from 59.35 to 0%. In conclusion, the developed fuzzy immune PID position controller can achieve shorter adjust time and non overshoot.
- If add a step disturbance signal at t = 5s whose amplitude is 0.2, the traditional PID controller step response curve and the developed fuzzy immune PID position controller step response curve are shown in Fig. 5.
  From Fig. 5 it can be seen, in contrast to the traditional PID controller, the adjust time with the developed fuzzy immune PID position controller decreases from 1.95s to 0.95s markedly and the overshoot decreases to 0%. In other words, the developed fuzzy immune PID position controller can spend lesser adjust time to come back to steady-state.

## CONCLUSION

The CNC machine tool position controller often adopts traditional PID control technology to compute controlled quantity. But the traditional PID control technology can't achieve rapid adjustment and lesser overshoot at the same time. In order to improve the traditional PID controller performance, the CNC machine tool fuzzy immune PID position controller based on immunity feedback control theory is developed in the study. The experiment results show that in contrast to traditional PID position controller, the developed controller can achieve shorter adjust time, better rapidity and higher steady-state precision.


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