Analysis of Fuzzy PID and Immune PID Controller for Three Tank Liquid Level Control

Sharad Kumar Tiwari, Gagandeep Kaur

Abstract— In industrial control systems the liquid level is carrying its significance as the control action for level control in tanks containing different chemicals or mixtures is essential for further control linking set points. The three level control models are considered in our work. The conventional control algorithm is difficult to reach required control quality with more strict restriction on overshoot. Design a parameter self-tuning PID-controller based on fuzzy control, which can adjust PID-parameters according to error and change in error. Biological immune system is a control system that has strong robusticity and self-adaptability in complex disturbance and indeterminacy environments. The artificial intelligence technique of fuzzy logic and immune controller is adopted for more reliable and precise control action which incorporate the uncertain factors also. In this work the comparison of the conventional model, fuzzy model and immune feedback mechanism is clarified.

Index Terms— Fuzzy logic, PID, immune control, artificial immunity, three level control, vertical tank.

I. INTRODUCTION

Artificial Immune System (AIS) is a new branch of computational intelligence inspired by the biological aspects of the immune system. Immunology as a study of the immune system inspired the evolution of artificial immune system, which is an area of research over the last few years. Artificial immune system imitates the natural immune system that has sophisticated methodologies and capabilities to build computational algorithms that solves engineering problems efficiently. They are useful in constructing novel computer algorithms to solve complex engineering problems. At the present time, the immune system has already had the certain research results in the projects, but is still needed to be researched on its function and several mechanisms. The human immune system has motivated scientists and engineers for finding powerful information processing algorithms that has solved complex engineering tasks. In cell level, immunology concerns mainly in T lymphocytes and B lymphocytes, focusing primarily on their interactions. Modern immunology shows that there are different cells with various functions in immune system, for instance, antibodies attach on the B lymphocyte surface. Each antibody has idiotope which acts as antigen, paratope which recognizes other antibodies and antigens, and epitope which can be recognized by other antibodies and antigens. There are different immune system models that explore various immune mechanisms and cell roles in the immunity process; amongst those is idiotypic immune network theory. It is interesting to observe that the process of recognition, identification and post processing involve several mechanisms such as the pattern recognition, learning, communication, adaptation, self organization, memory and distributed control by which the body attains immunity.

The variable universe fuzzy logic control is suitable for the system of nonlinearity, parameter uncertainty and large-time delay, which has some adaptability to the nonlinear time-delay and time-variable of the subject under control, except for certain systematic static deviations. A controller based on variable universe fuzz logic control, which consists of the self-tuning PID control is presented in this paper. The proposed controller inspects and analyzes the elements such as uncertain conditions, parameters, delays and disturbs, etc., achieving the features of PID parameters self-tuning on-line. It not only keeps the advantages of PID controller, such as simple principle, convenient operation and stronger robustness, but also has bigger flexibility, applicability and the better control precision.

Artificial immune system is a new research field as artificial intelligent system. The biological immune system is characterized by its strong robustness and self-adaptability even when encountering amounts of disturbances and uncertain conditions. Immune PID controller is a nonlinear controller designed by immune mechanism, which performs well and has better robustness.

II. MATHEMATICAL MODELING OF THREE TANK SYSTEM

In this paper, the liquid level control system of a container water tank system is discussed. A 3 – container water tank is usually connected by three first-order non periodic inertia links in series, and its structure can be schematically shown in Fig.1.

Mathematical modeling:-

2) Tank 1;-

$$F_1(t) - F_2(t) = A_1 \frac{dh_1}{dt} \quad \text{……………………………..…..1}$$

Where

F1 (t) =tank1 inflowing liquid (m3/s), F2 (t) =tank1 outflowing liquid(m3/s), A1 =area of the tank1 (m2) and h1 =liquid level in tank1 (m).

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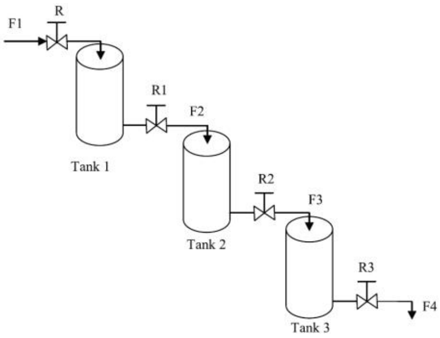

Fig.1: Three tank level system

2) Tank 2:-

$$F_2(t) - F_3(t) = A_2 \frac{dh_2}{dt} \quad \text{...2}$$

Where

F2 (t) =tank2 inflowing liquid (m3/s), F3(t) =tank2 outflowing liquid(m3/s), A2 =area of the tank2 (m2) and h2 =liquid level in tank2 (m).

3) Tank 3:-

$$F_3(t) - F_4(t) = A_3 \frac{dh_3}{dt} \quad \text{……………………………….3}$$

Where

F3 (t) =tank3 inflowing liquid (m3/s), F4(t) =tank3 outflowing liquid(m3/s), A3 =area of the tank2 (m2) and h3 =liquid level in tank3 (m).

F2 (t)=h1/R1
F3 (t)=h2/R2
F4 (t)=h3/R3

where R1, R2 and R3 are linear resistance of tank1,tank2 and tank 3 (m/(m3/s)).

The overall transfer function of three tank system is

$$\frac{H_3(s)}{F_1(s)} = \left(\frac{R_1}{A_1R_1s+1}\right)\left(\frac{R_2/R_1}{A_2R_2s+1}\right)\left(\frac{R_3/R_2}{A_3R_3s+1}\right)$$

By considering

A1=A2 =1m2 ; A3=0.5m2 and R1 =2 (m/(m3/s)),R2 =2 (m/(m3/s)); R3 =4 (m/(m3/s)).

$$\frac{H_3(s)}{F_1(s)} = \left(\frac{2}{2s+1}\right)\left(\frac{1}{2s+1}\right)\left(\frac{2}{2s+1}\right)$$

Transfer function of valve (R)= $\left(\frac{.133}{3s+1}\right)$

III. THE SELF TUNING CONTROL PRINCIPLE OF FUZZY PID PARAMETER

PID control requirements model structure very precise, and in practical applications, to different extent, most of industrial processes exist to the nonlinear, the variability of parameters and the uncertainty of model, thus using conventional PID control can not achieve the precise control of the process. But the dependence on the mathematical model of the fuzzy control is weak, so it isn't necessary to establish the precise mathematical model of the process, and the fuzzy control has a good robustness and adaptability. According to their own characteristics, we combine fuzzy control with PID control, and provide a based on fuzzy PID parameters self-tuning controller with MATLAB. Fuzzy PID parameters Self-tuning Control takes error "e" and Change-in-error "ec" as the input of Fuzzy PID controller, meets the request of the different moments of "e" and "ec" to PID parameters self-tuning. Using fuzzy control rules on-line, PID parameters "kp", "ki", "kd" are amended, which constitute a self-tuning fuzzy PID controller, the principle of which control program as shown in Fig. 2.

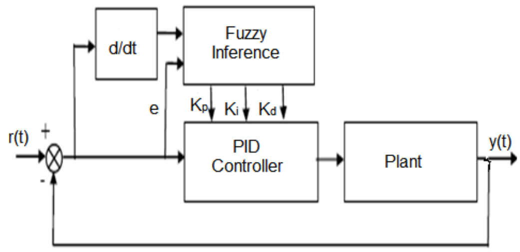

Fig 2 The block diagram of self-tuning fuzzy PID controller

PID parameters fuzzy self-tuning is to find the fuzzy relationship between the three parameters of PID and "e" and "ec", and according to the principle of fuzzy control, to modify the three parameters in order to meet different requirements for control parameters when "e" and "ec" are different, and to make the control object a good dynamic and static performance. selecting the language variable values of error "e" and the error rate of change "ec" is (NB, NM, NS, ZO, PS, PM, PB) seven fuzzy values, so is selecting the language variable values of kp, ki and kd.

A. Fuzzy Inference System (FIS) Editor

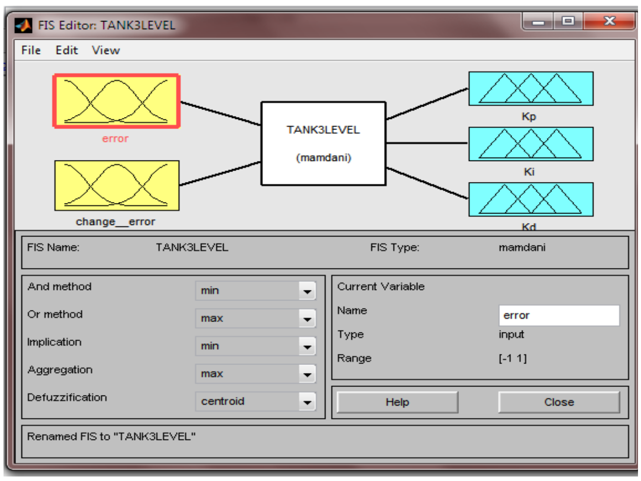

Fig.3 Fuzzy Inference System

B. Membership Functions

Using the fuzzy membership function editor, membership functions are given for two inputs and three outputs. A picture of linguistic variables and the membership functions used are given below.

C. Role Base

These rules are set based on the knowledge and experience with proportional, integral and derivative controllers. The unique characteristics of our level process system have been kept in mind while formulating these rules. It is generally accepted that the proportional action is proportional to error and the derivative action is proportional to change in error. The integral action is less proportional to error.

IV. IMMUNE PID CONTROL

Immune PID controller is a discrete controller based on the principle of biological immune system.

A. Feedback Principle of Immune System

Immune is a characteristic physiological reaction of biological body. Immune system of biology could produce relative antibody to resist invading anti-source from extraneous. After antibody combines with anti source, a serial reaction will be brought to destroy antibody by swallowing effect or producing special enzyme. In immune system, there is a feedback mechanism that enables human survival of infection and disease. Fig.4 presents the principle of feedback mechanism. The basic cells that are involved in the process are antigens Ag, antibodies Ab, B-cells B, helper T-cells TH and suppressor T-cells TS. According to Fig.3, we know that antigens will be recognized by APC (Antigen Presenting Cell) when they invade into organisms, then, the message will be sent to T-cells. After receiving the message, B-cells will be stimulated by T-cells and create antibodies immediately to eliminate the antigen. When the number of antigens is increasing, the number of TH-cells will increase and the human body can create more B-cells to protect itself. Along with the decrease of antigens, the amount of TS-cells in the body would increase and the number of B-cells would reduce accordingly. After a period of time, the immune system inclines to balance. Table 1 summarizes the regulation actions of T-cells in the process of the above immune response.

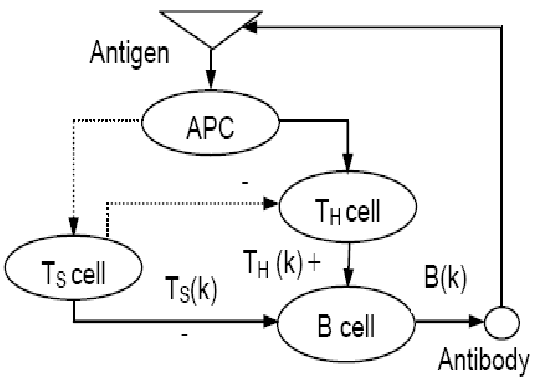

Fig.4 Schematic diagram of immune humoral response

Table 1.Regulations actions of T-cells in immune response

Immunit y response process	Antigen consistency	Antibod y consistency	T-cells consistency
Antigen invasion	High	minimu m	----
Prophas e	High	Low	Promotio n
Anaphas e	Low	High	Suppressi on
Telopha se	Minimu m	Low	-----

As aforementioned, the TS cells have the function of restraining the TH cells and B-cells. This paper mainly focuses on the suppression action of the B-cells. For the invasion of the antigen, the B-cells are activated and restrained by the TS cells. Therefore, the consistency of the kth generation B-cells can be given by:

B(k)=TH (k)-TS(k)……………….4

TH(k)=K1Ɛ(k)……………….……5

TS(k)=K2{f[ΔB(k-d)]}Ɛ(k)….….6

where ε(k) is the consistency of antigen at the kth generation; K1 is the helper gene of TH; K2 is the suppressor gene of TS; ΔB(k) is the change of B-cell's consistency ΔB(k-d)=B(k-d)-B(k-d-1), and d is the delay-time of immune response; f(x) is an nonlinear function that represents the interaction between antibody which emerge from B-cells and antigen.

From (4)-(6), we can obtain the relationship formula about the consistency of B-cells and antigen. It is shown as follows:

$$B(k)=K_1Ɛ(k)-K_2\{f[\Delta B(k-d)]\}Ɛ(k)$$
$$=K\{1-\eta f[\Delta B(k-d)]\}Ɛ(k)……….7$$

Where η= K2/K1 denotes the proportional coefficient of effecting between TH and TS.

Table 2. Comparison between immune system and control system

Immune System	Control System
1) The kth generation reproduction of antigens and antibodies.	1) The kth sampling time of discrete system.
2)Ɛ(k) is the antigen concentration of the kth generation.	2) e(k) is the deviation of the set value and output value at the kth sampling instant.
3)B(k) is the B cell concentration of the kth generation.	3) u(k) is the output value of the controller at kth sampling instant.

B. Immune PID Controller

The principal function of the appropriate immune response lies in ensuring the stability of the immune system and simultaneously responding to the antigen invasion in a fast way, since all the antigens attacking the biological body have to be removed.

On the other hand, a high antibody consistency also does harm to the body, and must be controlled. Therefore, the general target of the immune system is to minimize the total injury of the biological body. In the dynamic regulation of a control system, it is requested that deviation should be slaked on the promise of the system stability, which is actually consistent with the target of immune system. Table 2 summarizes the comparison between the immune system and control system.

Let the amount of antigen ε(k) as error e(k) , total stimulation that is accepted by B-cells is the input of the control u(k). And then the law of feedback control can be expressed as follows.

$u(k)=K\{1-\eta f[\Delta u(k-d)]\}e(k) = K_I e(k)$………………...8

Where $K\{1-\eta f[\Delta u(k-d)]\}=K_I$ is the proportional gain of immune controller. $\eta = K2/K1$ is called steady gene which controls the amount of proportional gain K_I; $f(x)$ is a nonlinear function about $\Delta u(k-d)$.

When antigen enters into the body the immune response is generated. According to the antigen consistency's influence on antibody in immune response, we selected nonlinear function as T-cells regulating action function based on simulation. It is showed as follows

$$f(x) = 1 - \frac{2}{1+\exp(-cx)} \qquad c>0;$$

Where $-1 < f(x) < 1$, the value of c determines the zone of action of variable x.

The output of Immune controller can be computed as follows:

$$u(k) = K\left[1-\eta\left(1-\frac{2}{1+\exp(-cx)}\right)\right]e(k) \text{……9}$$

It is obvious that Immune Controller（IC）is a nonlinear proportional controller, its proportional gain will transform with the transformation of the output of controller. Therefore, Immune P Controller cannot compensate noises and errors arose by nonlinear disturbance. Thus, the fusion of the immune controller and conventional PID controller, namely immune PID controller, can learn from each other's strengths and overcome the weaknesses to improve the system performance.

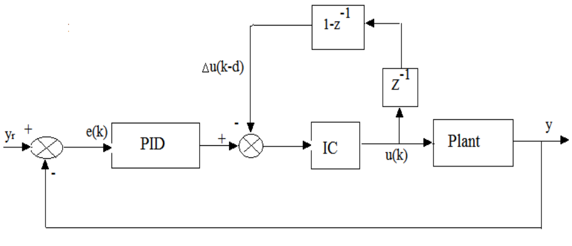

Fig.5. The structure of immune PID controller.

The structure of our immune PID controller is described in Fig. 3, whose output is:

$$u(k) = K_I * k_p\left[1+\frac{K_I}{1-z^{-1}}+k_d\left(1-z^{-1}\right)\right]e(k)$$

$$u(k) = K_{pI}\left[1+\frac{K_I}{1-z^{-1}}+k_d\left(1-z^{-1}\right)\right]e(k) \text{……..10}$$

Where k_{pI} represents k_p which adjusted by mechanism of immune feedback.

V. SIMULATION AND RESULTS

The mathematical model of the controlled plant is described by:

$$\frac{H_3(s)}{F_1(s)} = \left(\frac{2}{2s+1}\right)\left(\frac{1}{2s+1}\right)\left(\frac{2}{2s+1}\right)$$

Transfer function of valve = $\left(\frac{.133}{3s+1}\right)$

In this paper PID controller, fuzzy controller and immune and immune PID controller are explored in simulations using MATLAB. The reference input of this control system is a step function signal. Based on the Ziegler-Nichols method, the PID controller parameters are obtained as follows:

$K_p = 7.4$, $K_d = 18.9$, $K_i = 10.7$

The simulation results in Fig.6 and Fig.7 show that with some obvious overshoots, the PID controller based control system can achieve the stable output. The parameters of our immune PID controller are K_I *and* η.

$Kp_I = 0.001$, η=0.71 and c=7.

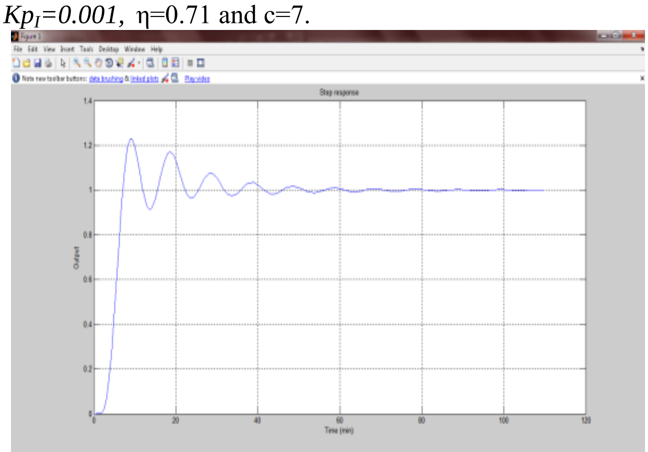

Fig.6:pid control for 3 tank

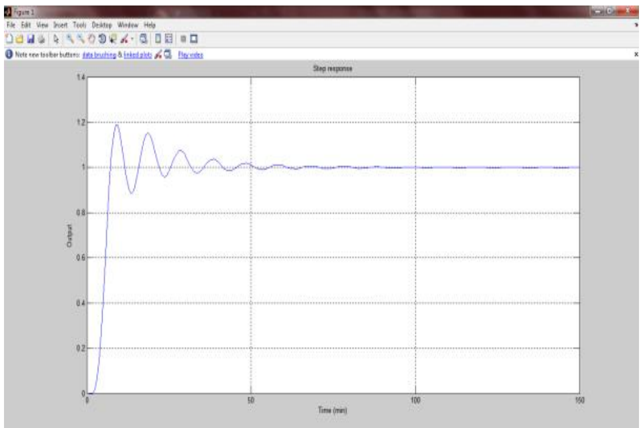

Fig.7 fuzzy pid control for 3 tank

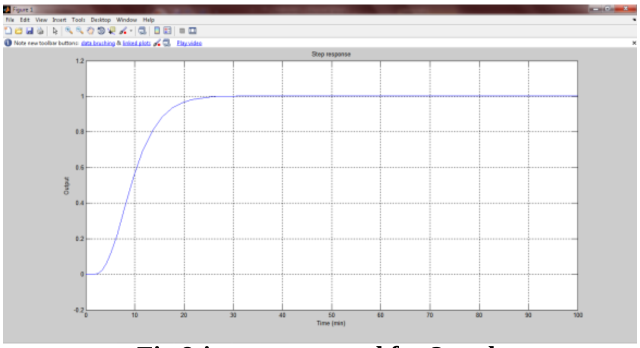

Fig.8:immune control for 3 tank

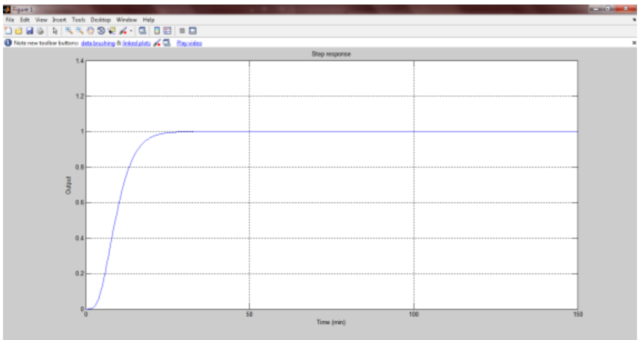

Fig.9: immune pid control for 3 tank

Table 3: Comparisons of results

	PID	Fuzzy-PID	Immune	Immune-PID
PEAK TIME	9.4132	8.8426	NO PEAK	NO PAEK
PEAK OVERSHOOT	22.9169	18.8555	0.2288	NO OVERSHOOT
SETTLING TIME	29.8016	29.8961	17.5197	17.400

VI. CONCLUSION

A new immune and immune PID controller is proposed in this paper, and applied to the three tank-level control. MATLAB simulations show that this method results in a quicker response with a smaller overshoot than the conventional PID controller and fuzzy PID. Moreover, it has a strong ability to adapt to the significant change of system parameters. To summarize, the immune PID controller has been proved to be an effective method in the level control. It can be also used in a variety of nonlinear control systems with time-varying, pure delay, and large time constants.

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