A Study on Performance Characteristics of Immune System for Practical Application

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Abstract. This paper deals with the characteristics of performance of Immune System (IS) for practical application. Research builds immune based control model for pendulum with nonlinear characteristic and compare its characteristics with GA. IS always has a new parallel decentralized processing mechanism for various situations by using the antibody communication function. Antibody has huge communication system function among different species of antibodies B-cells through the stimulation and suppression chains among antibodies that form a large-scaled network. In addition to that, the structure of the network is not fixed, but varies continuously. That is, IS has a flexibly self-organizes according to dynamic changes of external situation. From the above facts, this paper studies performance of controller of IS and compare its control function with GA.

Keywords: Genetic algorithm · Immune algorithm · AI · Nonlinear · Pendulum control

1 Introduction

Recently, IS has been influencing on everywhere such as agriculture, design, literature, drawing, art, management, and etc. as well as high technologies of manufacturing, smart city, power system, semiconductor, robot, drone, and medical. The turning point of AI was play go by Alphago of Google of 2016. From that time, many countries and global companies have been recognizing the importance of AI and investing. The AI in the site has been developing into an emerging technology, so-called 'Industrial intelligent system'. Basic theory of Alphago is deep learning and it is organized from neural network that is getting and dealing with well information. Also, many researchers are interesting in developing AI tool and deep learning is one of strong AI tool. A combined learning-based artificial intelligence (Hybrid AI) NN (neural network), GA (genetic algorithm), and AIS (immune network system) have been interested in studying much attention using their advantage [1–3]. AI related technologies or application are highly multi-disciplinary systems, which is composed of operations research, artificial intelligence,

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information and signal processing, computer software and production background [1–3]. Each theory such as fuzzy, neural, and neuro-fuzzy has been offering new possibilities and making intelligent system even more versatile and applicable in an ever-increasing range of industrial applications. Over the past decade or so, significant advances have been made in two distinct technological area: fuzzy logic (FL) and neural networks (NNs) [1, 8, 16, 18]. Of course, there have been considerable interests for the past few years in exploring the application of fuzzy or neural network (FNN) systems to deal with uncertain information, nonlinearities, and uncertainties of systems. On the other hand, biological information processing systems such as human beings have many interesting functions and are expected to provide various feasible ideas to engineering fields such as intelligent control, robotics, power system, etc. Biological information in living organisms can be mainly classified into the following four systems: brain nervous, genetic system, endocrine system, and immune system.

Brain nervous and genetic systems have already been applied to engineering fields by modeling as neural network and genetic algorithms, they have been widely used in various fields. The aim of immune network system (IS) is to implement a learning technique inspired by the human immune system which is a remarkable natural defense mechanism that learns about foreign substances. However, the immune system has not attracted the same kind of interest from the computing field as the neural operation of the brain or the evolutionary forces used in learning classifier systems [8, 22]. This paper provides the characteristics of AINS as AI tool through comparing GA (Genetic Algorithm) and IS in nonlinear system.

2 The Characteristics of IS as AI Tool

A study of the models that have been performed for various computational aspects of the immune system and their applications to real world problems are available in [12, 15, 19, 20]. There are many intelligent approaches for their purpose as shown in Table 1. The AIN has many merits for engineering and herein it has been attracting for control, computer and network security.

The learning characteristic of the immune system is a distributed function with no central controller, since it has behavior which is consisted of an enormous number and diversity of cells throughout our bodies.

2.1 The Characteristics of Information Processing of IS

IS application implements a learning technique inspired by the human immune system, which is a remarkable natural defense mechanism that learns about foreign substances. Its main function is the clonal selection. That is, biological information processing systems such as human beings and natural systems have many advantages and function for AI tool. Therefore, many have been interesting in functions and expecting to provide various feasible ideas to engineering fields [2, 4–6, 11, 19, 20]. Biological information in living organisms can be classified into the following four systems: brain nervous, genetic system, endocrine system, and immune system [6, 9, 10]. Brain nervous and genetic systems have already been applied to many engineering fields [7–9]. Table 1 is the results of comparison to each AI tools.

Table 1. Comparison of characteristics of AI tools [16–22].

Purpose of intelligence ○: Best ●: Good								
Control	Diagnosis	Pattern Recognition	Control	Plan	Decision	Design	Identify	Focast
Fuzzy	●	●	○	○	○		○	●
NN	●	○	●				○	○
GA	●			○	○	○		
Chaos	○	●	●				○	○
Classical Control			●	●		○		●

However, only a little attention has been paid to application of immune algorithm in engineering, not to mention their important characteristics. The AIS uses a learning technique inspired by the human immune system which is a remarkable natural defense mechanism that learns about foreign substances as shown in Fig. 1. Therefore, currently, there are many the characteristics of the immune system [1, 3, 5, 12, 19, 20] and summarized;

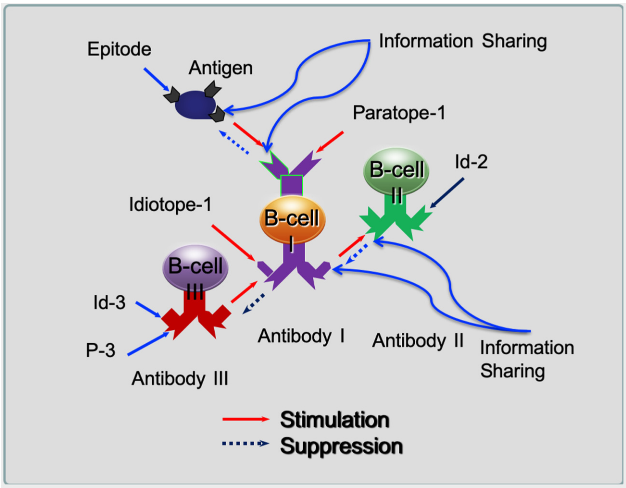

Fig. 1. The role antibody and antigen in IS.

The learning rule of the immune system is a distributed system with no central controller, since the immune system consists of an enormous number and diversity of cells throughout our bodies; The immune system has a naturally occurring event-response system which can quickly adapt to changing situations and shares the property with the central nervous system; The immune system possesses a self-organizing and distributed memory. Therefore, it is thus adaptive to its external environment and allows a PDP (parallel distributed processing) network to complete patterns against the environmental situation. Immune system has various interesting features such as immunological memory, immunological tolerance since it can play an important role to maintain own system dynamically changing environments. Therefore, immune system would be expected to provide a new paradigm suitable for dynamic problem dealing with unknown environments their rather than static system. Brooks, a pioneer of the approaches, has presented architecture for behavior arbitration of autonomous robots [15]. He has argued that intelligence should emerge from mutual interactions among competence modules, and interactions between a robot and its environment. Some researchers particularly focused on the new decentralized consensus-making system [2, 3, 5, 10] because facts that IS can maintain its own system against dynamically changing environments.

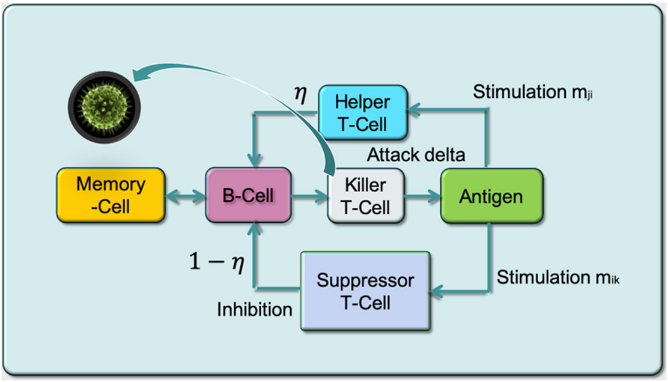

Fig. 2. Dynamic the role of antibody and antigen in IS.

2.2 The Response Mechanism in IS

The IS has two types of response: primary and secondary. The primary response is reaction process when the clonal selection system encounters the antigen for the first time. At this point the AIS learns about the antigen, thus preparing the body for any further invasion from that antigen. This learning mechanism creates the immune system's memory. The secondary response occurs when the same antigen encountered again. This has response characterized by a more rapid and more abundant production of antibody resulting from the priming of the B-cells in the primary response [9, 10]. Life of the memory B-cells has a long term they work continuously to the external agents [16, 20].

2.3 The Role of Antibodies

The antibodies of IS has actually three-dimensional Y shaped molecules, which consist of two types of protein chain: light and heavy. It has two paratopes to match the antigen [9, 10].

2.4 Interactions Between Antibodies

The antigen antibody interaction is similar to that of enzyme substrate interaction. The reaction between an antigen and antibody is noncovalent type, where the antigenic determinants or epitodes interact with domain of the antibody molecule. The noncovalent interaction between antigen and antibody is brought about by hydrogen bonds, vander Waals interactions, ionic bonds and hydrophobic interactions. Therefore, a strong affinity interaction should occur between antigen and antibody to form a stable complex. The interaction among antibodies is important to understand dynamic characteristics of clonal selection system. Figure 1 shows behavior the three antibodies (I, II, III) that respond to the antigens (Virus), respectively. When the antigens come in, it stimulates the antibodies. When the antigens do not come in (no interaction between antibody (II) and antibody (III)), the antibodies have the same concentrations. The interaction among the antibody has behavior by the principle of a priority adjustment mechanism. Antibody has killer and helper cell for this activity as shown in Fig. 2. By using these cells antibody can promptly attack antigen.

2.5 Dynamics of IS

Figure 1 shows the level of each cell in antibody is defined by the interaction between antibodies stimulation. The matching level between the antibody and the antigen decides. Therefore, the concentration of i-*th* antibody, which is denoted by δ_i, is calculated as follows [1, 9, 10, 15]:

$$\frac{dS_i(t)}{dt} = \begin{pmatrix} \alpha \sum_{j=1}^{N} m_{ji}\delta_j(t) \\ -\alpha \sum_{k=1}^{N} m_{ik}\delta_k(t) + \beta m_i - \gamma_i \end{pmatrix} \delta_i(t) \tag{1}$$

$$\frac{d\delta_i(t)}{dt} = \frac{1}{1 + \exp\left(0.5 - \frac{dS_i(t)}{dt}\right)} \tag{2}$$

From Eqs. (1) and (2), N shows the number of antibodies and positive constants. m_{ji} represents affinities between antibody j and antibody i (i.e. the degree of interaction), m_i is affinities between the detected antigens and antibody i, respectively. Figure 2 shows the dynamic relation operated by antibodies and antigen.

2.6 Selection Mechanism

Selection mechanism is to calculate affinity between antibodies among several antibody groups and antigen. Therefore, there are two methods in mechanism: One thing is to compute between antibody and antibody; another thing is to calculate between antibody and antigen. Response of IS is quite different depends on these selection mechanisms and its mechanism is decided by designer's idea. That is, there can be several possibilities in selection mechanism. Here this paper uses selection method obtained in lymphocyte population [4–6, 13]:

$$\Omega_j(N) = \sum_{i=1}^{S} -x_{ij} \log x_{ij} \tag{3}$$

Here, N is the antibody size, S is the allete variety, and x_{ij} has the probability. Therefore, the means of information $\Omega_{ave}(N)$ is obtained as the following equation [5, 6, 13]:

$$\begin{aligned} \Omega_{ave}(N) &= \frac{1}{M} \sum_{j=1}^{M} \Omega_j(N) \\ &= \frac{1}{M} \sum_{j=1}^{M} \left\{ \sum_{i=1}^{S} -x_{ij} \log x_{ij} \right\}. \end{aligned} \tag{4}$$

where M is the size of the gene in an antibody.

The affinity $m_{\alpha\beta}$ between antibody α and antibody β is given as follows:

$$m_{\alpha\beta} = \frac{1}{\{1 + \Omega(\alpha\beta)\}} \tag{5}$$

$$\Omega(\alpha\beta) = H_s(x) = \left[f_1(x) + f_2(x) + f_3(x) \right].$$

where $\Omega(\alpha\beta)$ is an information which obtained by antibody α and antibody β. If $\Omega(\alpha\beta) = 0$, the antibody α and antibody β match completely. Generally, $m_{\alpha\beta}$ is given by range of 0–1. In this paper, we propose controller that can control by intelligent controller by using immune algorithm and by using membership function for antibody concentration and affinity to antigen. This paper suggests a novel controller structure which has a characteristic mentioned above.

3 Simulation and Results

This paper built a model to obtain the characteristics of IS and compare with GA. The comparison of GA and AINS is obtained from structure that is composed by Simulink and pendulum, which is so much nonlinear function, as shown in Fig. 3. Figures 4 shows model of pendulum (mass, 2 kg and pendulum length, 2 m), which is given state equation and car moves from set point to current position while experiment (simulation).

Figure 5 illustrates variation of objective function to GA (Genetic) and IM (Immune), Fig. 6 represents angle variation of pendulum position to concentration of antibody.

It means when we adjust the concentration of antibody, we can obtain response that we are going to apply to plant control. Usually, antibody concentration is quite delicate and can adjust easily because of chemical area. Figure 7 is variation of controller gain K_i. The fluctuation of AINS is bigger than that of GA. It means IS tries to adjust parameter to plant variation. Figure 8 is variation of controller gain k_p. It has also bigger

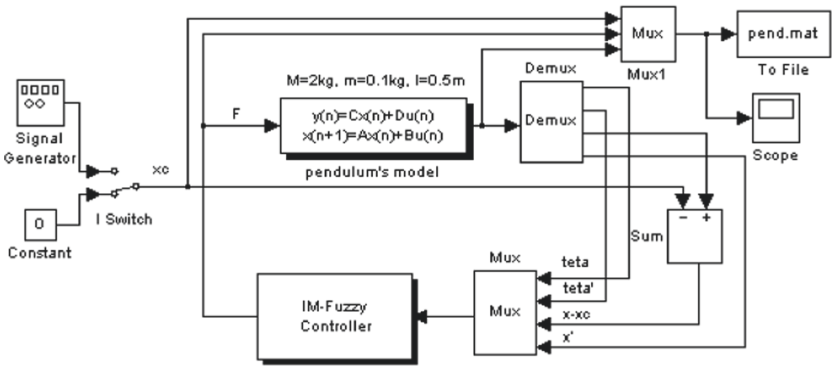

Fig. 3. Simulink model for IS.

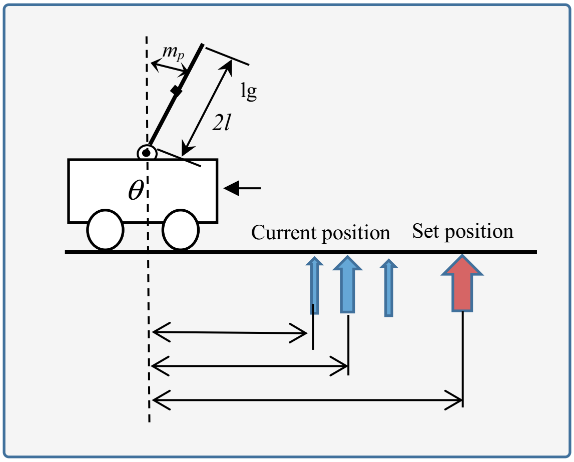

Fig. 4. Nonlinear Pendulum system for control performance of IS.

fluctuation that that of GA. From these two Fig., we can see IS has a dynamically changing behavior to find target value. Figure 9 shows variation of position (θ, θ') by IS. Figure 10 is variation of position to concentration of IS. Figure 10 reveals that we can obtain response through adjusting concentration. To express effectively the characteristics of IS, this paper compares its characteristics on the control performances with GA as shown from Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14, Fig. 15 and Fig. 16.

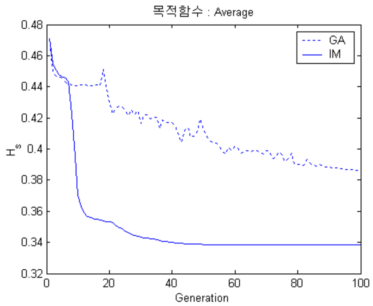

Fig. 5. Variation of objective function.

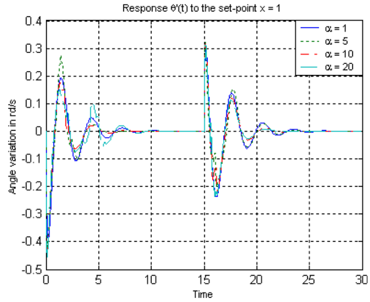

Fig. 6. Angle variation of pendulum to concentration of antibody.

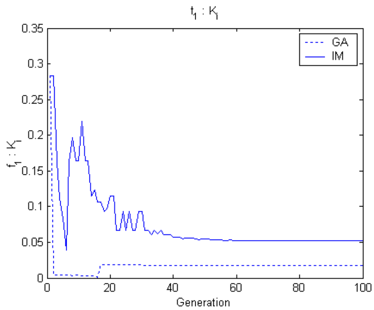

Fig. 7. Variation of controller gain k_i by GA and IM.

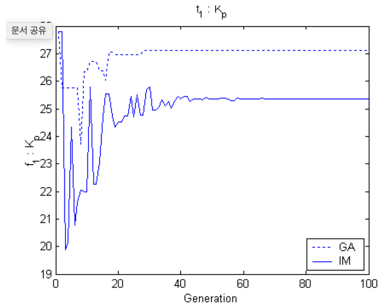

Fig. 8. Variation of controller gain k_p by GA and IM.

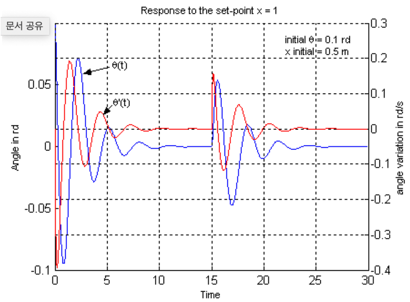

Fig. 9. Variation of position (θ, $\theta\prime$) by GA and IM.

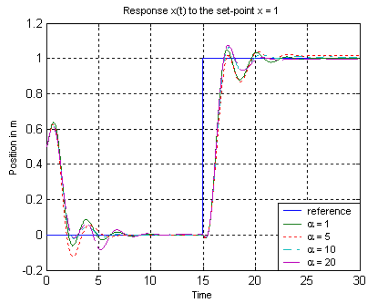

Fig. 10. Variation of position to concentration.

Figures 11 and 12 shows the variation of parameter K_p and K_i. From these two Fig, we can see that IS has a good searching function to new situation. It reveals the characteristics of AINS, which has search and attack external substrate (antigen: bacteria). Figure 13 illustrates variation of fitness function in GA and IS. Figure 14 shows control results by GA and IS selected parameter value after simulation. Figure 15 and Fig. 16 represent variation of parameter K_p, T_i, T_d by GA and IS, respectively. In case of T_i, T_d, the

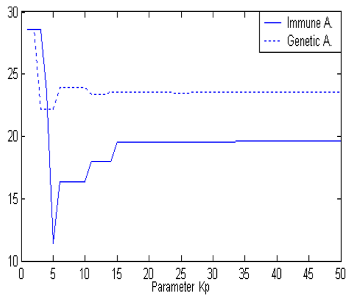

Fig. 11. Variation of parameter K_p.

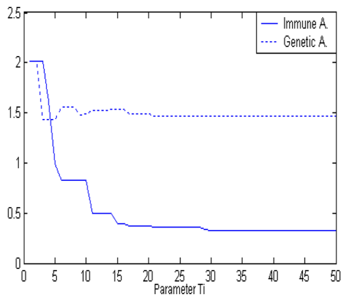

Fig. 12. Variation of parameter K_i.

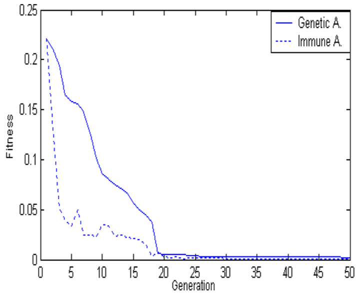

Fig. 13. Variation of fitness function.

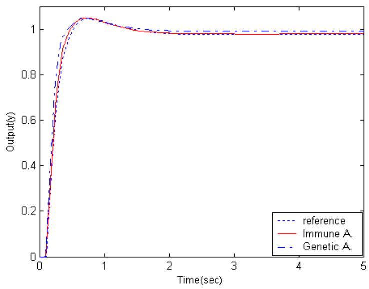

Fig. 14. Response by selected control parameter.

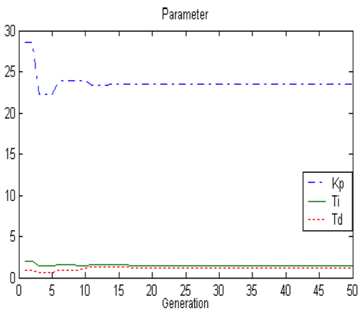

Fig. 15. Variation of parameter by GA.

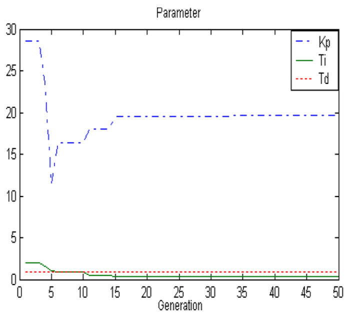

Fig. 16. Variation of parameter by IM.

value is very similar but K_p has a different shape. That is very important remaining topic to research in the future. In Fig. 16, variation of K_p has very wide width. It means that AINS has a dynamically searching function to new target. It is very similar to the results of Fig. 11 and 12. Figure 17 shows variation of angle and position pendulum to concentration of antibody 50. After 15 s, all system is stable position. Figure 18 is variation of angle and position pendulum to concentration of antibody 100. It means the concentration of antibody is too strong. So, we should adjust slowly and weaker to control system at this stage. Figure 19 represents variation of fitness to lamda, which

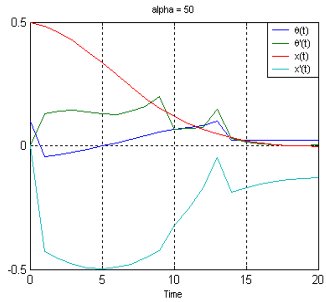

Fig. 17. Variation of angle and position to concentration 50.

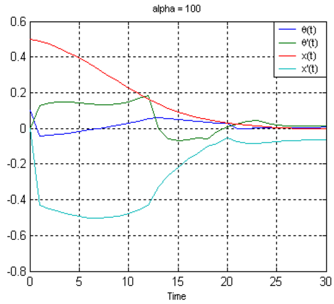

Fig. 18. Variation of angle and position to concentration 100.

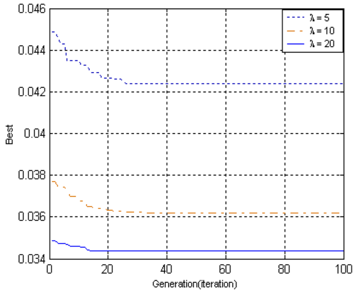

Fig. 19. Variation of fitness to lamda.

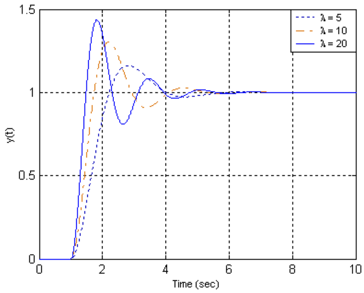

Fig. 20. Response to selected lamda.

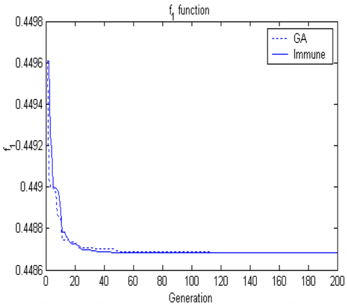

Fig. 21. Response to f_1.

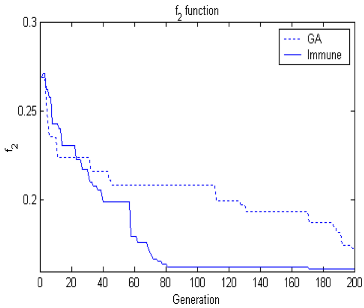

Fig. 22. Response to f_2.

is concentration between antibody and antigen. Figure 20 is response by using lamda selected in Fig. 19. The response of control system is different depends on value of lamda. Figure 21, Fig. 22, and Fig. 23 is variation to generation given by selection mechanism Eq. (5) the above.

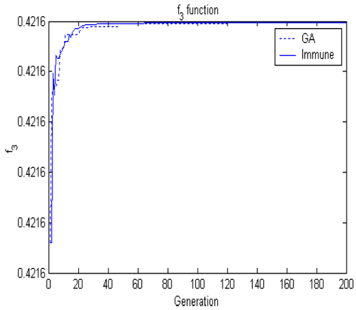

Fig. 23. Response to f_3.

4 Conclusion and Future Works

This paper deals with the characteristics of the control performance of IS through comparing with GA. Basically, both neural networks and immunity-based systems are biologically inspired techniques that have the capability of identifying patterns of interest. They use learning, memory, and associative retrieval to solve recognition and classification tasks. But the underlying mechanisms of recognition and learning are very different. However, the immune system provides diversification instead of converging to local or global optimization. The immune system possesses self-organizing memory and it remembers its categorizations over long periods of time [7, 8, 13, 14]. The IS is best artificial tool for artificial intelligence because it has many advantages such as no leader processing, distribution function, and networking function between antibodies in information processing. Some papers studied that genetic algorithms (GAs) are only an efficient and robust tool for generating AI tools and optimization function. The IS studied in this paper also has many advantages due to the optimal behavior, information sharing networking function, PDP computing processing, and memory function. These can also have a possibility to be used for many cases of nonlinear system as well as security, control, and application for other AI. The results of this research reveal well the characteristics of IS. Unfortunately, due to the limited time, all detailed results do not present in this paper. If there is a chance, authors will publish soon.

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