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Optimization design of fuzzy controller based on improved genetic algorithm

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ABSTRACT

A systemic research about the basic theory and implement technique of the simple genetic algorithm is made in this paper. An index which scales the population diversity is defined, and this index is imported into the genetic operator. For the selection process, it can be more excellent individual and increase the population diversity. In addition, this paper also uses population diversity index to instruct the crossover probability and mutation probability. Finally, the proposed method is applied to a typical room temperature control problem and the result shows that fuzzy controller has better performance than controller based on traditional genetic algorithm and PID controller.

KEYWORDS

Optimization design; Fuzzy controller; Genetic algorithm; Population diversity.

INTRODUCTION

The genetic algorithm (GA) is a kind of overall search algorithm, it can be used as an efficient stochastic optimization tools to analog nature[1,2]. It is not necessary to know the internal mechanism, just only driven by the fitness function and also easy to combine with other technologies[3]. So it is usually applied in optimal control of the parameters, structure or the environment in the intelligent control system. However, there are some shortages in the simple genetic algorithm[4,5], for example, the probability of premature convergence caused by its lower search efficiency. Considering the disadvantages of simple genetic algorithm, it is of great importance to be improved on GA, subsequently many improved methods are proposed[6-10].

Fuzzy Control is an important branch of Intelligent Control, and it mainly depends on the human experiences but not the mathematical model of controlled-object[11,12]. Thus, Fuzzy controller can fulfill some human's intelligence and is widely used in complex process and object-model control. So, the proper selection of fuzzy logic rules and fuzzy control membership functions, which determines the dynamic and static performance and control effect, are the key to design a fuzzy controller[13-15]. But the conventional fuzzy controller design is often based on expert or the vague semantic knowledge or statistical data provided by the actual operators, and then determine the basic fuzzy control rules and membership functions, so there exists subjectivity and randomness. GA is normally used to optimize fuzzy controller parameters, but most of the research, or using GA in previous has mostly focused on optimizing the fuzzy control rules or membership functions on the one hand, artificially cut off the contact between them, or complete to optimize the fuzzy control rules and membership functions simultaneously but with no good coding schemes and effective genetic operator, the result is not too satisfactory[16-20]. In order to solve the above problems, this paper proposed a fuzzy system design method that uses an improved genetic algorithm based on real coding to optimize membership functions and the fuzzy control rules simultaneously at the same time.

In the next section, we introduce principle of genetic algorithm. In Section 3 we introduce genetic operation based on population diversity, adaptive crossover and mutation and give the improved genetic algorithm. In Section 4, we do empirical research based on improved genetic algorithm. In Section 5 we conclude the paper and give some remarks.

PRINCIPLE OF GENETIC ALGORITHM

Individual encoding of generic algorithm is $X=[x_1,x_2,x_3,x_4,x_5,x_6]^T$ and the process of Generic Algorithm is as follows.

Step1.Random initialization of the population. $P(0)=\{X(1),X(2),\ldots,X(N)\}$, N is the number of population and d is the corresponding generation of the population.

Step2.Calculate fitness $f(X(g))$ of $P(d)$ and using the select operator produces parent groups $P_r(d)$.

Step3.Child group $P(d+1)$ is produced after crossover and mutation. In adaptive generic algorithm, crossover probability and mutation probability is shown in formula 1 and formula 2.

$$P_c=\begin{cases} P_{c1}-\dfrac{(P_{c1}-P_{c2})(f_m-f_a)}{f_{\max}-f_a}, & f>f_a \\ P_{c1}, & f<f_a \end{cases} \quad (1)$$

$$P_m=\begin{cases} P_{m1}-\dfrac{(P_{m1}-P_{m2})(f_l-f_a)}{f_{\max}-f_a}, & f>f_a \\ P_{m1}, & f<f_a \end{cases} \quad (2)$$

f_a is average fitness of each population, $f_{\max}$ is the maximum fitness of the population, f_m is the bigger fitness of the two crossover individuals. f_l is the fitness value of crossover or mutation, and $P_{c1}, P_{c2}, P_{m1}, P_{m2}$ are chosen properly.

Step4. $d+1$, and judges whether meet the termination condition. If it does not meet the condition, turn to step 2 to continue.

AN IMPROVED GENETIC ALGORITHM

Genetic operation based on population diversity

The process of selection algorithm is as follows.

Step1. Calculate the fitness value of the initial population.

Step2. Choose m number of individuals using classical roulette method and m is an even number.

Step3. The selected individuals are ordered according to the size of the fitness value and it is labeled as $x_1^1, x_1^2, \cdots x_1^m$, where $x_1^i = \{x_1^{i(1)}, x_1^{i(2)}, \cdots, x_1^{i(n)}\}$, $i = 1, 2, \cdots, m$ and m is the size of population.

Step4. $m/2$ number of individuals with the highest fitness value are copied to the next generation to form the new population.

Step5. Firstly takes out x_1^1 with the highest fitness value and then produces k number of individuals randomly. Calculates f_i and $dist(x_1^1, x_1^j)$, $j = 1, 2, \cdots, k$. Then we obtain formula 3.

$$\max F(j) = f_j + dist(x_1^1, x_1^j) \quad \textbf{(3)}$$

j is the new chosen individual and the obtained new individual is $x_1^{1'}$. $dist(x_1^1, x_1^j)$ is calculated by formula 4.

$$dist(x_1^1, x_1^j) = \sqrt{\sum_{l=1}^{n} (x_1^{1(l)} - x_1^{j(l)})^2}\text{, } j = 1, 2, \cdots, k \quad \textbf{(4)}$$

Step6. Take out x_1^2 with the second highest fitness value. Do as it is shown in step 5 and produce k number of individuals randomly. Calculate $\max F(j)$ according to formula 5 and the obtained new individual is $x_1^{2'}$.

$$\max F(j) = f_j + dist(x_1^2, x_1^j) \quad \textbf{(5)}$$

Step7. At last, we obtain the new population $x_1^1, x_1^2, \cdots, x_1^{\frac{m}{2}}, x_1^{1'}, x_1^{2'}, \cdots, x_1^{\frac{m}{2}'}$ with m number of new individuals and the next stage is crossover and mutation.

Adaptive crossover and mutation

We use population diversity index ϕ to guide the dynamic change of p_c and p_m. The improved crossover probability and mutation probability is shown in formula 6 and formula 7. ϕ is calculated by formula 8, where V_t is calculated by formula 9. $dist(x_p^i, \overline{x_p})$ represents the distance between individual x_p^i of the p-th population and average individual of the p-th population, which is calculated by formula

10. Average individual of the p-th population is $\overline{x_p} = \{\overline{x_p^{(1)}}, \overline{x_p^{(2)}}, \cdots, \overline{x_p^{(n)}}\}$. $\overline{x_p^{(l)}}$ is calculated by formula 11. Individual x_p^i of the p-th population is composed of n number of genes $x_p^i = \{x_p^{i(1)}, x_p^{i(2)}, \cdots, x_p^{i(n)}\}$, $i = 1, 2, \cdots, m$ and m is the size of the p-th population.

$$P_c = \begin{cases} P_{c1} - \frac{(P_{c1} - P_{c2})(f' - f_a)}{f_{\max} - f_a} \cdot \frac{1}{1 + \exp(-k_c \cdot \phi)}, & f' > f_a \\ P_{c1}, & f' < f_a \end{cases} \quad (6)$$

$$P_m = \begin{cases} P_{m1} - \frac{(P_{m1} - P_{m2})(f - f_a)}{f_{\max} - f_a} \cdot \frac{1}{1 + \exp(-k_m \cdot \phi)}, & f > f_a \\ P_{m1}, & f < f_a \end{cases} \quad (7)$$

$$\phi = \frac{V_t}{V_{\max}} \quad (8)$$

$$V_t = \frac{1}{m} \sum_{i=1}^{m} dist(x_p^i, \overline{x_p}) \quad (9)$$

$$dist(x_p^i, \overline{x_p}) = \sqrt{\sum_{j=1}^{n} (x_p^{i(j)} - \overline{x_p^{(j)}})^2} \quad (10)$$

$$\overline{x_p^{(l)}} = \frac{1}{m} \sum_{i=1}^{m} x_p^{i(l)} \quad (11)$$

The improved genetic algorithm

Step1. Population initialization and determine control parameter.

Step2.The individuals are ordered according to the size of fitness value of individual in current population.

Step3. Define population diversity index ϕ and obtain the new population according to the process of 2.2.1.

Step4.Do the crossover operation according to formula 6. Crossover probability changes adaptively with the fitness value and population diversity index ϕ.

Step5. Do the mutation operation according to formula 7. Mutation probability changes adaptively with the fitness value and population diversity index ϕ.

Step6. Determine whether it meets the demands of maximum iteration times and at the same time the optimal individual fitness value is obtained. Otherwise turn to step 2 to continue.

FUZZY CONTROLLER BASED ON IMPROVED GENETIC ALGORITHM

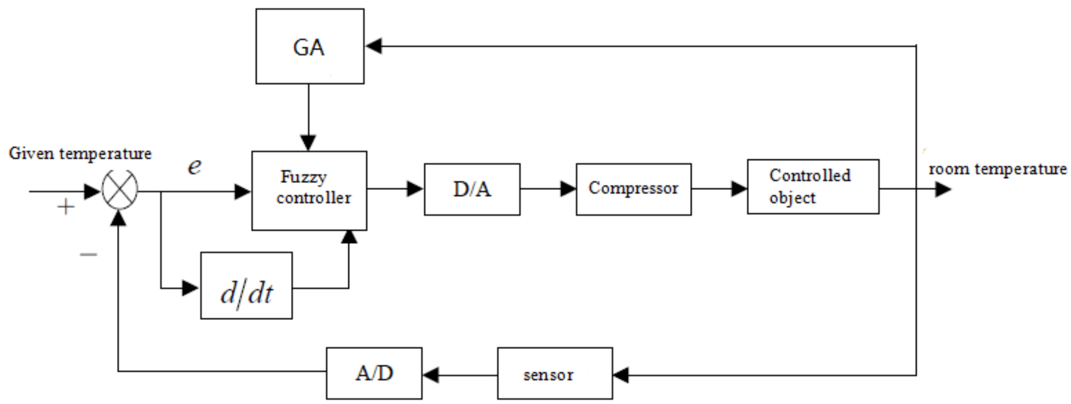

Figure 1 : The structure diagram of temperature control system

The structure diagram of temperature control system is shown in Figure 1. The two input variables are given temperature e and error change ec, and the output variable is control variable u. Fuzzy domains of the two input variables are $[-6,6]$, and fuzzy domains of the output variable is $[0,12]$. Word set used to describe the three fuzzy variables are $\{NB, NM, NS, ZE, PS, PM, PB\}$. This article uses the isosceles triangle membership function as the research object, then vertex coordinate and the bottom width need to be determined. Assuming that the vertex coordinate is invariant, so that only half of triangle bottom width (L) is a parameter to be optimized. Typical membership function, typical membership function of e and ec, and typical membership function of u are respectively shown in Figure 2, Figure 3 and Figure 4.

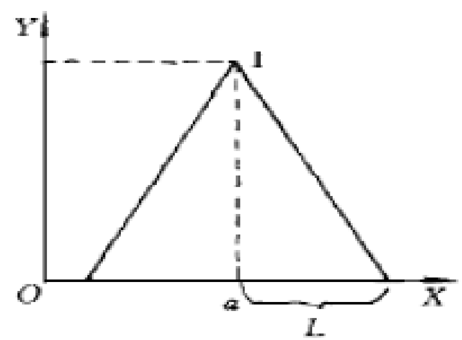

Figure 2 : Typical membership function

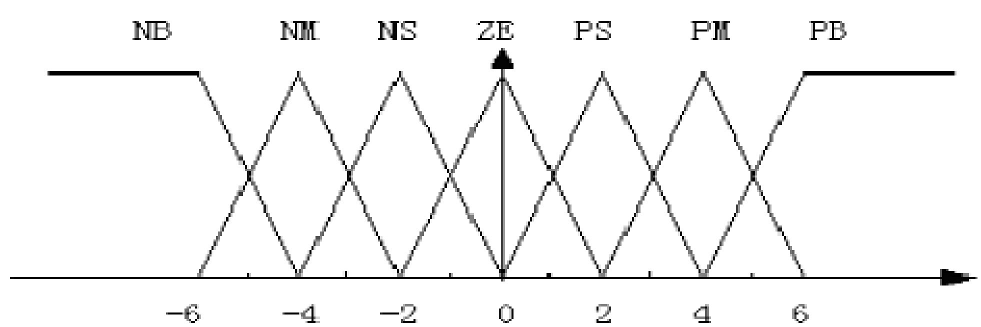

Figure 3 : Membership function of e and ec

For fuzzy control rule, we adopt real number encoding to constitute a complete chromosome combined with membership function. NB, NM, NS, ZE, PS, PM, and PB are represented with 1, 2, 3, 4, 5, 6, and 7. Fuzzy rule form expressed by language variable value is shown in TABLE 1 and fuzzy rule form expressed by numerical is shown in TABLE 2. Diagram of chromosome coding is shown in figure 5.

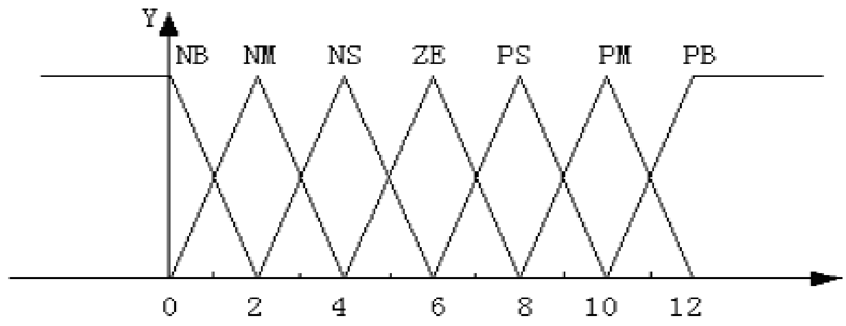

Figure 4 : Membership function of u

TABLE 1 : Fuzzy rule form expressed by language variable value

u		*ec*						
		NB	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***
	NB	*PB*	*PB*	*PM*	*PM*	*PS*	*PS*	*ZE*
	NM	*PB*	*PM*	*PM*	*PS*	*PS*	*ZE*	*NS*
	NS	*PM*	*PM*	*PS*	*PS*	*ZE*	*NS*	*NS*
e	*ZE*	*PM*	*PS*	*PS*	*ZE*	*NS*	*NS*	*NM*
	PS	*PS*	*PS*	*ZE*	*NS*	*NS*	*NM*	*NM*
	PM	*PS*	*ZE*	*NS*	*NS*	*NM*	*NM*	*NB*
	PB	*ZE*	*NS*	*NS*	*NM*	*NM*	*NB*	*NB*

TABLE 2 : Fuzzy rule form expressed by numerical

u		*ec*						
		NB	***NM***	***NS***	***ZE***	***PS***	***PM***	***PB***
	NB	7	7	6	6	5	5	4
	NM	7	6	6	5	5	4	3
	NS	6	6	5	5	4	3	3
e	*ZE*	6	5	5	4	3	2	2
	PS	5	5	4	3	3	2	2
	PM	5	4	3	3	2	2	1
	PB	4	3	3	2	2	1	1

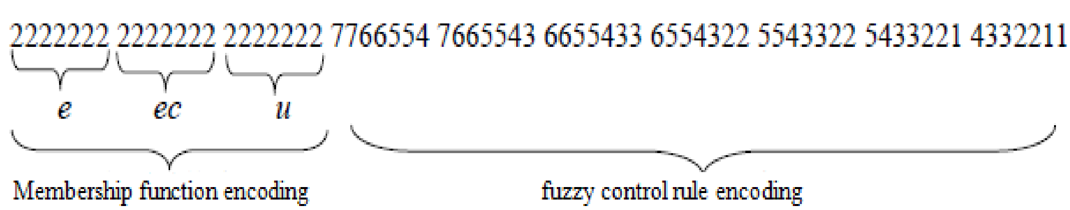

Figure 5 : Diagram of chromosome coding

The fitness function is determined according to formula 12. In order to be implemented conveniently by computer, formula 13 is established.

$$f(t)=\frac{1}{1+CJ(t)}\cdot 10^4 \quad \textbf{(12)}$$

$$\Delta J = J(t+\Delta T)-J(t)=\int_0^{t+\Delta T}\tau\,|\,e(\tau)\,|\,d\tau-\int_0^{t}\tau\,|\,e(\tau)\,|\,d\tau \quad \textbf{(13)}$$

Selection operation is done according to the process of chapter 2. Then it turns to the stage of crossover and mutation. The random cross point is c, and parent individuals taking part in crossover are $x_t^1=\{x_t^{1(1)},x_t^{1(2)},\cdots x_t^{1(c)},\cdots,x_t^{1(n)}\}$, $x_t^2=\{x_t^{2(1)},x_t^{2(2)},\cdots x_t^{2(c)},\cdots,x_t^{2(n)}\}$. Calculate the new gene at cross point, and $x_t^{1(c)'}=\alpha x_t^{1(c)}+(1-\alpha)x_t^{2(c)}$, $x_t^{2(c)'}=\alpha x_t^{2(c)}+(1-\alpha)x_t^{1(c)}$ are obtained where $\alpha=m\cdot\lambda^{\phi^\beta}$. The left 49 bit codes are rounded using $round()$ function through formula 14.

$$x_t^{1(j)'}=round[\alpha x_t^{1(j)}+(1-\alpha)x_t^{2(j)}]$$
$$x_t^{2(j)'}=round[\alpha x_t^{2(j)}+(1-\alpha)x_t^{1(j)}],\ j\in[21,70] \quad \textbf{(14)}$$

Supposing $x=\{x_1,x_2,\cdots x_k,\cdots,x_n\}$ is parent population and the mutation result is $x^{'}=\{x_1,x_2,\cdots x_k^{'},\cdots,x_n\}$. The forward 21 bits carry out mutation operation according to formula 15.

$$x_k^{'}=\begin{cases}x_k+\Delta(\phi,y) & random(0,1)=0\\ x_k-\Delta(\phi,y) & random(0,1)=1\end{cases} \quad \textbf{(15)}$$

$\Delta(\phi,y)=y\cdot(1-r^{\phi b})$ and b is 2 usually, r is a random number belonging to $(0,1)$. The left 49 bits carry out mutation operation when $|\,x_k-x_k^{'}\,|<2$, otherwise mutation does not occurs. In addition, mutation operator need to be coped with using formula 16 so that the result is integer ranging form 1 to 7, where $D=round(D_{\max}\cdot\phi^b)$, $D_{\max}=7$, b belongs to 2~5, and $rnd(D)$ is the result of integer number after modulus operation. The size of population is $m=100$. $k_c=2.0, p_{c1}=0.9, p_{c2}=0.6$.

$$x_k^{'}=[x_k+rnd(D)]\%7 \quad \textbf{(16)}$$

$k_m=2.0, p_{m1}=0.1, p_{m2}=0.001$, $T=60$. The population constraints of genetic algorithm are as follows.

If eε NB and ecε NB then u ε PB

If eεZE and ecεZE then uεZE

If eε PB and ecε PB then u ε NB

Room temperature control model can approximate to a second-order system with pure delay link, and mathematical model is $G(s)=\frac{K}{(1+TS)}e^{-\tau s}$, where $T=470s$ is inertia time constant and $\tau=20s$ is pure delay time constant. $K=12$ is gain coefficient, $T_0=10s$, and $N=100$. Performance comparison for temperature control system using three methods is shown in TABLE 3. The result shows that our improved method has better performance than the other two methods.

TABLE 3 : Performance comparison for temperature control system

Controller type	Overshoot amount	Adjustment time	System error
PID	18.15	1750	13.05
Fuzzy	15.27	1001	10.29
GA+fuzzy	0.19	499	9.57

CONCLUSIONS

This paper proposes a fuzzy system design method that uses an improved genetic algorithm based on real coding to optimize membership functions and the fuzzy control rules simultaneously at the same time. Finally, the proposed method is applied to a typical industry object and the room temperature control problem and has been shown to be more effective through a comparison with normal fuzzy controller and PID controller. The result of the simulation illustrates that it has good overshoot time, adjustment time and system error.

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