PID Parameters Online Setting Based on Elite Genetic Algorithm

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***Abstract* — For online tuning of PID controller parameters the Standard Genetic Algorithm (SGA) suffers from slow convergence, while the Adaptive Genetic Algorithm (AGA) has high individual fitness but can easily be de-tuned, which lead us to propose the Elite Genetic Algorithm (EGA). EGA has uniform binary encoding scheme and inherits the elite policy from parents, and the two-way crossover and adaptive mutation means to ensure the diversity of the population in the evolutionary process. But to retain the elite status in each step of the algorithm, after the completion of each iteration, it attempts to acquire the best of individual genes and reduce redundant calculations, thereby improving the efficiency of the algorithm. By PID parameter tuning and control system simulation, our results show that EGA in convergence speed and control accuracy is significantly better than the SGA and AGA.**

Keywords - Binary Uniform Coding; Elitist; Two-way Cross; Climbing Policy

I. INTRODUCTION

In classical control theory based on the transfer function in the frequency domain of single-input single-output system analysis and design, of which the most successful PID control. Currently, industrial process control, there are still more than 80% of the systems in use PID controllers. PID tuning parameters directly affect the control effect is good or bad, because of the different application environments, the PID parameters have different requirements, which the PID control put forward higher requirements for online tuning parameters. The GA has nothing to do with the characteristics of the problem in the process of optimization parameters, therefore, use a genetic algorithm to achieve PID controller parameter tuning online has become a hot topic [1,2]. Traditional genetic algorithm global search capability, parallel search, but its slow convergence, multiple iterations, there is a high degree of individual adaptation destroyed hidden in the optimization process. Therefore, this article will issue for the online PID tuning parameters to elite-oriented strategy, the traditional genetic algorithm improvements.

II. PID CONTROLLER AND ITS PARAMETER TUNING METHOD

PID controller. PID controller includes a proportional gain, integral and differential three links, link proportionally reflect the proportional gain deviation control system, integral part of the system used to eliminate static error, the role of differential part of the change is to change the speed deviation, speed up system response.

Typical PID controller control law can be expressed as:

$$u(t) = K_P(e(t) + \frac{1}{T_I}\int_0^t e(t)dt + T_D\frac{de(t)}{dt}) \quad (1)$$

In $u(t)$ of the formula (1) control amount, K_P is the proportional gain, T_I is the integral time constant, T_D is the differential time constant, $e(t)$ is the error signal (given input value and the output value of the difference).

The formula (1) discrete, set the sampling time T_S, k is the sampling frequency, mathematical expressions can be obtained positional PID controller [3]:

$$u(k) = K_P e(k) + K_I\sum_{i=0}^{k} e(i) + K_D[e(k) - e(k-1)] \quad (2)$$

Formula (2). K_I , K_P , K_D respectively, said proportional coefficient, integral coefficient and differential coefficient.

Position control PID control is as follows: First, the parameters K_I, K_P, K_D initialized to T_S is the sampling interval taken into the given input and output, and then calculate the deviation signal e (t), so that $e(t)$ and K_I, K_P , K_D decided by formula (2) the output of the PID controller $u(t)$, followed by $u(t)$ controls the controlled object, controlled object output is again collected to calculate new PID controller output amount $u(t)$, so the cycle, according to the output feedback control system to adjust the output of the next, so that controller system output to input the set value.

PID parameters online setting. Online PID parameter tuning PID controller refers to the control object in the work

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process with the external environment, or other circumstances change constantly adjust PID parameters to achieve online real-time control of the controlled object purpose [4]. It requires two basic elements: the objective function and optimization algorithm.

The objective function is usually controlled quantitative description of system performance, reflected in:

(1) The system control accuracy: The system outputs the stable value and the expected (given input value) of the difference;

(2) The system response speed: the first time to reach steady-state output value;

(3) The stability of the system: the performance of overshoot and settling time.

PID parameter tuning goal is to find a good optimization algorithm to find the best K_I , K_P , K_D parameter combination, to obtain a high precision, fast response, good stability PID controller.

III. Genetic Algorithm and Its Improvement

Standard genetic algorithm. Standard genetic algorithm basic genetic algorithm based on elitist added, effectively avoiding the basic genetic algorithm crossover and mutation operation, damage to the high fitness individuals.

SGA evolutionary strategy [5]:

Step 1: given the population size is S, the maximum number of iterations is T, elite reservation number is m, cross probability Pc, mutation probability Pm, initial population.

Step 2: forming a parent population, so the number of iterations t = 0;

Step 3: decoding and calculating individual fitness, and fitness in descending order according to the individual, to retain outstanding individuals as the elite of m determines whether convergence conditions are met, if it satisfies stop counting the output, otherwise proceeds to step four.

Step 4: Using the ratio of individual choice selection;

Step 5: Using a fixed crossover and single-point crossover way crossover operation produce progeny;

Step 6: Using gene alleles way to generate new individual variability;

Step 7: forming a new population, according to their fitness in descending order, with just reserved for the elite m replaced by a new adaptation of the lowest population of m individuals;

Step 8: Let t = t +1, return to step two.

Adaptive Genetic Algorithm. And mutation probabilities SGA cross (both collectively referred to as genetic probability) is fixed, if the genetic probability is too large, then the algorithm will destroy a large number of individuals of high fitness, but the genetic probability is too small, it will reduce the individual's diversity, partial convergence. SGA for this feature, adaptive genetic algorithm emerged. AGA SGA on the basis of improvements have been made [6,7,8], step in the evolution of policy SGA five and six step approach using adaptive crossover and mutation probability is obtained, for example, can make the mutation probability Pm is:

$$Pm = 0.001 - [1:1:S] \times 0.001 / S \quad (3)$$

(3) in individuals with the mutation probability Pm individual fitness value decreases.

Improved Genetic Algorithm. SGA and AGA has been applied in many fields, there are shortcomings in the application as follows:

(1) The initial population is randomly generated, there may not even cover the entire search space, in the process of execution of the algorithm, the population gradually to adapt to a high degree of self-direction convergence may lead to the optimal solution where the search space cannot be searched to make the algorithm into a local optimum;

(2) It is not saved after a cross elite individuals mutate immediately destroy crossover produce high fitness INDIVIDUALS;

(3) With the convergence of the algorithm, there will be a lot of duplication of individual, one individual repeat too easy to make premature convergence algorithm, on the other hand will increase the number of redundant operations.

Based on the above analysis, this paper presents an improved genetic algorithm to SGA and AGA overcome various problems encountered in the application, because the improved algorithm will be used many times elitist strategy, so that the improved algorithm for the elite genetic algorithm.

For the first question, even binary coding scheme to obtain initial population, set code length is n, the population size is S, so that, even if the binary coding scheme in Table 1 can be used to represent the table 'd' represents a random number, in MATLAB with round (rand (S, a)) statement to achieve. A good parent population, will reduce the number of iterations of genetic algorithm, so fast convergence algorithm, based on this, the paper initial populations elite processed to obtain the parent population composed of individuals from elite, which would be performed separately for the initial population selection, crossover and mutation, ie after the end of each operation selected elite, elite and ultimately select S together constitute the parent population.

TABLE I. BINARY UNIFORM CODING SCHEME

n-1	**n-2**	. . .	**n-a**	**n-(a+1)**	**n-(a+2)**	**0**
0	0	. . .	0	0	d	d
0	0	. . .	0	1	d	d
0	0	. . .	1	0	d	d
. . .	. . .	. . .	. . .	. . .	. . .	. . .
1	1	. . .	1	1	d	d

For the second question, according to the order of individuals in the population, respectively, by way of a positive cycle and a reverse cycle operation on the implementation of cross-S individuals to give 2S individuals, then to sort, select Remove S from elite to form a new population , and then select the new population of m elitist. This improvement not only ensures the diversity of the population, but also to ensure the convergence of the population to the elite direction.

For the third question, the use of self-climbing strategy repeat mutate, that is, if b repeats individuals appear, leave one, and this variation in individuals, immediately after the fitness variation calculation, if the fitness of individuals larger than the original, the reservations, if less than the original individual's fitness, then give up, until a degree of adaptation b-1 greater than the original new individual or individuals reach the upper limit of variation in the number of c, c if the limit is reached only bd a new variation of the individual is out, the d tolerate population of duplicate individuals.

Based on the above analysis, we can summarize the EGA evolutionary strategy:

Step 1: use binary coding scheme produces a uniform size distribution of the initial population of S; Step 2: decoding and calculate the fitness value, the initial population of individuals in descending order according to fitness, individuals retain the former;

Step 3: decoding and calculate the fitness value, the initial population of individuals using single point crossover mode, make crossover probability Pc = 1 cross operation, after which the individual in descending order according to fitness, individuals retain the former;

Step 4: decoding and calculate the fitness value, the initial population of individuals with the mutation probability Pm = 1 gene alleles operation, after which the individual in descending order according to fitness, individuals retain the former;

Step 5: Step two, three, four individuals retained as the initial population size merged into S sets the maximum number of iterations is T, elite reservation number is m, cross probability Pc = 1, mutation probability Pm = 0.001-[1:1:S] 0.001/S;

Step 6: forming a parent population, so the number of iterations t = 0;

Step 7: decoding and calculating individual fitness, and fitness in descending order according to the individual, to retain the m outstanding individuals as elite, it is determined whether or not the convergence condition is satisfied, if it satisfies stop counting the output, otherwise proceeds to step eight.

Step 8: make the population of individuals with a positive cycle and a reverse cycle approach to the Pc = 1 separately cross to give 2S individuals, in descending order according to fitness, individuals retain the pre-S, S after removing individuals to form a new population;

Step 9: The new population in descending order according to their fitness, replaced with just reserved for the elite m new populations to adapt to the lowest degree m individuals to form a new population, and retain m elite for the new population;

Step 10: Using an adaptive manner Pm =.001-[1:1:S] * 0.001/S gene alleles operations to form a new population;

Step 11: on new population in descending order according to their fitness, replaced with just reserved for the elite m new populations to adapt to the lowest degree m individuals;

Step 12: a new strategy for dealing with the mountain populations duplicate individual;

Step 13: Let t = t + 1, return to Step Six.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

To verify the superiority and feasibility EGA, the paper respectively SGA, AGA and achieve a level control system EGA in PID parameter tuning and optimization.

Let the liquid level control system for the controlled object:

$$G(s) = \frac{500}{s^2 + 25s} \tag{4}$$

The principle of the level control system block diagram shown in Figure 1:

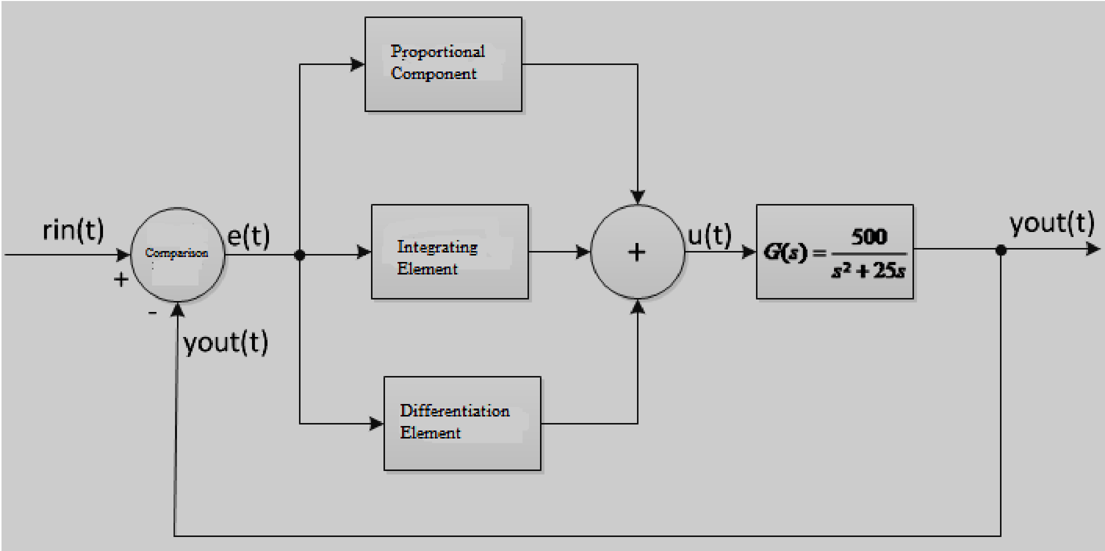

Figure 1. Block diagram of a level control system of FIG.

As shown, the input value is given step signal rin(t), the system output value yout(t), error signal e(t), the relationship between them can be expressed as:

$$e(t) = rin(t) - yout(t) \quad (5)$$

If $e(t) > 0$, it indicates that the system output has not increased to a given value, if $e(t) < 0$, it indicates that the system output overshoot phenomena occur.

To achieve the three-line tuning PID algorithm to select the target function as formula (6) (7):

$$J = \int_0^{\infty} (\lambda_1 |e(t)| + \lambda_2 u^2(t))dt + \lambda_3 t_u, \quad e(t) > 0 \quad (6)$$

$$J = \int_0^{\infty} (\lambda_1 |e(t)| + \lambda_2 u^2(t) + \lambda_4 |e(t)|)dt + \lambda_3 t_u, \quad e(t) > 0 \quad (7)$$

Wherein $\lambda_1 |e(t)|$ the time integral of the system can make a satisfactory dynamic characteristics, $\lambda_2 u^2(t)$ is to limit the size of the control amount for $\lambda_4 |e(t)|$ adjusting the overshoot, t_u indicating the rise time. Wherein, λ_1, λ_2, λ_3, λ_3 for the weights can be used depending on the corresponding adjustment of the controlled object, λ_3 the greater the shorter the response time resulting PID controller, λ_3 the greater the overshoot adjustment is faster, in order to take into account the PID controller overshoot adjustment, response time and other performance, the paper setting $\lambda_1 = 0.998$, $\lambda_2 = 0.001$, $\lambda_3 = 2.1$, $\lambda_4 = 90$ Genetic Algorithm iteration goal is to make the objective function value as small as possible. After determining the objective function, take the inverse of the objective function to obtain the desired genetic algorithm fitness function.

After the PID parameter tuning online with three algorithms and MATLAB PID controller Simulation experimental results obtained are shown in Figure 3, 4 and Table 2 below.

Figure 2 shows the experimental results of SGA, the iterative algorithm converges after 33 generations, PID controller is used to make the output reaches the set value 0.0689s.

Figure 3 shows the results of the AGA, iterative algorithm converges after 12 times, PID controller is used to make the output reaches the set value 0.0527s.

Specific results listed in Table 2, it can be seen in Table 2, the objective function value obtained after EGA convergence 20.063, less than SGA and AGA of 20.712 and 20.688, and thus it can be concluded: the convergence speed and accuracy on the EGAThey are superior to SGA and AGA.

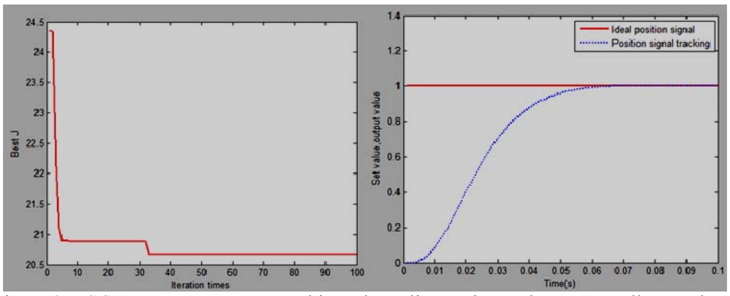

Figure 2. SGA PID parameters to achieve the online tuning and PID controller emulator

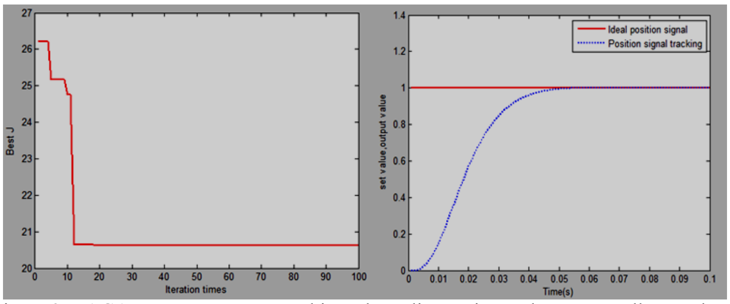

Figure 3. AGA PID parameters to achieve the online tuning and PID controller emulator

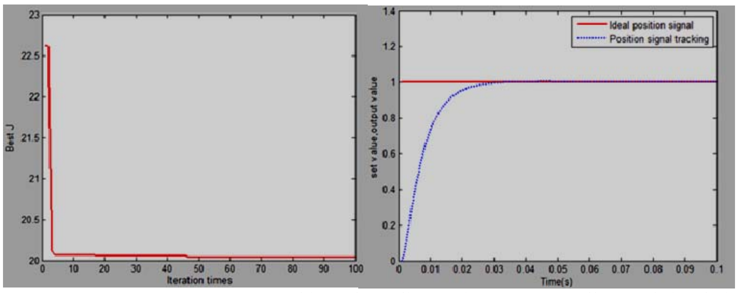

Figure 4. EGA PID parameters to achieve the online tuning PID controllers and simulation.

TABLE II. === THE RESULTS COMPARE THREE ALGORITHMS DATA

Algorithms	PID stabilize time（s）	Target function	Iterations
SGA	0.0689	20.712	33
AGA	0.0527	20.688	12
EGA	0.0281	20.063	5

V. CONCLUSION

In this paper online PID tuning parameters of the standard genetic algorithm and adaptive genetic algorithm analysis, proposed elite genetic algorithm, convergence speed and control accuracy has been improved. With level control system, for example, we will use three algorithms which realize the PID parameters online and PID controller tuning, simulation experiments show EGA convergence speed and control accuracy are better than SGA and AGA, illustrated by the EGA design solution level control system has the advantage of high precision and high response speed, EGA also be used for other control systems or optimization problems go.

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