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Research on PID Parameter Tuning Based on Intelligent Fusion Optimization Algorithm in Control System

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Abstract

This article will mainly introduce the effective access to get the value of PID parameter, and the method of tuning PID parameters is studied from two aspects. To ensure the PID parameter value of the whole set is optimal, the controlled object must be given and the value of intelligent optimization algorithm also must be optimal. Then to compare and test the parameters, we can use the method of simulation and experiment. Research deep traditional Z-N method and PID structure control model, and preliminary parameter values of PID can be acquired by it. After that, an intelligent fusion optimization algorithm based on intelligent computation and simulation analysis is constructed, finally, we can use this method to tuning PID parameters' value effectively.

Keywords: *particle swarm optimization; PID controller; parameter tuning*

1. Introduction

PID controller is one of the earliest feedback controllers. Because of its characteristics of simplicity, robustness and high reliability, it is widely used in industrial control systems. The designing of PID controller is an important topic in the field of control science, Ziegler and Nichols propose the method of tuning PID controller parameters since there have been many methods had been used, such as Cohen-Coon tuning methods, fast setting method, based on the ISTE index, IMC methods such as [1-3]. But these regular PID controller parameter tuning techniques are mostly a summary of experiences, and it is difficult to get the optimal solution. When the parameter of speed, stability and robustness are clear required in system, the general method of PID is often difficult to satisfy the requirements of the control system.

Fuzzy control technologies, such as artificial intelligence, neural network and genetic algorithm, have provided a new way for PID controller parameter optimizing. In these techniques, genetic algorithm, with its simple and fast convergence has drawn great attention from many scholars. However, recent studies have shown that genetic algorithm has its own inherent weaknesses [4]: firstly, when the correlation between the object and the parameter is optimized, the search capability of genetic algorithm will deteriorate; Secondly, this algorithm's premature convergence.

Particle Swarm Optimization algorithms (Particle Swarm Optimization, PSO) is proposed by two United States scholars Kennedy and Eberhart in 1995, it is an algorithm of global stochastic optimization[5]. Because of the PSO algorithm can be used to solve nonlinear, non-differentiable and multi-modal function optimization problems, and compared with other evolutionary algorithms, it has the advantages of simple and easy to implement, adjustable parameters and much more effective, so it has been extensively studied and applied [6-7].

Particle Swarm Optimization, the improvement of this algorithm and the widely application of it in the tuning of PID parameters in recently years have attracted a

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widely attention. Shao Wen of traditional optimization algorithms, such as gradient descent into the basic PSO algorithm, and algorithm applied to PID parameter tuning [8]. Zhang Xinghua, PSO with a shrinkage factor to multi-objective optimization PID, so as to realize the automatic parameter tuning of PID controllers [9].

There are a variety of modified PSO algorithm [10-12], but most of these algorithms focus on the dynamic modify policy of PSO parameter selecting and there is an argument that the improved algorithm was based on all the particles and their own search experiences toward the direction of optimal solution, and it is difficult to overcome the disadvantage of the algorithm, because it is vulnerable to local minimum and low speed of evolving the inherent weaknesses in later convergence.

Presents an improved PSO algorithm with the features of simple, consistent, fast search speed, and it use the worst position of the Particle Swarm Optimization algorithm (W-PSO). Algorithm use the mixed information of good and bad particle effectively, it not only have kept the diversity of this algorithm, but also improve the convergence speed and accuracy.

We tested it with the typical optimization function and compared it with standard PSO, the result of this algorithm performance have shown that the optimizing efficiency and optimization have been improved significantly. Use this algorithm for PID parameters tuning, the simulation results show that, based on the improved Particle Swarm Optimization algorithm for PID parameter tuning of control systems can achieve a better performance.

2. Standard Particle Swarm Optimization Algorithm

The basic idea of standard PSO algorithm is to simulate the behavior of nature to construct solutions of stochastic optimization algorithms [13]. Located in d-dimensional space, there is a community formed by m particles, of which i particle's position $x_i = [x_{i1}, x_{i2}, ..., x_{iD}]^T, i = 1, 2, ..., m$;Speed $v_i = [v_{i1}, v_{i2}, ..., v_{iD}]^T$; the i th particle has get the best location is x_i^*;at the meantime, the whole particle swarm have get the optimal location of x^*.Then, bring the x^* into objective function to calculate the fitness value, to ($k+1$)th iteration, each particle update their speed and position according to the following formulae [14]:

$$v_i^{k+1} = wv_i^k + c_1 r_1 (x_i^* - x_i^k) + c_2 r_1 (x^* - x_i^k) \tag{1}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{2}$$

In the formula: w is the linear weights, c_1 and c_2 are constants, $\mathbf{r_1}$ and r_2 are random numbers between [0, 1]. v_i^{k+1} is the vector sum for v_i^k, $x^* - x_i^k$ and $x^* - x_i^k$

3. Improved Particle Swarm Optimization Algorithm

3.1. Algorithm Principle

From standard PSO we can see that, during the process of a single particle's motion, they learn experiences and get information not only from their individual behavior, but also from the whole group. However, during the process of obtaining information, they take the best individual as learning objects. Learning groups In the standard Particle Swarm Optimization algorithm, they consider about the experience of failure of the worst individual in the community, that is, bring in the worst position of the particle individual and the worst position of the group. So the updating formula of speed will change according to the individual extreme, global extreme, the worst individual value and the global worst updating value, this can enable the particle have more information to adjust their status. Formula (1) and (2) will change to:

$$v_i^{k+1} = wv_i^k + c_1 r_1 (x_i^* - x_i^k) + u_1 r_1 (x_i^0 - x_i^k) + c_2 r_1 (x^* - x_i^k) - u_2 r_2 (x^0 - x_i^k) \quad (3)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (4)$$

Compare with standard PSO, new updating policy introduce two parameters, and the affecting factors of them are u_1 and u_2, we can use these two factors to describe the role of individual worst and global worst values play in the speed updating process. x_i^0 represents the worst position the particle find itself; x^0 represents the worst position found by the entire species. With regard to other parameters, they should keep consistent with standard PSO algorithm.

After the introduction of the worst value of particle swarm, it has the advantages like below: from the perspective of information, every particle in the new algorithm draws on its history worst and global worst values, the particle location away from the worst value, it accelerates the convergence rate of the particles; From a search perspective, PSO is no longer just search between individual extreme values and the global optimization, but among the individual extreme values, global optimization and the worst individual values, this can increase the diversity of the particles, the global optimal performance of convergence also can be improved relatively.

3.2. Algorithm Steps

Step 1: initialize, set speed constant c_1 and c_2, the inertia weight w_0. Maximum number of evolution, when defining the space, randomly generated an initial population which consists of m particles; the initial velocity of these particles is v.

Step 2: evaluation of species $x(k)$, calculate the fitness of each particle in every dimension.

Step 3: compare the particles' fitness value and optimum value x_i^*, their own worst value is x_i^0. If the current value is better than x_i^*, then reset x_i^* as the current value, then set the position of x_i^* as the current position in the n-dimensional space; If the current value is worse than x_i^0,then reset the current value and set the position of x_i^0 as the current position in d-dimensional space.

Step 4: Compare the particle's fitness value with population optimal value and population worst value. If the current value is better than x^*, then set the x^* as current particle matrix's subscript and fitness; If the current value is worse than x^0, set x^0 as current particle matrix's subscript and fitness value.

Step 5: according to the Formula (3) and (4) update the displacement and step of particle's motion, and produce a new species $x(k+1)$.

Step 6: check the end conditions, if met, end search; Otherwise, put $k=(k+1)$, and then go to Step 2. The ending condition for optimization is to reach maximum number of evolutionary $MaxDT$ or e value is less than the given precision.

3.3. Function Test

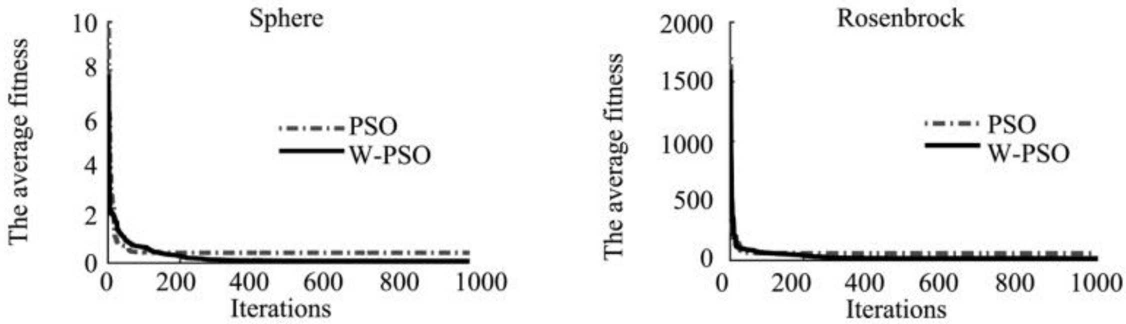
Table 1 shows different characteristics typical of the algorithm is tested to verify its accuracy and effectiveness, using shrinkage factor models, $c_1=c_2=1.4962$, $w=0.7298$, total number of particles is 20, other initial conditions and the results are shown in the following table. Using worst-value PSO algorithm, take a specific test function as example, test the value of u, after testing: correct the impact factor value u's value depend on the algebra change to $0.001k/MaxDT$ (k is the current number of iterations), in this condition, algorithm take on a best optimizing work.

Table 1. Testing Condition and Results

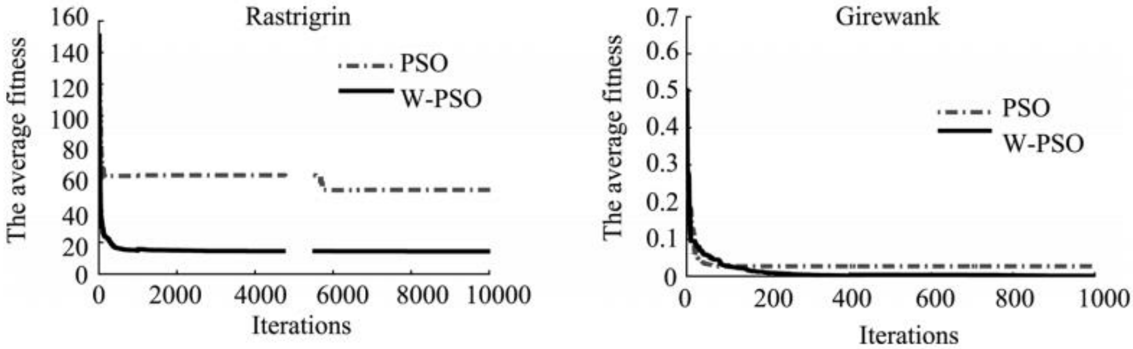
Number	Test function	expression	The initial range	dimension	algorithm	The average optimal fitness value
F1	Sphere	$f_1(x)=\sum_{i=1}^{n} x_i^2$	[−1, 1]	20	PSO	0.542 0
					W-PSO	0.391 1
F2	Rosenbrock	$f_2(x)=\sum_{i=1}^{n-1}[100(x_{i+1}-x_i^2)^2+(x_i-1)^2]$	[−1, 1]	20	PSO	62.208 5
					W-PSO	52.490 7
F3	Rastrigrin	$f_3(x)=\sum_{i=1}^{n}[xi2-10\cos(2\pi x_i)+10]$	[0, 5.12]	20	PSO	78.080 3
					W-PSO	78.039 3
F4	Griewank	$f_4(x)=\frac{1}{4000}\sum_{i=1}^{n} x_i^2-\prod_{i=1}^{n}\cos\frac{x_i}{\sqrt{i}}+1$	[−10, 10]	20	PSO	0.820 0
					W-PSO	0.438 2

Average optimal fitness value is the average of 30 times independent experiment optimal fitness value, which can be displayed at a given iteration algorithm under the attainable, it reflects the accuracy of the algorithm's convergence.

In order to better reflect the improved PSO optimizing results, I will compare the optimizing effect of worst position of PSO (W-PSO) with the standard PSO, they are shown in Figure 1.



Evolution curve of average fitness value of the average fitness values F1 and F2



Evolution curve of average fitness value of the average fitness values F3 and F4

Figure 1. Optimization Curve of W-PSO and Standard PSO for Testing Function

4. Improved Particle Swarm Algorithm for PID Parameter Tuning

4.1. Tuning Method of PID Controller Parameters

Tuning of PID controller's parameter refers to the law of the controller has been identified as a form of PID case, through adjusting the PID controller parameters, to make the loop consists of control object, controller and other components of the dynamic characteristics meets the desired requirements, and achieve the desired control objectives. After Ziegler and Nichols proposed the PID controller parameters empirical method, there have many ways has been applied to parameter tuning for PID controller. In accordance with the stage of development of these methods, they can be divided into conventional PID controller parameters tuning method and intelligent tuning method of PID controller parameters.

The biggest advantage of Z-N empirical law is simple, swift for using, without prior knowledge for the process, but the disadvantage is also obvious, control quality is terrible, especially when acting on the large time delay process, the system is difficult to work in satisfactory condition.

Critical percentage method is different to Z-N method, this method does not depend on mathematical parameters object model, by summarizing the primary theoretical and practical experience, then tuning the PID controller's optimal parameter depend on the empirical formula. But this method needs many times of experiment to adjust the proportional gain, particularly to this slow system whose time constant is very large, wait for the constant-amplitude oscillation is a process of time consuming; Often there will be many uncertainties in the field experiment, this can bring impact on experimental data, these external conditions can greatly affect the quality of control.

Intelligent PID control put the intelligent control and PID control together, this not only maintains the PID controller's advantages of simple structure, strong adaptability and good robustness, but also can correct the PID controller's parameters online flexibly to meet the complex control processes, and this method has been applied to practice. Especially for using of genetic algorithms, Particle Swarm Optimization algorithm to optimize PID controller parameters tuning. Genetic algorithm is a referring to natural genetic algorithm and it also is a referring to biological natural selection and evolutionary mechanisms, based on these developed a highly parallel, randomized adaptive search method. While PID controller parameters tuning, reproduction, crossover and mutation function groups and searching ways to avoid local optima to have a better tuning effect. But genetic algorithm involves tedious coding, decoding process and a greater amount of computation, but also throughout the search process, chromosomes share information with each other, the entire population is more evenly to shift to the optimal area, this can affect the searching efficiency of the algorithm. PSO algorithm in nonlinear and the methods of solving constraint problems than other smart shows superiority of PID parameter tuning.

4.2. Method of PID Parameter Tuning Based on PSO Algorithm

Based on PSO algorithm to optimize PID controller parameters tuning, you first need to choose an appropriate objective function. Different objective tuning functions can get the different PID controller parameters, but this can not affect the effect of analyzing and comparison of tuning. After determining the target functions according to the process of W-PSO algorithm and the termination condition. This target function is:

$$ITAE: J = \int_0^{\infty} t / e(t) / dt \tag{5}$$

ITAE is an effective integrated system performance objective description function, the code is easy to implement on a computer, and use it to calculate the best parameter combination many advantages, for example, it can make the system stability, and the overshoot is very small, the response time is very fast and so on, so in the experiment, J is the fitness functions of the algorithm.

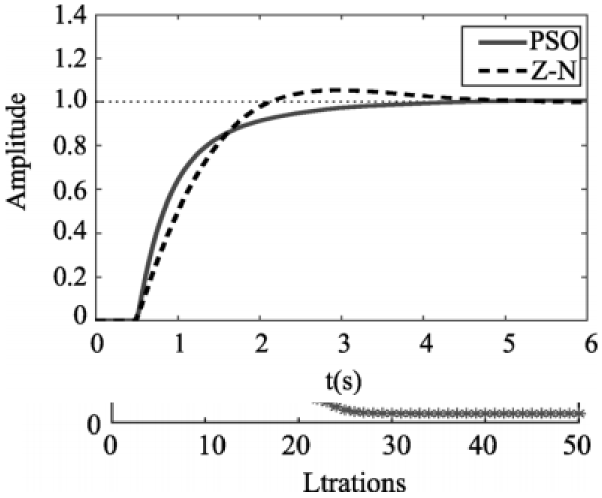
4.3. Simulation Experiments and Results Analysis

In order to investigate the W-PSO algorithm with optimal tuning of PID controller parameters of performance and simulation study for second-order delay and compares it with the Z-N method of the same performance. Take control order system, the transfer function is:

$$G_1(s) = \frac{1}{s^2 + 2s + 2} e^{-0.5s} \tag{6}$$

In the formula: the scope of parameter k_p, k_i and k_d respectively are [0, 20], [0, 5] and [0, 1], and the input signal for the unit is step signal. Group size is 20, terminal value is 40, the limit output value of controller is [10, 10]. Use the real number for coding, and figure of simulation is shown in Figure 2. By W-PSO and Z-N results of comparison can be seen, when the W-PSO method is used to optimize parameters, the step response of the system without overshoot, in 5s or less stable; Set by the Z-N method parameter, the system has some overshoot and stability grew up 6 s. Bionic optimization algorithms as represented by the PSO method is better than the conventional tuning methods represented by the Z-N method.

Adaptation of the optimization process function J



PSO and Z-N method step response comparison chart

Figure 2. PID Parameter Tuning Result Based PSO

4.4. Application of Improved Temperature Control Algorithm in Beer Fermentation Process

Beer fermentation is a key process in the production of beer; whether the fermentation temperature and pressure changes can meet the technological requirements will have a direct impact on beer quality and yield. Beer fermentation temperature is controlled variables, is a large scale time delay systems with large time constants. This process can generally be divided into 7~8 stages, we can according to the fermentation curve, choose the control policy of subsection control, that is, throughout the fermentation period, to different temperature we use different control method and parameter group. Aimed at one of these stages, based on the characteristics of the controlled object, carry out step response test, with characteristic area method to get approximate one-order inertia with pure delay system G2 for simulation objects [15].

$$G(s)=\frac{1.347}{369.4s+1}e^{-13.75s} \tag{7}$$

Using a PID controller to control the system, by using GA method and W-PSO algorithms come to optimal tuning of PID controllers of the three parameters, as shown in table 2, simulation of the unit step response curve as shown in Figure 3, PSO optimize tuning PID controller parameter to improve controller performance, improve the response speed of the system. Table 2 GA and W-PSO the results obtained after setting two different algorithms, can be seen from the data in the table with W-PSO optimization with GA optimization-tuning-tuning PID controller parameter has a short transition time, the number of iterations needed only a GA one-third. Therefore, tuning of PID controllers based on improved PSO methods with rapid, response with no overshoot.

Table 2. PID Parameter Tuning Results

method	Kp	ki	kd	Evolution Algebra
GA	19.1712	1.1501	0.2903	80
W-PSO	18.2355	0.7901	0.0501	30

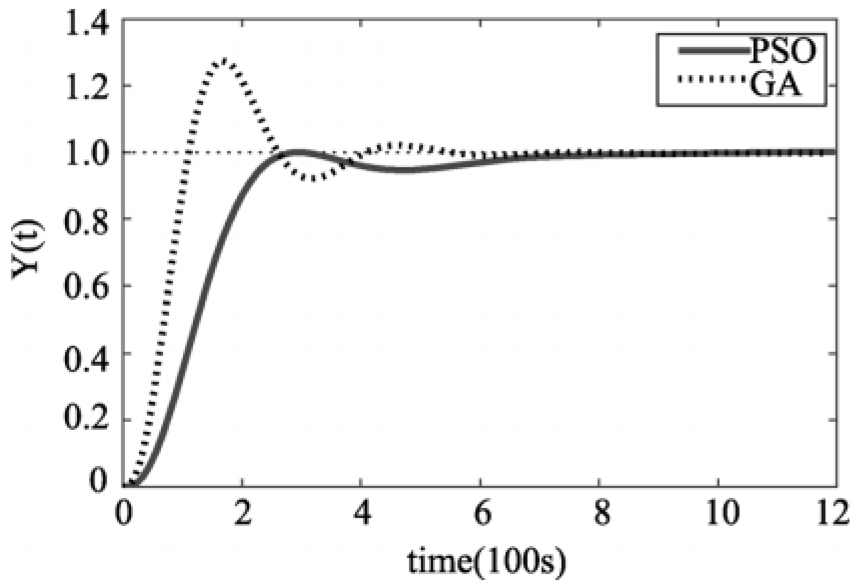


Figure 3. Profiles of Turning Parameter of G2

5. Conclusion

PSO algorithm is a new evolutionary computation method, it has the advantage of simple algorithm, less parameters and good optimize performance. By analyzing the principle of optimization, this paper presents a strategy of improved PSO algorithm and improved PSO algorithm applied to PID parameter tuning, this can help to achieve good results and good convergence properties. Compared with the Z-N method, you can see an improved PSO algorithm can get better solutions, and the performance can also be improved. When it is applied to beer fermentation temperature control, the simulation results show that the controller using Particle Swarm Optimization has effectively improved control precision and ability to suppress disturbances, apart from this, the setting time is also much lower than genetic algorithms. Controller based on particle swarm into the worst location algorithm parameter-tuning methods are effective, feasible, and has the advantages of easy to implement, small quality of computation. All in all, it provides a new method for tuning the parameters of control system.

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