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Neural Network Control of Large Time-Delay Object Based on Chaos Ant Colony Optimization

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Abstract: In order to study the way of controlling the large delay object, this paper introduces the chaos ant colony algorithm to the neural network control of large time-delay. It is found that chaos ant colony algorithm is an algorithm that steady astatic, good dynamic performance, and it has certain robustness, but it is also easy to appear stagnation phenomenon in the evolution process. This study constructs an intelligent neural network as a controller through improving the fuzzy PID control. Under this control scheme, improve ant colony algorithm through introducing chaos searching mechanism, and then use it in the off-line optimization of controller's parameters. The experimental results show that the scheme and its optimization strategy can effectively improve the performance of the system. *Copyright © 2013 IFSA.*

Keywords: Chaos ant colony optimization, TSP, PID, Large time-delay.

1. Introduction

Ant colony algorithm is a new type of evolutionary algorithm that simulates ant colony foraging process. It has openness, robustness, parallelism and global convergence, and it has no special requirements on the objective function and constraint function, and it has the merit that easy to combine with other heuristic algorithms [1]. The first successful application of ant colony algorithm is to solve the famous traveling salesman problem (TSP) [2]. This algorithm uses the computation mechanism that parallel positive feedback of distributing, it is easily combined with other methods, and has strong robustness. Using chaos ant colony algorithm to control large time-delay objects can overcome the prey of fuzzy rules, and it is has great significance to control time-delay object of industry. In recent years, ant colony algorithm is put forward for the first time, the participant is the Italian scholar M. Dorigo, etc. it is regarded as a novel simulated evolutionary algorithm [3], at present, many scholars still make in-depth research on it. This method is used to solve the traveling salesman problem, assignment problem, scheduling problem, etc. And it has obtained a series of good experimental results [4]. Ant colony algorithm has got good effects in many fields, such as in the telecommunication routing optimization [5], data clustering analysis [6] and data classification rules extraction [7], but there is no strict definition about chaos. This paper introduces chaos to ant colony algorithm, and put forward chaos ant colony algorithm through the movement characteristics of chaos. It constructs an intelligent neural network controller through improving the fuzzy PID control.

This paper tries to use chaos ant colony algorithm to effectively control the large time delay objects.

2. Ant Colony Algorithm

2.1. Theoretical Basis

Based on the ant colony optimization method can effectively find the shorter path, but it is not sure that the path is the shortest path [8]. Now there is no strict definition on chaos, in general, the random motion state which obtained by deterministic equations is called chaos. The Logistic map is a typical chaos system. The following is iterative formula:

$$z_{i+1} = \mu_{zi}(1 - z_i), i = 0,1,2,\cdots, \mu \in (2,4] \quad (1)$$

The μ is the control parameter, when the, $\mu = 4$, $0 \le z_0 \le 1$. Logistic is completely in a chaotic state, taking advantage of the chaos movement characteristics can optimized search. The basic idea first create a group of chaotic variables with the same number of optimization variables, using similar carrier way to introduce the chaos to optimization variables, and making it become chaos state, at the same time to enlarge the scope of the traverse of chaotic motion equal to the scope of optimization variables, and then directly use chaotic variables [9] to search. Due to the chaotic motion have randomization, ergodicity and sensitivity to initial conditions [10], etc. The search technology based on chaos will no doubt is more superiority than other random search. This paper makes use of the chaos characteristics that when $\mu = 4$, choose the Logistic map of formula (1), and regard it as chaotic signal generator.

2.2. Instance Analysis

Stating ant colony algorithm through example of ant colony choose path. Let the ants choose the path with equal probability, first take the full arrangement (1, 2, 3, 4) for example, discuss its structure, and present its transformation algorithms. The total number of all the different arrangement is 4! = 24, the construction sequence according to the dictionary, then structure of the first elements take minimum label, later the elements you take increase gradually, 1234 is a first structure, the first vector is 110, it means every time taking the minimum label of the remaining items. According to the dictionaries' structural sequence, the end structure is 4321, the end of the vector is 430. Serial number D, vector V and structure D become DVC table, as shown in Table 1.

Table 1. DVC Table of 1~4 Arrangement.

D	V	C	D	V	C
1	110	1234	11	309	3124
2	109	1243	12	310	3142
3	118	1324	13	319	3214
4	119	1342	14	320	3241
5	128	1423	15	329	3412
6	129	1432	16	330	3421
7	208	2134	17	409	4123
8	209	2143	18	410	4132
9	218	2314	19	419	4213
10	219	2341	20	420	4231
11	228	2413	21	429	4312
12	229	2431	22	430	4321

2.3. Result and Analysis

Above example is calculated according to using the ergodicity of chaotic motion to chaos initialization, a chaotic quantity corresponding to a path. It produces a large number of paths, choose more optimal path among them to make these path leave pheromone, the amount of information of the different paths is different, then using it to guide the ant to choose the path. According to the theory of the whole array structure, a chaotic quantity corresponds to a path [11].

According to DVC table, there is a relationship between D, V and C , there are six transformations between D, V and C, the six transformations are D/V, V/D, V/C, C/V, D/C, C/D. The transformation D/C that we care, at present, it is not directly written its transformation formula, it need through D/V conversion, and then finish its transformation through the V/C. D/V conversion formula is as follows:

$$\begin{cases} D_0 = D \\ v_i = \left\lceil \dfrac{D_{i-1}}{(n-i)!} \right\rceil \\ D_i = D_{i-1} - (v_i - 1)(n-i)! i = 1,2,\cdots, n-1 \end{cases} \quad (1)$$

V/C determines the structure C through the pointer function of the vector V. For example, $V = v_1 v_2 v_3 = 231$, then

$$\begin{aligned} v_1 = 2 \quad 1234 \quad c_1 = 2 \\ v_2 = 3 \quad 134 \quad c_2 = 4 \\ v_1 = 1 \quad 13 \quad c_3 = 1 \quad c_4 = 3 \end{aligned}$$

Producing the chaos $z_i(0 \le z_i \le 1)$ according to formula 1, then put $D_0 = n! z_i$ into formula 2, let $d_1 = n z_i$, then it gets

$$\begin{aligned} v_1 &= \lceil d_1 \rceil \\ v_i &= \lceil d_i \rceil \\ d_i &= (n - i + 1)\ i = 2,3,\cdots n-1 \end{aligned} \quad (3)$$

Then it determines the structure C according to the pointer function, then Z_i and C one-to-one correspondence, so choose path can choose relatively short route.

3. Improving Experiment of Chaos Ant Colony Algorithm That Control Large Time-Delay Neural Network

3.1. Theoretical Basis

3.1.1. The System of Controller

Controller is composed of two neural networks, its specific structure is as shown in Fig. 1. The inputs are the error change E and EC, they constantly adjust their weights and output control quantity U to make the system output and tracking expectations input according to the controller optimizes algorithm. When it is off-line optimization, according to the working condition of a given sample and optimization algorithm to find the approximate optimal controller parameters and then achieve online control. On the basis of off-line optimization obtains the approximate optimal parameters to use the error back propagation. In the diagram, E, EC, are respectively system deviation and deviation change; w is the last layer of FNN; U is the output of FNN; w_{ij}, w' are respectively the input of PIDNN, the output layer power system.

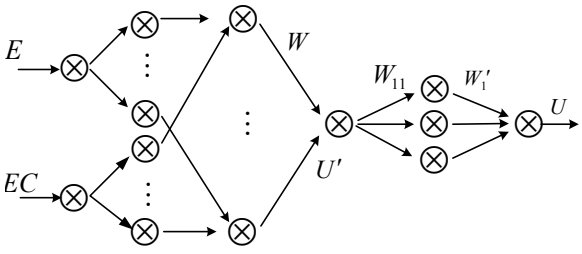


Fig. 1. Topological structure of neural network controller.

(1) Input and output of input layer

$$I_1(k) = O_1(k),\ \ I_2(k) = O_2(k)$$

(2) Input of hidden layer

$$I_{H_1}(k) = \sum_{j-1}^{2} \omega_{ij} I_j(k), i = 1,2,3.$$

The outputs are respectively proportion, integral and differential,

$$O_{H_1}(k) = \begin{cases} -1, & I_{H_1}(k) < -1 \\ I_{H_1}(k), & -1 \le I_{H_1}(k) \le 1 \\ 1, & I_{H_1}(k) > 1 \end{cases}$$

$$O_{H_2}(k) = \begin{cases} -1, & I_{H_2}(k) < -1 \\ I_{H_2}(k) + I_{H_2}(k-1), & -1 \le I_{H_2}(k) \le 1 \\ 1, & I_{H_2}(k) > 1 \end{cases}$$

$$O_{H_3}(k) = \begin{cases} -1, & I_{H_3}(k) < -1 \\ I_{H_3}(k) - I_{H_3}(k-1) & -1 \le I_{H_3}(k) \le 1 \\ 1, & I_{H_3}(k) > 1 \end{cases}$$

Input and output of output layer,

$$O(k) = I(k) = \sum_{j-1}^{3} \omega'_1 I_{H_1}(k), i = 1,2,3.$$

Synthetic FNN and PIDNN to a novel NN based on the way of adjusting fuzzy PID control of the amount of system control. Among them, FNN is mainly used to improve the fuzzy part of the fuzzy PID controller, it has an influence on adapting adjustment rules and adjusting the amount of error; PIDNN is used to replace the static PID parameter of fuzzy PID controller, and improve the accuracy of transient and steady state of the system through adjusting parameters. The method is: making the input of the PIDNN become a node, its input is the output of FNN, as an indirect control volume , it inputs to the PID function layer of PIDNN after weighted , it produces PID control effect after having effected by the P, I, D neurons and weighted sum again, then output the system control volume. This transforms the amount of system control which limited to rules and P, I, D static into dynamic adjustment, it not only enhance the function of processing network information, and combines the advantages of various control methods, it is a kind of improvement of the fuzzy PID control. The parameters of NN controller that need to be trained are only more six weight system value than the conventional intelligent methods, it does not increase the computational complexity of training controller. The adaptive adjustment effect With the help of FNNT and the function that PIDNN introduces the PID control, they are combined with the advantages of fuzzy reasoning, NN adaptive and simple control of PlD, it can improve the robustness and tracking accuracy of the control system, achieve good control quality on the basis of having designed offline and online optimization algorithm. It can deduce the control law according to NN structure:

$$U = \omega_1'\omega_{11}'U'(k) + \omega_2'\omega_{21}'\left[U'(k) + U'(k-1)\right] + \\ + \omega_3'\omega_{31}'\left[U'(k) - U'(k-1)\right]$$

3.1.2. The Controller's Optimization Algorithm

This paper makes use of Logistic map to produce chaotic motion:

$$g_{k+1} = \mu g_k(1-g_k),\ k = 0,1,2,\cdots,\ 0 < g_0 < 1$$

Among them, when the $\mu = 4$, it is in a chaotic state, and the chaotic variables g_k traverse within (0, 1); k is the sampling point of discrete time. The controller optimizes parameters: the center, width and the output layer's weights of the Gaussian function in the FNN's vague layer; each layer's weights in the PIDDN. Specific ideas of chaos ant colony optimization (CACO) are as follows:

1) Let apriori knowledge determine the controller structure, assume that there are n parameters that waiting optimized, and they are $p_{1,}p_{2,}\cdots p_n$. Initializing value set of each parameter within possible value scope, write $D_{pi,}(1 \le i \le n)$, each set have m random number. Initialize the parameters of ant colony algorithm: let the time $t = 0$, the iteration Num=o, give the biggest iteration $Num_{\max}$ and the number of ant A, then let the pheromone of the element j in the set $D_{pi}(1 \le i \le n)$, $\tau_j(D_{pi})(0) = 0,\ \Delta\tau_j(D_{pi}) = 0,\ 1 \le j \le m$.

2) Put initial points of all the ants into the disaggregation, let ant $a(a = 1,2\cdots A)$ start the set $D_{pi,}(1 \le i \le n)$, choose the j element from each set according to the probability $p(\tau_j^{ij}(D_{pi}))$. Until you choose all set and then reach the food source.

$$p(\tau_j^{ij}(D_{pi})) = \frac{\tau_j(D_{pi})}{\sum_{j-1}^{m}\tau_j(D_{pi})}$$

Update the pheromone, write down the best elements group as the optimal solution. Set all the ants in the process of optimization have experienced ε unit of time, at this moment, let $t = t + \varepsilon$, $Num = Num + 1$ update the pheromone for

$$\tau_j(D_{pi})(t+\varepsilon) = p\tau_j(D_{pi})(t) + \Delta\tau_j(D_{PI})$$

Let the pheromone chaotic disturbance [12], make the algorithm jump out local extremum. Algorithm chooses biggest pheromone's set of each set with a certain probability, makes the value of a new solution at the component concentrate on the largest collection of pheromone, then it is prone to appear stagnant phenomenon. Therefore, we need to make chaotic disturbance on pheromones. Setting the conditions of stimulating chaos: the number of iterations change Num' and judge η when it is in a halt state, and let initial value of chaotic disturbance quantity τ_c of pheromone become 0. The following is the pheromone adjustment under the chaos strategy:

If,

$$abs(e_{now}^{k} - e_{next}^{k-k+1,k+Num}) \le \eta,\ \tau_c = \tau_c + a(2g_i - 1),$$
$$g_{i+1} = 4g_i(1-g_i),\ i = i+1,$$

$$\tau_j(D_{pi})(t+\varepsilon) = \rho\tau_j(D_{pi})(t) + \Delta\tau_j(D_{pi}) + \tau_c,$$

$$\Delta\tau_j(D_{pi}) = \sum_{a-1}^{A}\Delta\tau_j^a(D_{pi})$$

Among them, e_{now}^{k}, $e_{next}^{k-k+1,k+Num'}$ respectively stand for the optimal value when error is in the k iteration and the every optimal value of $k + Num'$ iteration; η is the constant, and it is a small value, the change of optimal value of the current search in the N' iteration is not greater than η, it will produce chaos disturbance. α is the constant, and it is the radius of disturbance search. g_i is the chaotic variables, due to the Logistic mapping on (0,1) interval is symmetrical, to avoid repetition, the initial value is only between (0,0.5), the dimensions of g_i is consistent with the pheromone τ_j, $p(0 \le p < 1)$ stands for the durability of the pheromone. Generally take $p = 0.7$; $\Delta\tau_j^a(D_{pi})$ is the pheromones that the α ant leaves in the j element of set D_{pi} in this loop.

$$\Delta\tau_j^a(D_{pi}) = \begin{cases} \dfrac{q}{e^a} \\ 0 \end{cases};$$

A choose the j element in the D_{pi}, another q as constants are used to adjust the speed of adjusting pheromone, its value has no big influence on algorithm, generally $q \in [1,10000]$. When we are choosing actually, first select p, and then try to choose q. e^a is the error between system output and the expect produced by the sample when the selected element by α ant as a suboptimal solution.

Repeat steps until the algorithm converges or reach the maximum number of iterations.

3.2. Instance Analysis

3.2.1. Ant Colony Algorithm Controls Air Conditioning Room

For research need, this paper designs a model of air conditioning room to test. Air conditioning room model is a typical large delay object [13], usually it needs to meet the following conditions for temperature control: 1) small overshoot; 2) short setting time; 3) small steady-state error; 4) a certain robustness. Choose approximately the model object:

$$G(s)=K_p\frac{\exp(-t_{lag}s)}{Ts+1}.$$

Among them, K_p is the amplifying coefficient of air conditioning room; T is the time constant; t_{lag} is pure lag time; s is the complex quantity that after the transformation of pulling the zipper. LS_SVM is adopted to improve the recognition and compare designed control scheme with the control results of practical model of PID, fuzzy, fuzzy PlD. Simulation's parameters: expectation is signal amplitude of 10 step, triggering time $t=0$; Controller's structure: 2-10-25-1-3l, membership function of layer 2 chooses Gaussian function, the number of neurons depends on by fuzzy subset that controlled by fuzzy PID, parameters waiting for optimization are 51. Parameters of CACO:

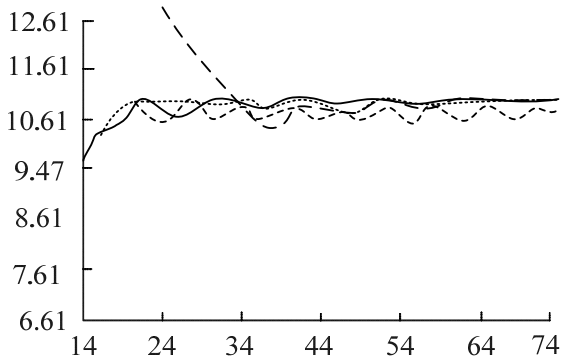
$$n=51, A=30, p=0.7, q=100, Num_{\max}=400,$$

$$n=51, A=30, p=0.7, q=100, Num_{\max}=400.$$

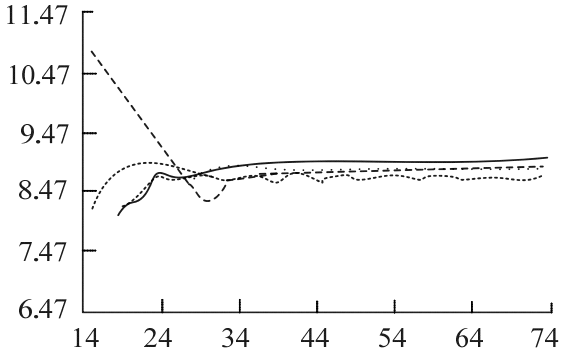
Set of values $D_{pi}=[-10,10]$, parameter of Chaotic and disturbed $Num'=20, \eta=0.0001$; The gathering of training sample is random Numbers of the normal distribution within $[-1,1]$, take 150 groups of data, among them, take100 group as the training set, 50 group as the test set, uses the index of Gaussian kernel; input and output variables of Fuzzy, fuzzy PID control are divided into 5 fuzzy subset, respectively is: 1) The temperature error: Fuzzy set {NB, NS, ZO, PS, PB) is corresponding to the cold, cool, comfortable, a bit hot, hot. 2) The changes of temperature error: Fuzzy set {NB, NS, ZO, PS, PB) is corresponding to the temperature's dropping fast, slow, unchanged, and rising slow, fast. 3) Valve opening: fuzzy set {NB, NS, ZO, PS, PB} is corresponding to close big, turn down, closed, open, small open. Domain of discourse are all [-1, 1], membership function selects triangle function, there are 25 rules. If use the index of mean square error, the error of LS_SVM's offline training is 1.275, the test error is 0.014.

3.2.2. Result and Analysis

This article does not realize the LS_SVM identifier that controller is completely stable under the condition of continuous time. From Fig. 2 (a), the method of this paper make the speed of system response is fast, overshoot volume is small, high steady state accuracy. The cause that causes overshoot is mainly due to the accuracy of the offline optimization's result is adjustable. On the one hand, the offline optimization of CAC0 makes the speed of online simulation system's response become fast; On the other hand, for complex problems, optimization only can get the more optimized approximate solution as far as possible, if you want to get a better control, the quality need more consumption. From Fig. 2 (b), when the system's parameters change a small scale, it still achieves good results, this shows that the system has certain robustness. Fig. 3 is the results of system identification, it shows that the indicators' comparing under various controlling methods, it is shown in Table 2.



(a) Original model



(b) When the model parameters change

Fig. 2. Verified results of step response and the system's robustness.

Table 2 The comparing results of all indicators under the step response

	Maximum overshoot	The time of adjusting/min	Steady state error
PID	3.4 %	34	without
Fuzzy	without	19	1.9 %
Fuzzy PID	without	19	without
The way of this paper	0.019 %	14	without

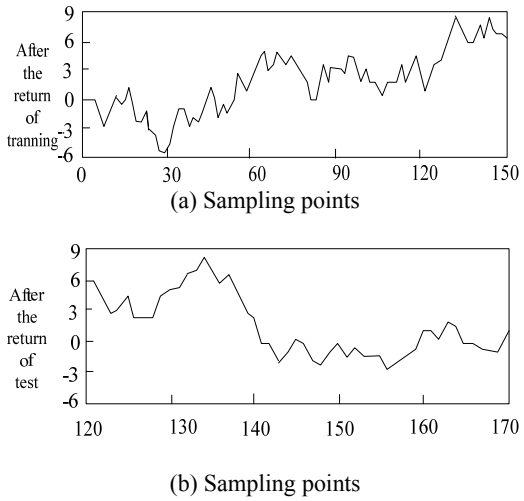


Fig. 3. Offline identification results of LS_SVM .

4. Conclusion

The chaotic ant colony algorithm of this paper can significantly improve the computational efficiency, and it has great practical value. And it mainly puts forward an intelligent solution strategy of controlling uncertain large delay object. It uses LS_SVM to get the forecasts of the system's next step, and carries on the system identification to solve the problem of time delay and uncertainty. Designing the method of combining and optimizing the optimization of offline CACO the adjustment of online BP, the sample's database the quality of the sample and the choice of algorithm's parameters can determine the precision of the off-line optimization's results, second-best solution with high precision can provide speed and accuracy guarantee for on-line quickly adjust. It can make use of Lyapunov analyze system's stability of this scheme, but readers only receive stable controlling effect under the condition of small sample, this is mainly not fuse well between LS_SVM's online identification and its controlling, at present, it is still the hot spot of researching, more in-depth work are waiting for further carrying out.

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