Self-tuning Optimized PID Control Algorithm with Electro-hydraulic Power Steering

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Abstract
According to the problems such as large calculation amount and easy to make the error pathological enlarge of the standard PID algorithm in the parameter control, the power steering control model is proposed based on the PID algorithm with the optimization of improved self-tuning swarm. First introduced artificial colony algorithm, and the particle colony is adopted to let the control parameters of the PID algorithm corresponding to the honey

behavior of artificial bees, and artificial colony is designed to simulate the nature colony. Then choose the strategy and nectar source by the Boltzmann, to realize the balance between the algorithm in global dispersibility search and local chemotaxis search. Finally, the improved artificial bee colony algorithm is used to optimize the PID controller. Through the simulation experiments show that the proposed improved artificial colony algorithm has good convergence, and the improved PID algorithm has higher control precision.

Key words: THE BOLTZMANN SELECTION STRATEGY, MELECTRIC HYDRAULIC, POWER STEERING, ARTIFICIAL COLONY ALGORITHM, PID CONTROL, THE SELF-TUNING OPTIMIZATION

1. Introduction

With the development of automotive technology, electronic technology application is becoming more and more widely in the car, car electronic modular, become the inevitable trend of its development [1]. Electric bus has become the focus due to its energy saving and no pollution. In the process of driving, the driver needs to change direction constantly according to road conditions, and automotive steering is the device that driver changes and restores the direction, which including steering mechanism, steering transmission mechanism and steering actuator [2]. When the car is running at high speed, the friction becomes sliding or rolling friction, and it becomes small, if the power does not change, the driver will be too light to change and loss accurate judgment of the road surface, that is losing the sense of road, affecting the driving safety. Therefore, in the design of steering system that usually exist the contradiction between the portability and sensitiveness [3]. To solve this contradiction, power steering system was introduced by the majority of automotive.

With the rapid development of automobile industry in our country and related technology in recent years, the study of vehicle steering system is also more deeply. According to the parameters of the electric hydraulic power steering system, Chen zhen [4] set up electric hydraulic power steering system simulation model by applying the software AMESim, analyzed the effect on the dynamical characteristics when the speed and steering wheel angular velocity to participate in the system control, not only ensure the steering portability, and prevent the high-speed direction quaffed drift, improve the system to follow a gender, to improve the return-to-center performance of the system. After analyzing the effect on each component of EHPS system to the steering performance and expounding the establishment of matching design and the system control model, Geng Guoqing et al [5] put forward the in situ steering control strategy, driving steering control strategy and linear driving control strategy, realized the purpose of energy saving, noise reduction, and provides the help. Chen yong established the mathematical model of the electronically controlled hydraulic power steering system hydraulic line by bond graph method [6], and get the state space equation of pipeline, and the Simulink is carried on the simulation analysis that various parameters such as liquid resistance, liquid solution, liquid pipeline influence on the piping work characteristic, to get changing the parameters such as the length and pipe diameter of the pipeline, the stiffness of rubber to improve the operating characteristics of pipeline, provide a reference basis for designing the EHPS system. Through the analysis of steering turn broadly and EHPS, Gao Feng et al established steering gear model and the shunt type EHPS model [7], and a simplified formula is for analyzing steering and the Cao snake force characteristic curve of the shunt type EHPS. Such as by establishing the steering column and torsion bar mathematical model of the steering system stiffness, H.Lee et al [8] studied steering system stiffness and change rate and change trend of road with dynamical characteristics. Falcone [9] analyzed the transient response of the electro-hydraulic servo control system with power steering gear, and combining the response data given by the response curve under the different parameters, thus finding out the important parameters affecting the system response performance, and pointed out that the steering system to obtain a satisfactory transient response curve, the best damping ratio between 0.3 to 0.7. On the analysis of the formation mechanism of the steering torque, according to the vehicle handling dynamics, steering system dynamics model and tire semi-empirical model, Lawson established the analysis model of steering torque[10], and speed or load transfer was analyzed through the simulation and the influence of the tangential force on steering torque. At present the function study of control algorithm mainly with the design of the dynamical characteristics curve, motor control algorithm is seldom involved in system, mostly adopts a simple closed loop control of dc motor [11]. Japanese Seiko Corporation [12], the Delphi matters [13] and TRW Company [14] and other companies, has designed a good dynamical characteristics curve, and the portability and the road feel of the vehicle are carried on the thorough analysis, which has the better performance than a simple linear model and the curve of dynamical characteristics curve [15].

According to the defects of PID algorithm in the parameters control, a power steering control model is proposed based on improved swarm self-tuning optimization PID algorithm, and verify the validity of the improvement strategy with experimental simulation.

2. The limitations of PID control algorithm

PID controller is a linear controller. Its block diagram is shown in figure 1.

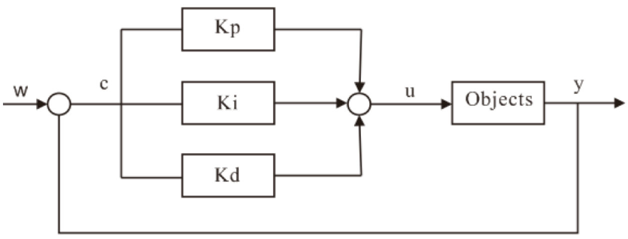

Figure 1. Diagram of the analog PID controller

According to the given value y_r, and the actual output value y it is constituting control deviation as follows.

$$e(t) = y_r - y \tag{1}$$

Through the linear combination, the proportion of deviation, integral and differential constitute control volume, to control the controlled object, and the control law is as follows.

$$u(t) = K_P e(t) + K_i' \int_0^t e(t)dt + K_d' \frac{de(t)}{dt} \tag{2}$$

Consider time for interval $[0,T]$, then discrete for the equidistance as interval τ, the equation (2) translate into equation (3).

$$u(k) = K_P e(k) + K_1 \sum_{j=0}^{k} e(j) + K_D(e(k) - e(k-1)) \tag{3}$$

In the equation (3), $t = k\tau$, $K_1 = K_i'\tau$, $K_D = K_d' / \tau$. To $Z-$ transform equation (3) on both sides, can get the transfer function corresponding to discrete PID.

$$G(z) = K_P + \frac{K_1}{1-Z^{-1}} + K_D(1-Z^{-1}) \tag{4}$$

The shortcoming of this method is with each output associated with the status value of all the past, to implement large amount of calculation and enlarge the pathological prone to error. In practice, the incremental PID control algorithm is generally adopted to subtract the two adjacent of the equation (3), so we get equation (5).

$$\Delta u(k) = K_P \Delta e(k) + K_1 e(k) + K_D(\Delta e(k) - \Delta e(k-1)) \tag{5}$$

In the equation (5): $\Delta u(k) = u(k) - u(k-1)$, $\Delta e(k) = = e(k) - e(k-1)$. The equation (5) is for simple merge and simplification.

$$\Delta u(k) = Ae(k) + Be(k-1) + Ce(k-2) \text{ v} \tag{6}$$

In practice, according to the different controlled properly set three parameters of PID. The process of setting parameters is the compromise in the control of the three parts proportion, integral and differential.

3. The power steering control model based on self-tuning optimization PID algorithm

According to the defects of PID algorithm, the artificial swarm algorithm is for self-tuning optimization, firstly, the artificial colony algorithm is introduced, to improve the convergence.

3.1. Optimize the optimization way based on particle swarm

The particle swarm is introduced into artificial colony algorithm in the improvement algorithm, the PID algorithm control parameters corresponding to the artificial bees honey behavior, design artificial colony to simulate the swarm of nature, also give intelligent behavior to the artificial swarm.

Improved algorithm is composed of two layers inside and outside circulation, the outer loop is artificial colony algorithm, the inner loop is PSO algorithm. The global search of artificial colony algorithm is to solve the local optimum of PSO algorithm, and the path planning of the PSO algorithm is adopted to optimize the path of the individual. Therefore, the improved algorithm can effectively use two kinds of optimization algorithm more quickly to look for the optimal nectar source and the best individual path.

For a D path optimization, the basic steps of improved artificial colony algorithm in the realization of group motion path planning are as follows:

(1) The initialization of algorithm. Randomly generated N bees and m possible solutions, and give up parameters such as honey threshold limit, maximum cycle times MCN.

(2) Dynamically select the target point of particles. Employed bees random chance new honey, observed bees select the information from employed bees through greedy selection mechanism, interaction work between bees, selecting individual goals.

(3) Control the group behavior. Through information sharing mechanisms, particle individual control group behavior, walking through the mutual referential experience to control individual path.

(4) After the limit cycles, judge whether there is solution need to throw away, if present, scout bees produce new explanation to instead, otherwise, return to step (2) to continue.

(5) After the largest number MCN of cycle times, complete the path planning, output the global optimal solution and the optimal path.

The steps of the improved artificial colony algorithm are as follows:

(1) The initialization of individual and possible solutions

For one D dimensional optimization, first the algorithm initializes each individual position, speed and m possible solutions Y_i. Set the population size for N, randomly generate individuals matrix X and velocity matrix V within the limits of location, in order to avoid the randomly generating initial solution may be uneven distribution, minizones is used to initialize possible solution, namely between the optimization range evenly divided into N minizones. Generated minizones method can accelerate the convergence speed of the algorithm.

(2) The dynamic selection of target point

When particles to choose target, employed bees first according to the memory of nectar source information and around the honey to create a new sources through the following equation (7).

$$v_{ij} = x_{ij} + \Phi_{ij}(x_{ij} - x_{kj}) \quad (7)$$

The swarm using greedy selection mechanism decided to choose old or new sources, if the fitness of new sources is higher than the old, employed bees would accept new honey bees and give up the old, otherwise, do not make processing. Here, the fitness of the sources can calculate by distance between the individual and honey and the average honey contention individual.

$$f(y_i) = \alpha\sqrt{y_{i1}^2 + y_{i2}^2 + \ldots + y_{id}^2} + \beta\frac{S}{n} \quad (8)$$

After searching, employed bees tell observed bees about honey information such as location and fitness. According to fitness, observed bees choose the sources by the Boltzmann selection strategy, the following equation (9) instead of roulette method for choice.

$$p_i = \frac{\exp(f_i / T)}{\sum_{i=1}^{SN}\exp(f_i / T)}, T = T_0(0.99^{0-1}) \quad (9)$$

In the equation (9), f_i is the fitness of i solution, p_i is the probability of choosing sources x_i. Determine target position after collecting honey, role reversal, observed bees back to honeycomb after determining again new honey according to equation (7) and greedy selection mechanism, to complete a cycle. To prevent fall into local optimum, after limit cycles, scout bees to judge whether there is solution need to throw away, if there is, by equation (4) to produce the new to instead, if there isn't, then it is to continue. After the largest number MCN of cycle times, complete the path planning, output the global optimal solution and the optimal path.

(3) The behavior control of swarm

After observed bees choosing nectar source by the Boltzmann selection strategy, the individuals choose same sources y_{ij} that make up a small colony, do individual path planning by information sharing mechanisms, to avoid individual collisions. Initialize each individual bees position x_i, speed v_i, individual extremum P_{best} and global extremum g_{best}, according to $f(x_i) = \alpha d + \beta f(y_{ij})$ to calculate the individual fitness $f(x_i)$, here, the distance d between the individuals and honey y_{ij} and the fitness $f(y_{ij})$ of honey y_{ij} are determine the individual fitness. At the same time, considering the distance between the individual particles and target location and the superiority-inferiority of the target point, α and β are impact factors. And then update the particle's position and speed according to the following equations, loop iteration to complete the selection of the optimal path.

$$v_{id} = \omega v_{id} + c_1 rand(P_{id} - x_{id}) + c_2 rand(P_{gd} - x_{id}) \quad (10)$$

$$x_{id} = x_{id} + v_{id} \quad (11)$$

In the equations, ω is the inertia weight, c_1 is for the weight coefficient of particle acceleration; c_2 is the weight coefficient of global accelerates, usually take $c_1 = c_2 = 2$, $rand$ is random number between 0, 1. In the process of calculation, if $v_{ij} > v_{\max}$, then $v_{ij} = v_{\max}$.

(4) The control of parameters

Improved algorithm has three important control parameters: nectar source that is the number m of possible solutions, giving up nectar source threshold $limit$, maximum cycle times MCN.

$limit$ is an important control parameters of the algorithm, is control the convergence of the algorithm, and decides the ability to jump out of local optimal. After $limit$ iterations, if the fitness of one nectar source x_i is still at the lower levels, then give up the nectar source, and by the scout bees through the equation (7) to create a new solution to instead of x_i.

Observed bees and employed bees perform local search, observed bees and scouts perform global search, to implement the balance of the algorithm between decentralized global search and chemotaxis local search.

3.2. PID control based on self-tuning optimization

The simulation frame diagram of the PID controller with the improved artificial swarm algorithm to optimize self-tuning is as follows.

In the figure 2, $r(t)$ is the reference input of system; $e(t)$ is the system error, k_P, k_I, k_D, are the PID gain of the algorithm output; $u(t)$ is the control of the PID controller; $y(t)$ is the output of the system.

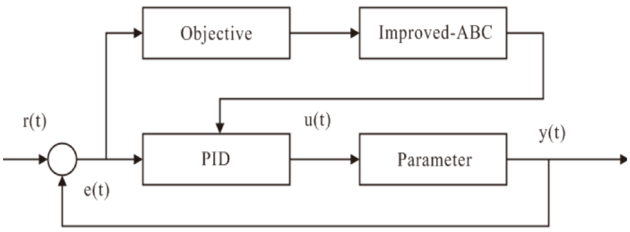

Figure 2. The improved PID control frame

The specific steps of the PID control based on self-tuning optimization are as follows.

(1) According to the characteristic information of the PID control system, determine the range and numerical precision of the three gain parameters K_P, T_d and T_i , and set the number M of populations of artificial swarm algorithm.

(2) The antibodies of the problem find out by PID control system in its memory or the M food source randomly generated are for initializing.

(3) Calculate the income efficiency of current food source and the largest fitness of the antibodies group as the elite antibodies.

(4) The followed bees choose food source according to the food source of revenue efficiency fit, p_i as the choice probability;

$$p_i = \frac{fit(i)}{\sum_{i=1}^{SN} fit(i)} \qquad (12)$$

(5) Update the location v_{ij} of the food source after every iterating by the following equation.

$$v_{ij} = x_{ij} + \alpha(x_{ij} - x_{kj}) \qquad (13)$$

x_{ij} is the position of the food source for this iteration, x_{kj} is randomly selected the location of the food source from the iteration before.

(6) Calculate the yield efficiency of new food source after iterative, that is, the fitness of antibody, compared with the fitness of the elite antibody in the record: if it is greater than the fitness of the elite antibody, replace the records of the elite antibodies; otherwise, continue.

(7) Calculate the antibody concentration at this moment according to the following equation.

$$a_i(t+1) = \frac{1}{1+\exp[0.5 - A_i(t)]} \qquad (14)$$

Some antibodies (food source) which are extracted proportionally from the current antibodies are for crossover operation and mutation operation with the same number of elite antibodies, produce new antibody is a new food source, and calculate the fitness of antibody that is the food source of revenue efficiency.

(8) If a food source is still not improved after a certain number of cycles, then it is abandoned by the bees, use the following equation to jump out of the food source location.

$$x_i^j = x_{\min}^j + rand(0,1)(x_{\max}^j - x_{\min}^j) \qquad (15)$$

In the equation, x_i is the location of abandoned food source, x_i^j is a new food source location, *limit* known as feeding cycle system, used to stipulate the number of iterations that jump out of local values.

(9) Determine whether the algorithm meet the objective function or not, if not satisfied, then jump to step (3) to continue; if meet the output, then output the optimal PID gains.

4. Performance simulation of the algorithm

To verify the effectiveness of the improved algorithm proposed in this paper, do simulation experiments on it. Start with 44 bees and 6 safe exits as an example, do the performance simulation of the improved artificial colony algorithm. Dot means the bee, square means security exit. Figure 3 for the 44 bees' state before running, figure 4 for the bees' state after fleeing.

We can see from figure 4, the number of particles falls in the big square is more than the number of particles falls in the small square. It proves that the improved algorithm has good convergence.

And then, Mark brand YS6120DG pure electric city bus as an example, the improved PID algorithm is adopted to carry out steering control. To test and verify the control effect of improved PID algorithm, compare the corresponding test results of the standard PID controller and the improved PID controller. Figure 5 shows the unidirectional rotating signal waveform with constant speed under the control of the standard PID. Figure 6 shows the unidirectional rotating signal waveform with constant speed under the control of the improved PID. Figure 7 shows the multistep step rotating signal waveform under the control of the standard PID and figure 8 shows the multistep step rotating signal waveform under the control of the improved PID.

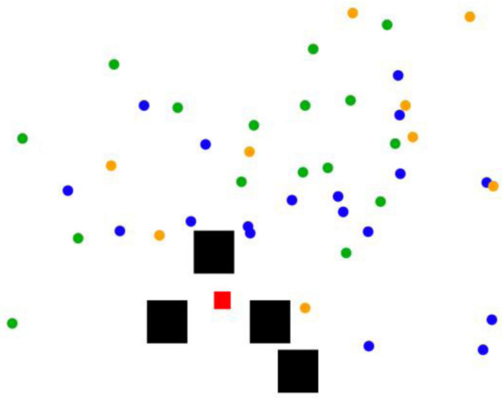

Figure 3. The 44 bees' state before running

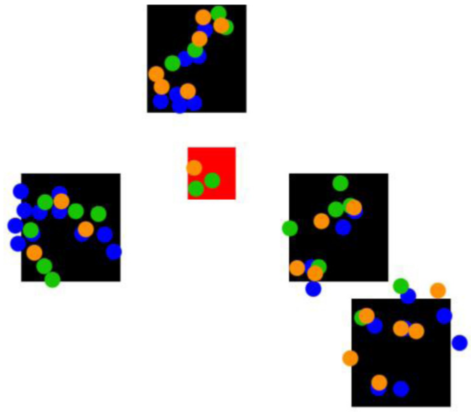

Figure 4. The bees' state after fleeing

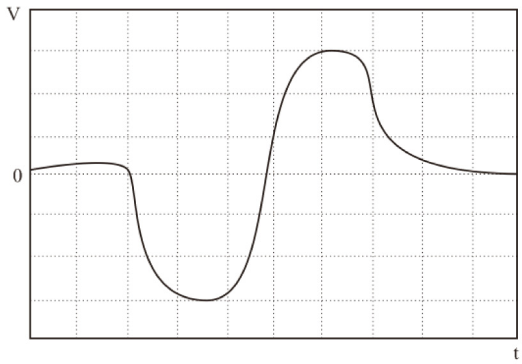

Figure 5. The unidirectional rotating signal waveform with constant speed under the control of the standard PID

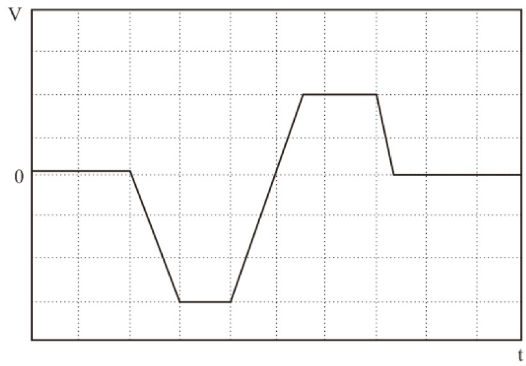

Figure 6. The unidirectional rotating signal waveform with constant speed under the control of the improved PID

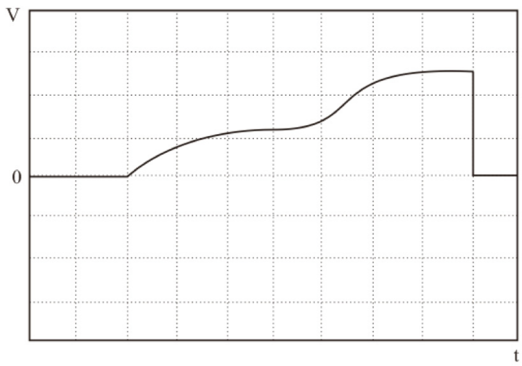

Figure 7. The multistep step rotating signal waveform under the control of the standard PID

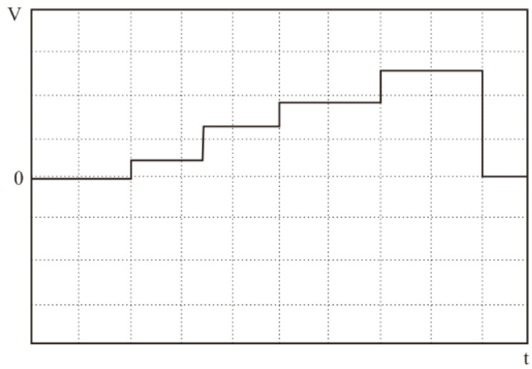

Figure 8. The multistep step rotating signal waveform under the control of the improved PID

Seen from the result, after adding the improved PID control, the speed waveform distortion of the signal input by steering wheel drives and smoothness are dramatically improved, then the control precision of the system is improve.

5. Conclusions

Because electric bus has the characteristics such as large weight, long running time and high safety factor, it is essential to find a safe and reliable power system. Electric hydraulic power steering system driven by motor driven hydraulic pump hydraulic system to provide the power-assisted steering, and control system according to the vehicle speed and the steering wheel input torque to judge and change the power size real-time which should be provided, to make the vehicle steering portability at low-speed and stability at high-speed. According to the defects of PID algorithm in the parameters control, a power steering control model is proposed based on improved swarm self-tuning optimization PID algorithm, the experimental simulation results show that the proposed improved model has better control effect, and it is worth using widely.

Acknowledgements

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