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Dynamic Performance-Oriented PID Optimization for BLDC Motor Speed Control via Enhanced Firefly Algorithm

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Abstract: This study proposes a multimodal factor mining method that integrates market data, financial texts, and social emotions to improve the accuracy and interpretability of stock market forecasts. Traditional factor models often rely on a single data modality and are difficult to fully describe market dynamics. This study introduces multimodal data integration to not only extract traditional factors from market fundamentals and technical indicators but also extract sentiment and topic factors from financial texts using natural language processing technology and generate investor influence and social sentiment factors by modeling social media data through graph neural networks. Experimental results show that the integration of multimodal factors significantly improves the prediction ability of the model, and the benchmark model shows superiority in indicators such as mean square error, directional accuracy, and prediction R2. At the same time, factor contribution analysis further verifies the complementary effects of market factors, text factors, and social factors, reflecting the practicality of multimodal methods. The research results provide an important reference for the application of multimodal data in financial markets and provide new ideas for building more intelligent factor models.

Keywords: Brushless DC Motor; Firefly Algorithm; Applicability Function; PID Setting.

1. Introduction

Brushless direct current motor (BLDCM) is widely used in fine control field because of its excellent mechanical and electrical characteristics, and PID control is always an important control method of BLDCM[1,3]. For PID parameter setting, most need to rely on the experience of technical personnel to adjust, strong dependence on the experience of technical personnel, often difficult to meet the control requirements[4,5].

Firefly optimization algorithm (FA) is a population intelligent optimization algorithm with global optimal search ability[6,7]. It only relies on fitness function and does not need to know all the information of the object[8,9]. In this way, even when the object model is uncertain, PID parameters can still be optimized according to the output of the object.

The commonly used fitness functions are mainly generalized functional integrals based on errors, including IAE, ITAE, ISTAE, ISE, ITSE and ISTSE[10]. However, the system control effects obtained by using these fitness functions for PID parameter tuning are different. They respectively focus on better control effects for a certain stage or state of the system[11]. It is difficult to have a comprehensive consideration of the whole dynamic and static process of the system.

Therefore, a fitness function based on the system dynamic performance index is proposed in this paper, and the PID parameters in the brushless DC motor speed control system are automatically adjusted by firefly optimization algorithm. The simulation results show that the PID parameters optimized by the response function have better control characteristics[12].

2. Design of BLDCM PID Control System Simulation Model

The control system of brushless DC motor uses the control mode of double closed-loop, which refers to the speed outer loop PID control and the current inner loop PID control. Speed outer ring PID is used to adjust the fluctuation of speed to achieve the purpose of stable speed. Current inner loop PID is used to stabilize the current and speed up the dynamic response of the system.

After confirming that the brushless DC motor simulation control system adopts double closed-loop control, it is particularly important to select suitable software to establish the simulation model. The simulation model built in the software can not only measure the pros and disadvantages of the control algorithm selected by the system, but also observe the dynamic and static performance of the system under different conditions. For the motor control system simulation model, Matlab software can achieve the above functions. In the Matlab Simulink environment, depending on its rich model library and modify the parameters of the module according to their actual needs, we can quickly complete the establishment of the system simulation model. The essence of the power system model library in Simulink is to encapsulate the mathematical model of the motor. The user only needs to drag and drop the module when establishing the simulation model, which greatly reduces the cycle of establishing the simulation model. In order to verify the rationality of firefly control algorithm, this section uses the powerful analysis and calculation ability of Matlab software, and uses the relevant modules in the power system model library in the Simulink toolbox to build the simulation model. The built model contains several modules with independent functions, as shown in Figure 1, including the motor body, back electromotive force detection, motor commutation, current detection, three- phase inverter, speed regulation and current regulation modules.

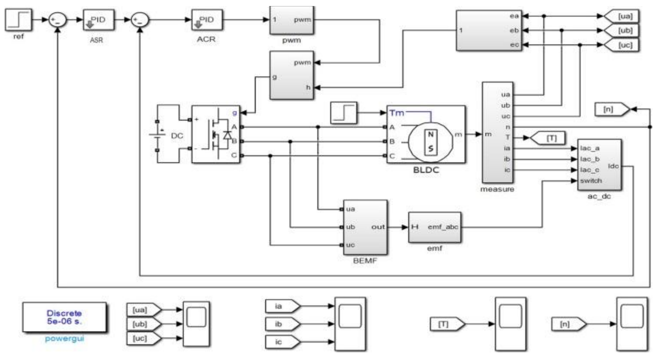

Figure 1. BLDCM PID control system simulation model

3. PID Self-tuning based on Improved Firefly Optimization

3.1 The Principle and Characteristic of Firefly Algorithm

3.1.1 The Principle of the Firefly Algorithm

Firefly algorithm makes use of the characteristic that the light emitted by fireflies attracts other individuals, and designs the corresponding objective function according to the actual needs. Through calculation, the moving direction and distance of individual fireflies are determined. Fireflies with lower brightness will move closer to fireflies with higher brightness, and fireflies will gradually move closer to the relatively brighter area during the continuous position update. Finally, the value of the space position of the brightest firefly is taken as the optimal solution of the objective function.

3.1.2 The Characteristics of Firefly Algorithm

Self-organization.In the complex optimization process, it is not necessary to know the internal specific information, only need to calculate the fitness value of the objective function. After the initialization of firefly population is completed, individual fireflies within the population will calculate the fitness value of the objective function and determine the direction and distance of the next movement by relying on the information of fireflies near them.

Parallel computation.Firefly algorithm draws on the movement pattern of firefly group. In the process of the movement of firefly group, there is no clear movement guide, and the individual firefly does not need to consider the global information when moving, so it is easy to realize parallel processing of firefly algorithm. In order to shorten the running time of the algorithm, parallel calculation can be carried out on multiple computers.

Global search.Firefly algorithm is a random optimization algorithm. When solving the fitness value of the objective function, it is not easy to fall into the dilemma of local search. It will carry out effective global search in the search space to find the global optimal solution.

The principle of firefly algorithm is simple and easy to understand. It mainly carries out two and two traversals of firefly individuals within the firefly population. Fireflies with lower brightness will move towards fireflies with higher brightness, so as to calculate relative brightness and attraction, so as to achieve target optimization.

3.2 Improvement of Fitness Function

The steady-state error of the step response of the brushless DC motor system controlled by PID is zero, so only the dynamic performance of the system needs to be considered when designing the fitness function. In this paper, a new fitness function is proposed by taking the dynamic performance index as the direct evaluation parameter, and its mathematical expression is shown in Formula 1.

$$K = M_1F + M_2S. \tag{1}$$

Where, F(Fast) is used to describe the rapidity of the system;S(Stability) is used to describe the relative stability of the system; M1 and M2 represent the weight of F and S respectively.

The rapidity and relative stability in the dynamic performance of the system are often contradictory. In general, the faster the system is, the greater the overshoot and the greater the number of oscillations, the worse the relative stability and the better the relative stability of the system, the worse the rapidity of the system. Therefore, the motor control always needs to be balanced between the speed and stability according to the actual situation, and constantly modify the control parameters so as to achieve a relatively optimal system strategy. By modifying M1 and M2, the weights of F and S in the whole formula can be changed, so as to modify the focus direction of automatic optimization. For example, increasing the value of K can make the optimization tilt to the aspect of rapidity. In this way, the ideal PID parameters can be obtained more conveniently and quickly in the optimization process, and the PID tuning process becomes more simple and effective. The PID tuning process based on improved firefly algorithm is shown in Figure 2.

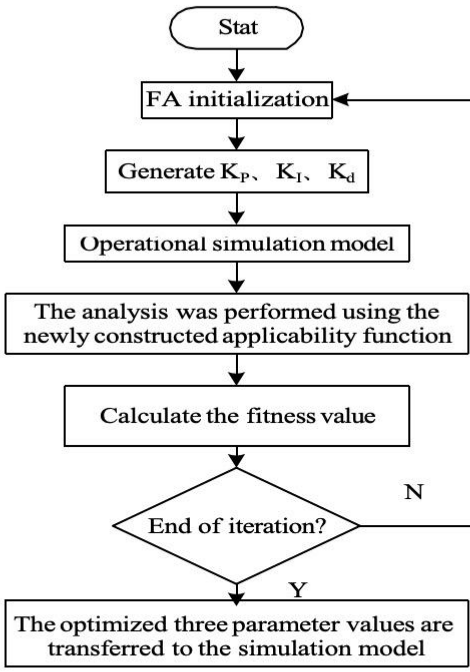

Figure 2. The PID tuning process based on improved firefly algorithm

4. Simulation Results and Analysis

In this paper, the traditional PID control mode and the PID control mode based on the improved firefly algorithm are respectively used to change the speed regulator in the brushless DC motor control system. The two control modes are simulated under the same external parameters of the brushless DC motor.

4.1 Simulation Results and Analysis of No-Load Start-up Reaching the Given Speed

In order to explore the change of overkill and response speed of the brushless DC motor control system under the traditional PID control mode and the PID control mode based on the improved firefly algorithm, no load was added when the motor was started and the given speed was set at 60000r/min.

It can be seen from FIG. 3 and 4 that the PID control based on the improved firefly algorithm has a small overshoot and no obvious fluctuation, while the traditional PID control has a large overshoot and a large fluctuation range. The time required for the system using PID control based on the improved Firefly algorithm to reach the given speed of 60000r/min is shorter than the time required for the system using traditional PID control to reach the given speed of 60000r/min. It can be seen that the PID control method based on the improved firefly algorithm has faster response speed and smaller overshoot when the no-load startup reaches the same speed.

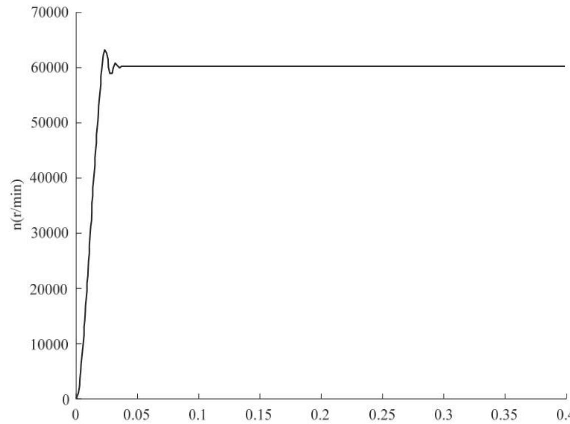

Figure 3. Speed curve of traditional PID during no-load startup

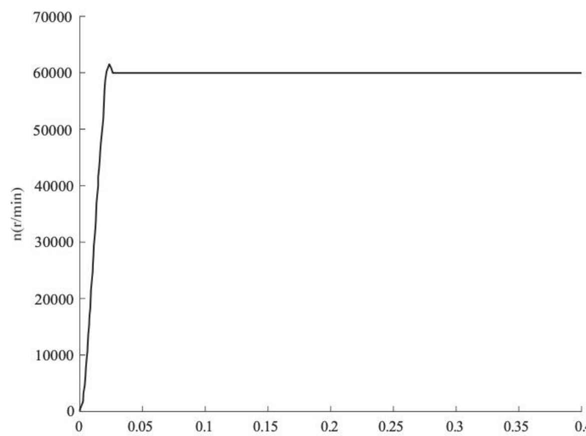

Figure 4. Improve the speed curve of firefly PID during no-load startup

4.2 Simulation Results and Analysis of Sudden Load Experiment at Given Speed

In order to verify the anti-interference capability of the brushless DC motor control system under the traditional PID control mode and the PID control mode based on the improved firefly algorithm, no load is added when the motor is started and the given speed is set at 60000r/min. When the motor speed is stable, when t=0.2s, Increase the load torque of the motor from 0N.m to 3N.m.

4.3 Simulation Results and Analysis of Speed Change under Set Load

Set the initial speed to 60000r/min and the initial load torque to 1N.m. Change the speed from 60000r/min to 70000r/min at 0.15s. The purpose of the simulation experiment to change the speed after starting with a given load torque is to verify the ability of the brushless DC motor control system to adjust the speed using the traditional PID control mode and the PID control mode based on the improved firefly algorithm.

As can be seen from FIG. 5 and FIG. 6, when the speed changes from 60000r/min to 70000r/min, the PID control method based on the improved firefly algorithm has much smaller speed fluctuation than the traditional PID control method. Combined with the adjustment time and speed fluctuations, it can be seen that under the condition of the same initial load torque, the PID control method based on the improved firefly algorithm has better speed adjustment ability than the system using the traditional PID control method.

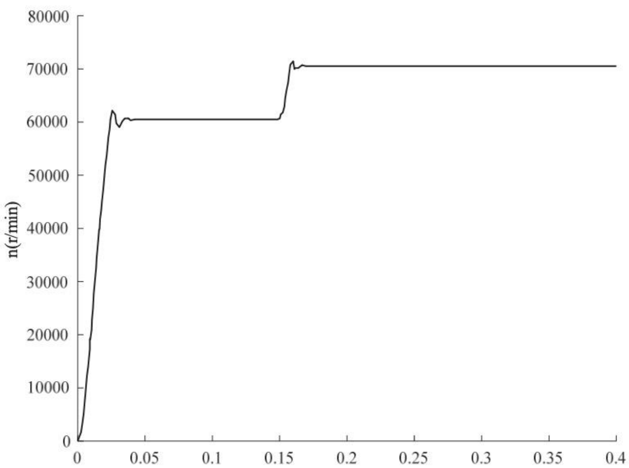

Figure 5. Speed curve of traditional PID when speed changes abruptly

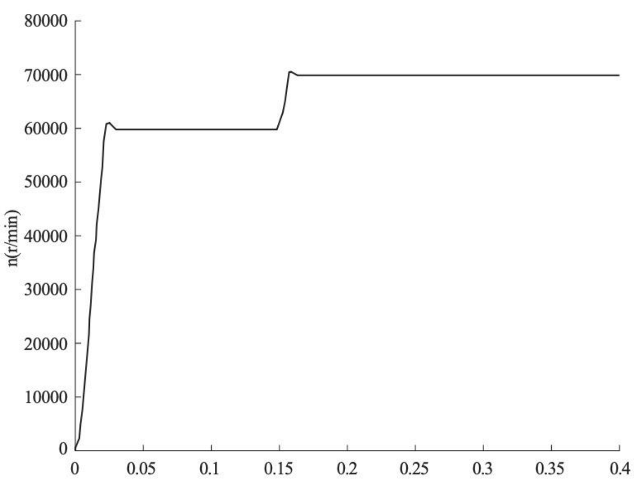

Figure 6. The PID speed curve of firefly is improved when the speed changes abruptly

5. Conclusion

The traditional PID simulation model of brushless DC motor control system and the PID simulation model based on the improved firefly algorithm were built, and the simulation experiments were carried out under the three conditions of no-load starting, sudden loading and changing speed under the given load at the same speed. Finally, by comparing with the simulation results of the traditional PID control brushless DC motor control system, it is proved that the PID control system based on the improved firefly algorithm has the advantages of small overshot, fast response speed and strong anti- interference ability.

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