Research step of PID control method of stepper motor based on improved fuzzy control algorithm

Zichi Zhang[1], Xiangding Meng[2], Yilei Kou[3]

[1,2,3]College of Electrical Engineering, North China University of Science and Technology, 063210, Tangshan, Hebei Province, China

Abstract

The significance of PID control within the management system of stepper motors is noteworthy; nonetheless, it is worth noting that stepper motors are susceptible to issues such as low power, step loss, and vibration. The conventional Proportional-Integral-Derivative (PID) control method is insufficient in addressing the control challenge specific to stepper motor management systems. Hence, this research work presents an enhanced fuzzy control method that integrates the principles of fuzzy control theory with traditional PID control theory. The integration of fuzzy control into the P ID control is undertaken to create a fuzzy controller that satisfies the demands of stepper motor control. Additionally, the division of indices is conducted in accordance with the specifications of the fuzzy controller in order to mitigate the disruptive elements of PID control. then, the use of fuzzy control rules is employed to achieve control over the stepper motor, resulting in the development of an enhanced scheme that is then subjected to rigorous validation. The present study employs a MATLAB simulation to compare the performance of the enhanced fuzzy control algorithm with that of the P-ID control method. The results demonstrate that the improved fuzzy control algorithm significantly enhances the stability and dynamic performance of the stepper motor. Superior to traditional Proportional-Integral-Derivative (PID) control.

Keywords: PID control; Improved fuzzy control algorithm; management systems; Theory

Received on 01 December 2023, accepted on 20 February 2024, published on 26 February 2024

doi: 10.4108/eetsis.5205

*Corresponding author. Email: 3257414465@qq.com

1. Introduction

The management of stepper motors is a crucial component of servo system control and has significant importance within the realm of motor control technology [1]. Nevertheless, within the context of the PID control process, it is worth noting that the PID control scheme exhibits inherent issues such as vibration and motor frequency instability. These challenges, in turn, impose a certain level of financial burden on the firm [2]. Certain academics argue that the enhanced fuzzy control algorithm is used in the management system for stepper motor control, and it is combined with the traditional PID control [3]. Through this integration, the benefits of both control systems are identified, hence offering appropriate reinforcement for PID control [4]. This research aims to enhance the fuzzy control algorithm, optimise the PID control scheme, and validate the efficacy of the model [5-6].

2. Related Concepts

2.1. Improved mathematical description of the fuzzy control algorithm

The enhanced fuzzy control algorithm aims to enhance the performance of the PID control scheme by integrating fuzzy control theory with classical control theory. It involves identifying unfavourable factors in the stepper motor management system based on the indicators specified in the fuzzy control rules. Subsequently, adjustments are made to the PID control scheme. Ultimately, the feasibility of the stepper motor management system is evaluated. The enhanced fuzzy control algorithm integrates the merits of classical control theory and quantifies it via the implementation of the stepper motor management system. This integration enables the improvement of both the precision of PID control and the operational efficiency of the stepper motor, while simultaneously reducing the occurrence of failures.

Hypothesis I. The total load of the motor rotor is J, the electromagnetic torque is T, the load torque is T_i, the self-inductance is L_{ij}, and the mutual inductance is L_{ik}, as shown in Equation (1).

$$T=\frac{1}{2}\sum_{\partial\theta}^{\partial L_{ij}} i_j^2+\frac{1}{2}\sum_{\partial\theta}^{\partial L_{ik}} i_j i_k\cdot\frac{d\theta}{dt} \quad (1)$$

2.2. Selection of stepper motor management scheme

Hypothesis II. Self-inductance is L, resistance is R, angular velocity is J, then, the fuzzy control rule requires the unqualified stepper motor management system as shown in Equation (2).

$$J=\frac{d^2\theta}{dt}+D\frac{d\theta}{dt}+k_m i_A(Z,\theta) \quad (2)$$

2.3. Analysis of PID control schemes

Prior to enhancing the fuzzy control algorithm, it is essential to conduct a comprehensive analysis of the PID control scheme across several dimensions. Additionally, it is necessary to align the PID control specifications with the stepper motor management system library in order to eliminate any incongruities with the fuzzy control rules. The first phase of the stepper motor management system involves conducting a thorough analysis, wherein the threshold and index weight of the fuzzy control rule are established to guarantee the precision of the fuzzy control algorithm. The current stepper motor management system uses a PID control approach, which requires further improvement and analysis. The accuracy of the overall PID control may be compromised if the PID control method is applied to a stepper motor management system that exhibits nonlinearity. To enhance the precision of the fuzzy control algorithm and elevate the proficiency of PID control, it is necessary to choose for the PID control scheme. The selection of the particular scheme is shown in Figure 1.

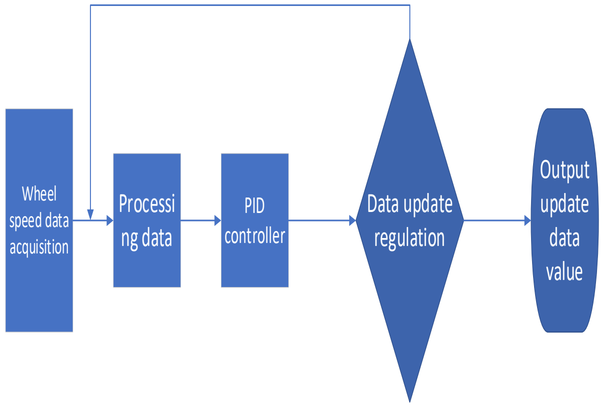

Figure 1. Selection results of stepper motor management scheme

The examination of the PID control scheme reveals that the management approach for the stepper motor exhibits a linear and multi-dimensional distribution, aligning with empirical evidence. The use of the stepper motor control method is justified by its inherent stochastic nature, making it suitable for rigorous analytical investigation. The linear requirements of the stepper motor management system are effectively addressed through the utilisation of fuzzy control theory. This approach enables the adjustment of the stepper motor management system, thereby eliminating the error value present in classical control systems. By combining the strengths of both fuzzy control and classical control systems, the overall PID control scheme exhibits a robust dynamic correlation.

3. Optimization strategy of stepper motor management system

The fuzzy control method employs a random optimisation technique for the management system of the stepper motor. It modifies the motor data parameters based on fuzzy control rules to optimise the scheme of the stepper motor management system. The enhanced fuzzy control method partitions the stepper motor management system into several PID control tiers, and stochastically picks various strategies. The iterative process involves the optimisation and analysis of the best performing PID control system across several levels of PID control. Following the completion of the optimisation study, a comparison is conducted among the PID control systems of various schemes in order to document the most effective management of the stepper motor.

4. Practical case of stepper motor management system

4.1. PID Control Briefing

In order to facilitate PID control, the stepper motor management system in complex cases is the research object, with 12 paths and a test time of 24 h, and the PID control scheme of the stepper motor management system is shown in Table 1.

Table 1. Fuzzy control rule requirements

Model	Maximum static torque	Startup frequency	Operating frequency
Reactive stepper motor	86.90	85.02	89.97
Permanent magnet stepper motor	83.94	89.79	94.02
Hybrid stepper motor	89.46	85.89	88.92
Single-phase stepper motor	87.56	85.72	87.80
Planar stepper motor	80.46	86.98	90.37

The PID control process for the fuzzy control rule in Table 1. is shown in Figure 2.

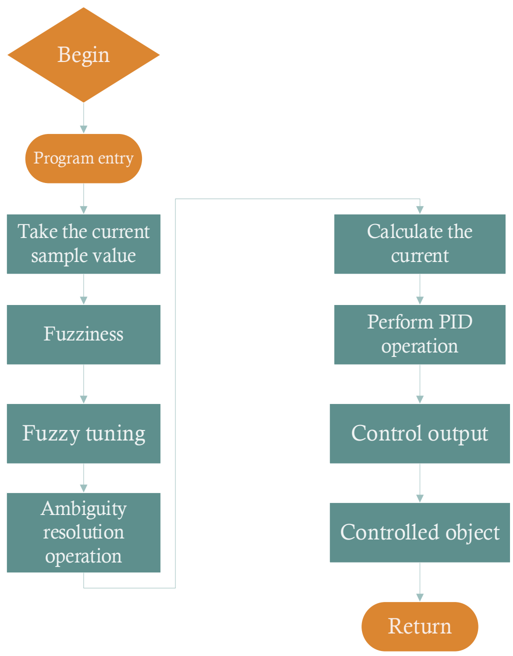

Figure 2. Analysis process of stepper motor management system

The PID control scheme used in the enhanced fuzzy control algorithm exhibits a greater adherence to the stipulated needs of the fuzzy control rules when contrasted with the classical control effect. The enhanced fuzzy control method outperforms the conventional control technique in terms of stepper motor management system accuracy and motor oscillation. The enhanced fuzzy control method has superior stability and increased operational efficiency, as shown from the modification of the PID control scheme depicted in Figure 2. Consequently, the enhanced fuzzy control method has effectively optimised the accuracy, failure rate, and operational efficiency of the PID control.

4.2. Stepper motor control management system situation

The control method for the stepper motor management system incorporates three types of information: non-structural, semi-structural, and structural. Following the preselection process of an enhanced fuzzy control algorithm, a prototype PID control scheme is derived. Subsequently, an analysis is conducted to assess the viability of implementing the PID control scheme inside the management system of a stepper motor. To enhance the accuracy of verifying the effectiveness of stepper motor control management, a stepper motor control management system is chosen with varying degrees of fuzzy control rules and a PID control scheme, as shown in Table 2.

Table 2. Stepper motor management scheme situation

Category	Satisfaction	Analysis rate
Maximum phase current	91.60	91.15
Maximum phase voltage	88.44	91.47
Operating frequency	87.54	85.42
Low frequency oscillation frequency	86.00	86.05

4.3. PID-controlled stepper motor control management and stability

In order to verify the accuracy of the improved fuzzy control algorithm, a scheme is compared with the classical PID control, and the comparison scheme is shown in Figure 3.

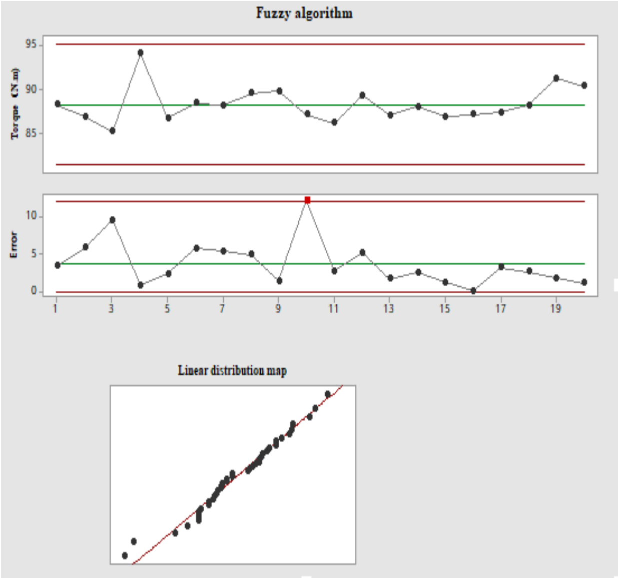

Figure 3. Stepper motor control management with different algorithms

The data presented in Figure 3 demonstrates that the management of stepper motor control using the enhanced fuzzy control algorithm surpasses that of the conventional PID control. The frequency error rate of the motor is lower, and the motor exhibits a stable state. These findings suggest that the PID control implemented within the improved fuzzy control algorithm is comparatively stable. The conventional proportional-integral-derivative (PID) control has non-uniform characteristics. Table 3 displays the average PID control scheme for the aforementioned two techniques.

Table 3. Comparison of PID control accuracy of different methods

algorithm	Stepper motor control management	Magnitude of change	Error
Improved fuzzy control algorithm	87.94	88.88	0.91
Classic PID control	85.62	92.33	6.72
P	35.12	33.87	35.10

The analysis of Table 3 reveals that the conventional PID control method has deficiencies in both the management of stepper motors and the stability of the overall stepper motor control system. Furthermore, the stepper motor management system has experienced significant modifications, resulting in a notable increase in error rates. The performance of the revised fuzzy control algorithm in managing stepper motors is superior and more effective compared to the conventional P-ID control method. Simultaneously, the enhanced fuzzy control algorithm exhibits a stepper motor management rate of 90%, while maintaining a relatively consistent level of precision. To enhance the validation of the enhanced fuzzy control algorithm, several analytical techniques are used to assess its performance, as seen in Figure 4.

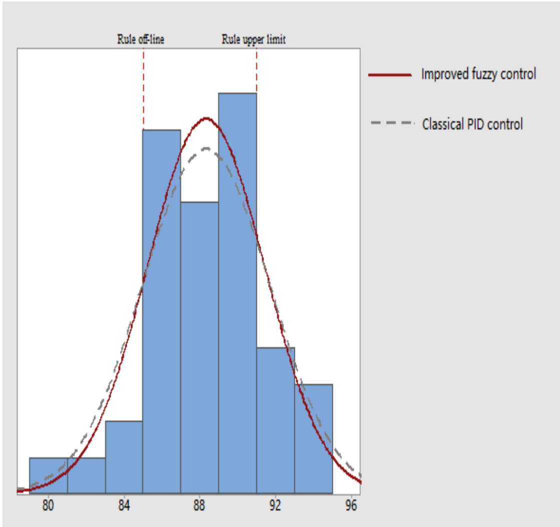

Figure 4. Improved fuzzy control algorithm PID-controlled stepper motor management

The superiority of the improved fuzzy control algorithm in managing the stepper motor can be observed in Figure 4. This can be attributed to the integration of fuzzy control and PID control in the improved algorithm, which allows for the identification and utilisation of the most advantageous rules through fuzzy control. By setting rule thresholds, non-compliant PID control schemes are effectively excluded from consideration. In order to mitigate the occurrence of vibration phenomena, the implementation of a fuzzy PID controller can efficiently return the system to its normal operational state and rectify the error induced by step loss and vibration in real-time.

5. Conclusion

This paper addresses the issue of inadequate control management in stepper motor systems. To tackle this problem, an enhanced fuzzy control algorithm is proposed. The algorithm integrates the principles of fuzzy control theory with classical PID control theory to develop a fuzzy PID controller specifically designed for stepper motors. The effectiveness of this controller is evaluated through MATLAB simulation and verification, alongside the comparison with classical PID control. The suggested fuzzy control algorithm in this study exhibits considerable enhancements in the smoothness, vibration reduction, and operational efficiency of the stepper motor system, as compared to the control effect achieved by the conventional method.

Acknowledgements

National Innovation and Entrepreneurship Training Program for College Students 202210081008

References

[1] Pichainarongk, S., & Bidaisee, S: An Assessment of High-Performance Work System Theory towards Academic De-velopment, Work Environment and Promotion in Higher Education: A Thailand and International Comparison, Educational Administration: Theory and Practice.2022; 28(03): 13–28.

[2] Al AlI, R., & Fathi Abunasser: Can the Leadership Capabilities of Gifted Students be Measured? Constructing a Scale According to Rasch Model, Educational Administration: Theory and Practice. 2022; *28*(03): 109–126.

[3] Mesiono: Model of Education Management using Qualitative Research Methods at a Private School in Medan, Educational Administration: Theory and Practice.2022; *28*(02): 88–93.

[4] Garg, M. ., Sharma, S. ., Balu, M. V. ., Sinha, D. K. ., Bhatt, D. P. ., & Bhagat, A. K: Underwater Acoustic Sensor Network Data Optimization with Enhanced Void Avoidance and Routing Protocol, IJCNIS. 2022; 14(3): 150–162.

[5] Liu, E., & Yifei Li: Research on the implantation and dissemination strategy of short creative advertising videos in the new media era, IJCNIS. 2023;15(1): 146–161.

[6] Batyha, R. M. ., Janani, D. S. ., Hymlin Rose, D. S. G. ., Lolandes, Y. G. ., Ortiz, G. G. R. ., & Navaz, S: Cyclostationary Algorithm for Signal Analysis in Cognitive 4G Networks with Spectral Sensing and Resource Allocation, IJCNIS.2022; 14(3): 47–58.