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PID control combined with control to improve DC motor speed regulation adaptability

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Abstract:

PID control has become the cornerstone of industrial control with its simple structure and efficient computation, but its adaptability to dynamic working conditions depends on precise parameter adjustment. To overcome this limitation, this paper thoroughly investigates the combination of fuzzy control and PID control, and dynamically adjusts the PID parameters by introducing fuzzy logic, thus significantly improving the adaptability and robustness of the DC motor speed control system. Through theoretical derivation and detailed simulation verification, the fuzzy PID control strategy proposed in this paper shows excellent performance under a variety of dynamic loads and complex environments.

Keywords: PID control, fuzzy control, DC motor, speed regulation, adaptive control.

1. introduction

DC motors have a high efficiency and are easy to control, making them widely used in the critical industrial fields affected by the rapid development of industrial automation and intelligent technology. And Conventional PID Controller executes very poor under the load disturbances, nonlinear dynamic characteristics and environmental uncertainties. The reason for this is the strong sensitivity of conventional PID control parameters in real-time working environment and the fact that the PID parameter optimization process relys on empirical manual debugging, which bring plenty of difficulties to cater for intense and difficult working condition of the device.

Recently, fuzzy control has been an important means to complement PID control and improve the performance of PID control with its superiority of not relying on accurate mathematical models and solving nonlinear problems. P, PD and PID controllers can be applied to this at lv to analyse the system, but in order to overcome the limitations of these traditional controllers fuzzy logic can be added to change the control parameters dynamically as well as to confront the adaptability and robustness of the system for dynamic changes. The majority of existing studies are still in the initial theoretical validation stage, and there is a scarcity of systematic analysis and validation on the performance of fuzzy PID control under complex working conditions.

This is why, in this paper, the method of combining fuzzy control and PID was explored, and numerical feedback for the PA system design and the simulations analysis was given, intending to provide theoretical guidance and concrete framework for indus-

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try practice.

2. PID control principle and its limitations

The PID controller controls the system through three functions: proportional (P), integral (I) and differential (D). Its mathematical expression is:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{de(t)}{dt} \tag{1}$$

where e(t)e(t) is the error between the setpoint and the actual value, and Kp, Ki, and Kd are the proportional, integral, and differential gain coefficients, respectively. Although the PID controller performs well in steady-state error elimination and dynamic characteristic optimization, its limitations are mainly reflected in

1. complexity of parameter tuning: traditional parameter tuning methods (e.g., Ziegler-Nichols method) rely on empirical debugging and are difficult to cope with variable environments.
2. lack of robustness: sensitivity to system parameter changes and external disturbances leads to unstable performance.
3. poor adaptability to nonlinear systems: they cannot effectively deal with nonlinear and time-varying characteristics.

3. Overview of Fuzzy Control Methods

The fuzzy control approach translates control logic expressed verbally by a human into accurately defined control plans using fuzzy sets and fuzzy rules. Its key steps include

1. Fuzzification: the process of mapping input variables such as error and rate of change of error into linguistic or fuzzy sets.
2. fuzzy inference: empirically derived rules-table defining output fuzzy sets.
3. Defuzzification: The process of converting fuzzy sets to specific control values.

In DC motor speed control, fuzzy control can also adjust PID parameters in real time and greatly improve the system performance under dynamic operation [4]. It has the following advantages over traditional PID control

- Having strong adaptability: it does not have to depend on exact mathematical models, it can also be adapted to nonlinear and time-varying systems.
– Excellent robustness: Very strong anti-interference ability under complex working conditions.
- Real-time responsiveness: It can timely update the control strategy based on the real-time changes of the operating conditions.

4. Combination Strategy of Fuzzy Control and PID

4.1 Fuzzy PID Control Design

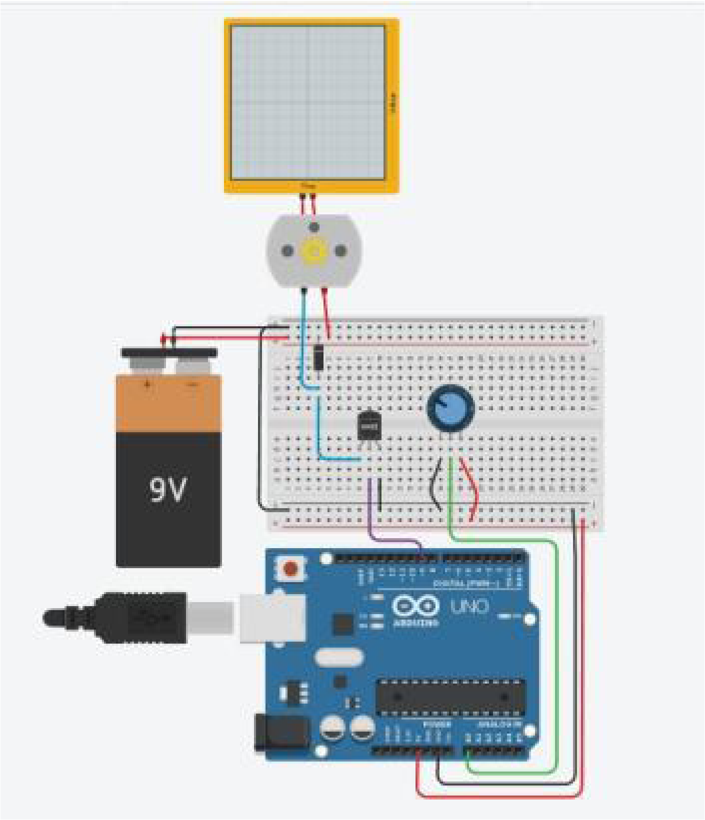
By introducing fuzzy logic here, the system can timely adjust the Kp, Ki and Kd, enabling the system responding quickly and maintaining stability under external disturbances.

Kp (proportional gain): governs the system's response to the existing error. Using a large Kp helps the system respond to the error faster, but may cause even oscillations.

Ki (integral gain): eliminates steady-state errors. Ki, on the other hand, corrects the accumulated error when the system has been away from the desired target value for a long time.

Kd: [differential gain used to predict the trend of error changes, so it can eliminate the overshoot and oscillation of the system.]

This design constructs a fuzzy reasoning system from existing experience rules, self-tunes PID parameters to meet the context needs of control, and finally establishes an efficient and stable composite control strategy.



4.2 Some other intelligent control methods

While neural networks and genetic algorithms can find the global optima in theory, both of them need a lot of computing time to train, which does not suit real-time control, as opposed to fuzzy control which will be treated in the rest of the study, and it is very speedy. 。

5. Verification through simulation and experimental results

5.1 Simulation platform setup and experimental design

It is utilized to design a model of the DC motor control system due to testing the performance of the fuzzy PID controller through typical working conditions such are load disturbances and parameters varying.

Same, Arduino UNO, MOSFET, DC motor, speed sensor (rotary encoder / potentiometer) and a 9V battery should use as the analogy circuit

The circuit design is an important part of the system hardware, mainly to complete the connection between the controller, sensor, motor and power supply. Through closed-loop control, the whole circuit achieves the effect of real-time adjustment of motor speed.

5.2 Performance Indicators

Types of Error in Control System:- —Steady state error: It shows the accuracy of controller.

- Overshoot: Measures smoothness and safety of the systems response.
- Response Time: Measures how fast the system reach stabled state from start state
- Robustness: Checks how well the system can adapt to events happening in the external world and changes to the load.

5.3 Simulation Results

1. A) Rapid adjustment to abrupt load change:

The fuzzy PID control system has a dynamic adaptability in case of sudden load changes, which can rapidly adjust the parameters and greatly reduce the steady-state error. Because through the dynamic updating of fuzzy rules, the control system can respond accurately to changes in complex working conditions.

2. High anti-interference performance:

Fuzzy PID control has more advantages of anti-jamming than traditional PID control. This has also led to research on fuzzy-PID systems, where coming across disturbances such as noise interferences, the fuzzy logic would dynamically adjust the PID parameters, then suppressing quickly the alteration caused by the interference to guarantee

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system stability.

3. Robustness improvement:

Fuzzy control has high robustness in non-linear complexity environment. For parameter uncertainty or modeling error, fuzzy control dynamically modifies the control strategy by fuzzy reasoning so that the system still has good performance in the face of various uncertainties. As such, it reflects the robustness strength and is well suited to industries dynamic control.

The simulation and validation results show that the fuzzy PID control can maintain high control performance in variable environment, the parameter dynamic adjustment mechanism enhancesthe robustness and ability of resist interference much more better than traditional PID controller.

6. Conclusion and Outlook

Fuzzy control (FC) with proportional-integral-derivative (PID) is a common combination control method to apply to DC motors exerting dynamic control for higher precision meanwhile better efficiency [5]. Fuzzy PID control is adopted to eliminate the effect of parameter sensitivity in traditional PID, so that the dynamic performance and adaptability of the system are effectively improved.

Future research directions can be:

1. Deepen the fuzzy rule optimization algorithm, and improve control accuracy and computational efficiency;
2. Applications of Multiple Motors in MultiMotor Cooperative Control[1]
3. industrial embedded hardware design and development

And the content of this article is just a review to explain the viewpoints. I will do some actual research later to discuss more content.

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