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Research on Intelligent Vehicle Control based on PID Algorithm

Yuhang Zhang*

School of Management Science and Engineering, Anhui University of Finance and Economics, Bengbu, Anhui, 233030, China

*1512013871@qq.com

Abstract

With the development of autonomous driving technology, the design and optimization of intelligent vehicle control systems have become a hot topic of research. This paper mainly studies an intelligent vehicle control system based on the improved PID algorithm, especially the application of fuzzy PID control strategy. In view of the limitations of traditional PID control in dealing with actual road conditions, this paper proposes a new type of fuzzy PID control strategy. By using fuzzy logic to optimize the PID parameters in real time, the performance and robustness of the intelligent vehicle control system are improved. The research work includes theoretical analysis, simulation experiments, and result analysis, which verify the obvious advantages of fuzzy PID control in response speed, control accuracy, and robustness compared with traditional PID control. In addition, this paper also provides a system performance evaluation framework, laying a foundation for further research and practical application of intelligent vehicle control systems. Despite certain research results, there are still some limitations, such as the difference between simulation experiments and actual road tests, and the empirical issues of parameter tuning. Future work will focus on optimizing parameters based on data-driven methods, as well as testing and verification on real vehicles.

Keywords

Intelligent Vehicle; PID Control; Fuzzy Logic; Adaptive Control; Autonomous Driving.

1. Introduction

With the rapid development of autonomous driving technology, intelligent vehicles, as an important part of this field, are gradually becoming a hot topic of research [1]. Intelligent vehicles rely on advanced control systems to achieve accurate path planning and tracking, as well as adaptation to complex traffic environments. Among many control algorithms, the Proportional-Integral-Derivative (PID) control algorithm is widely used in the speed and direction control of intelligent vehicles due to its simple structure, high stability, and ease of implementation.

However, the operation of intelligent vehicles under actual road conditions faces the challenges of high nonlinearity and uncertainty, and traditional PID control strategies may not meet increasingly strict performance requirements. This requires us to innovate and improve the PID algorithm to adapt to the complexity and variability of intelligent vehicle control systems.

This paper aims to study and develop an intelligent vehicle control system based on the improved PID algorithm. By introducing advanced control theories and technologies, we aim to overcome the limitations of traditional PID control and improve the performance and robustness of intelligent vehicles under various operating conditions [2]. The main contributions of this research include: proposing a new type of PID control strategy that realizes optimized control of the direction and speed of intelligent vehicles; verifying the

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effectiveness of the proposed method through simulation and experiments; and providing theoretical basis and practical guidance for the design of intelligent vehicle control systems.

Intelligent vehicle technology, as a revolutionary progress in the field of transportation, integrates sensors, computers, communication, and automatic control technologies to achieve the intelligence and automation of vehicles [3]. Intelligent vehicles can perceive the surrounding environment, make decisions, and execute corresponding control commands to safely and efficiently complete driving tasks. Among the key technologies of intelligent vehicles, the control system plays a central role, directly determining the stability and responsiveness of the vehicle.

The PID control algorithm, as the cornerstone of industrial control fields, has been widely applied in intelligent vehicle control due to its simple structure, ease of implementation, and adjustability. The PID controller, through the synergistic action of proportional (P), integral (I), and derivative (D) links, can accurately control the driving state of intelligent vehicles. However, due to the complexity of actual road conditions and the nonlinear and time-varying characteristics of vehicle dynamic models, traditional PID control strategies face many challenges [4].

Firstly, intelligent vehicles will encounter various uncertain factors during driving, such as changes in road surface friction coefficients, uncertainty of traffic signals, and dynamic interference from surrounding vehicles. These factors may all affect the performance of the PID controller [5]. [Secondly, the dynamics model of intelligent vehicles usually has nonlinear and time-varying characteristics, making it difficult for traditional linear PID control to adapt to rapidly changing control requirements. In addition, the intelligent vehicle control system often needs to meet various performance indicators such as real-time, stability, and high precision, which puts forward higher requirements for the adjustment and optimization of PID parameters.

In response to the above issues, scholars at home and abroad have carried out a lot of research work. Some studies have introduced advanced control theories, such as fuzzy logic, neural networks, and adaptive control, to enhance the robustness and adaptability of PID control. Other studies have focused on the online optimization and adaptive adjustment of PID parameters to improve the performance of intelligent vehicles in complex environments. However, how to design an intelligent vehicle control system that can meet performance requirements and adapt to complex and changeable environments is still an open research question.

This research is carried out against this background. Through in-depth analysis and improvement of the existing PID control algorithm, we aim to propose a more intelligent, flexible, and robust control strategy to meet the control needs of intelligent vehicles under various actual road conditions. This is not only of great theoretical significance in promoting the development of intelligent vehicle technology but also has practical application value in improving road traffic safety and efficiency.

2. Research Methods

He precision and robustness of the intelligent vehicle control system are crucial for autonomous driving technology, and the application of the PID control algorithm in this field has been widely recognized and deeply studied.

2.1. Traditional Application of PID Control Algorithm

The Proportional-Integral-Derivative (PID) control algorithm is a classic control strategy that reduces the deviation between the system output and the desired value by adjusting the control amount. In the field of intelligent vehicles, the PID control algorithm is mainly applied to two key aspects: speed control and direction control:

Speed Control: The PID controller dynamically adjusts the throttle or brake according to the deviation between the actual speed of the intelligent vehicle and the target speed to maintain a stable speed.

Direction Control: By adjusting the steering angle, the PID controller can keep the driving direction of the intelligent vehicle consistent with the predetermined path, achieving precise path tracking.

Early research focused on manually adjusting PID parameters, where researchers determined suitable proportional gains (Kp), integral gains (Ki), and derivative gains (Kd) through experiments and trial and error. These parameters directly affect control stability, response speed, and overshoot. Although the manual adjustment method is effective in some cases, it lacks the ability to adapt to changes in complex working conditions.

2.2. Adaptive PID Control Strategy

To overcome the limitations of traditional PID control algorithms under different working conditions, researchers have developed a series of adaptive PID control strategies [6]. The core of these strategies is the ability to dynamically adjust PID parameters according to the actual operating state and environmental changes of the intelligent vehicle:

Adaptive Mechanism: Adaptive PID controllers usually include an adaptive mechanism that can monitor the performance of the control system in real time and adjust PID parameters according to changes in performance indicators.

Environmental Perception: The sensor array on the intelligent vehicle can provide information about vehicle speed, direction, surrounding environment, etc. Adaptive PID controllers use this information to predict changes in control requirements.

Parameter Optimization: Through algorithms such as gradient descent and genetic algorithms, adaptive PID controllers can optimize parameters during operation to achieve better control performance.

Research on adaptive PID control strategies has not only improved the robustness of intelligent vehicle control systems but also enhanced their adaptability in changing environments. For example, in complex traffic environments, adaptive PID controllers can quickly respond to the needs of speed changes and path adjustments, thereby improving the safety and efficiency of intelligent vehicles.

3. Scheme Design

Fuzzy PID control integrates the traditional PID control algorithm with fuzzy logic reasoning. The core principle is to use fuzzy set theory to fuzzify the input quantities of the controller (such as the deviation e of the intelligent vehicle from the centerline of the track and the rate of change of the deviation ec, that is, de/dt). By defining appropriate fuzzy subsets and membership functions, these precise input quantities are converted into fuzzy values. Subsequently, the fuzzy controller uses preset fuzzy control rules, which are based on expert experience and system dynamics, to reason about the fuzzy values to determine the direction and extent of the adjustment of the PID controller's proportional (Kp), integral (Ki), and derivative (Kd) parameters. The fuzzy reasoning process combines the input fuzzy set with the control rules through fuzzy logic operations to produce a fuzzy set for the adjustment of PID parameters. Finally, through the defuzzification process, the fuzzy control quantity is converted into a precise value, which serves as the parameter of the PID controller to adjust the control signal input to the PI controller in real time, thereby affecting the behavior of the controlled system. The entire fuzzy PID control system is a closed-loop feedback mechanism that dynamically

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adjusts control parameters according to the real-time state of the system to achieve better control effects. As shown in Figure 1.

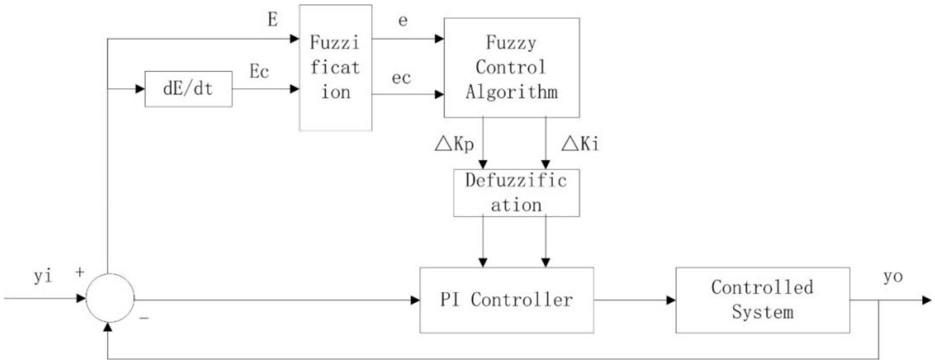

Figure 1. Fuzzy PID Principle Diagram

4. Result Analysis

In the research on intelligent vehicle control systems, we conducted simulation experiments on two types of PID control strategies-traditional PID and fuzzy PID-to evaluate their performance in terms of response time, overshoot, steady-state error, adjustment time, and control accuracy. The experimental results are detailed in the following table, aiming to reveal the potential advantages of the fuzzy PID control strategy compared to traditional methods.

Table 1. Comparison of Simulation Data for Traditional PID and Fuzzy PID Control Strategies

ControlStrategy	ResponseTime	Overshoot	Steady-State Error	Settling Time	ControlAccuracy
Traditional PID	2.5	15	1.2	3.2	Medium
Fuzzy PID	1.8	5	0.5	2.1	High

From Table 1, it can be observed that the fuzzy PID control outperforms the traditional PID control in terms of response time and settling time, with reductions of 0.7 seconds and 1.1 seconds, respectively. This indicates that the fuzzy PID controller can respond to system deviations more rapidly and achieve a stable state in a shorter amount of time. Additionally, the overshoot and steady-state errors of the fuzzy PID control are significantly lower than those of the traditional PID control, being 5% and 0.5% compared to 15% and 1.2%, respectively. This suggests that the fuzzy PID controller possesses higher control accuracy.

In terms of control accuracy, the fuzzy PID control, due to its ability to adaptively adjust parameters, can optimize control inputs based on real-time feedback information from the system, thereby achieving more precise control effects. In contrast, traditional PID control, with fixed parameters, may not adapt well to changes in system conditions under various working conditions, leading to relatively lower control accuracy. Robustness refers to the ability of a control system to maintain performance in the face of model uncertainties and external disturbances. Fuzzy PID control, due to the introduction of fuzzy logic, can better handle system uncertainties and external disturbances, thus exhibiting higher robustness. In comparison, traditional PID control, lacking adaptability to system changes, shows relatively lower robustness.

In summary, fuzzy PID control demonstrates clear advantages over traditional PID control in response speed, control accuracy, and robustness, providing an effective improvement scheme for the design of intelligent vehicle control systems.

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5. Conclusion

The main contribution of this study is the proposal of an improved fuzzy PID control algorithm that dynamically adjusts control parameters based on real-time feedback information from intelligent vehicles, effectively dealing with complex and variable traffic environments. Moreover, this research also provides a system performance evaluation framework, offering theoretical basis and practical guidance for the design and optimization of intelligent vehicle control systems.

Despite the positive results achieved in this study, there are still some limitations and room for future improvement. Firstly, the current simulation experiments are primarily conducted under idealized conditions, and there is insufficient testing and verification for actual road conditions. Secondly, the parameter tuning and design of fuzzy rules in the fuzzy PID control algorithm are still somewhat empirical, and further exploration of data-driven methods to optimize these parameters could be pursued in the future.

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