# Analysis And Optimization of Automotive Systems Based on PID Control

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**Abstract.** The development of modern technology has made automation an important part of life. Proportion Integral Derivative (PID) control is a basic control theory of automation which has many applications because of its simple construction and great performance. This article introduces the application of PID control technology in the automotive field. This paper mainly introduces the following aspects: the basic principles and theories of PID control, the challenges of automotive systems and their control, some solutions for PID control in automotive systems, and the improvement and optimization of control. The limitation of the application of traditional control theory in new automotive control have led to the emergence of more optimization algorithms, which can improve the system in more ways. In the future, automotive control systems will continue to be based on PID control as the framework and combined with some optimized new algorithms for practical application. Therefore, understanding PID control is of great significance to clarify the future development of automotive control technology.

**Keywords:** PID control, automation, optimization algorithm.

## 1. Introduction

With the continuous development of automation technology, Proportion Integral Derivative (PID) control has become a basic element in life, and it has many applications. As a basic technology, its principle and application field are worth knowing. For example, in the field of automotive control, there are many PID control technologies. With the continuous improvement of modern living standards, people's requirements for automobile performance are also more stringent. Traditional PID control does not seem to meet people's needs, and some problems are beginning to come to light. This also provides a good basis for the optimization of the system.

This essay discusses the basic principles of PID control, the challenges of PID in automotive systems, the solutions of PID control in automotive systems, and the improvement and optimization of PID control, and combines some literature to explain personal insights on the application of PID control in the automotive field and speculates on its future development. The article has a simple overview of the application of PID control technology in the automotive field and provides some references for the development of automation technology in the future.

## 2. Theoretical analysis of PID Control

### 2.1. Introduction to PID Control

PID control is a fundamental control algorithm, which is widely used in automatic control technology, including temperature control, speed control of motors, level control in tanks, robotics, and many other automated systems [1]. It is a feedback control that adjusts a system's output based on the error between the set point and the actual measured value. By adjusting the gains of the PID controller, engineers can achieve the desired system response such as appropriate setting time and stability [2]. PID controller is combined with three components: proportional term($P$), integral term($I$), and derivative term($D$). The structure of PID control system is shown in figure 1.

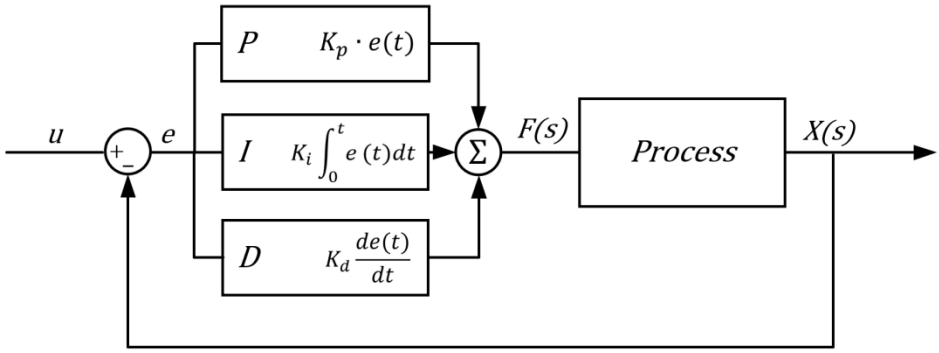



**Fig. 1** PID control system

### 2.2. Proportional, Integral, and Derivative Actions

Proportional (*P*) term: The proportional term produces an output proportional to the current error. It helps in reducing the steady-state error by applying a gain factor to the error signal. The proportional link formula is shown in Equation (1).

$$u(t) = Kpe(t) \tag{1}$$

Integral (*I*) term: The integral term takes into account the accumulated past errors and applies a gain factor to correct for any residual steady-state error. It helps in reducing the offset between the desired set point and the system's response. The integral link formula is shown in Equation (2).

$$u(t) = Ki \int_0^t e(t)dt \tag{2}$$

Derivative (*D*) term: The derivative term predicts the future trend of the error by calculating the rate of change of the error signal. It helps in damping the system's response and improving its stability. The differential link formula is shown in Equation (3).

$$u(t) = Kd \frac{de(t)}{dt} \tag{3}$$

These three components can be combined with each other to form a new controller such as PI controller and PD controller to make the system desired.

### 2.3. PID Controller Design and Tuning Methods

To design a PID controllers, it is important to set proper value of *Kp*, *Ki*, and *Kd* to get better dynamic and static characteristics for the system. *Kp* value will result in the response but may introduce overshoot or instability. *Ki* can reduce steady-state error, allowing the system to reach the desired set point accurately. Be cautious, as a high Kt value may lead to slow response or instability. *Kd* helps dampen the response and minimize rapid changes in the system's output. Adjust Kd carefully to avoid amplifying noise or introducing excessive oscillations. Operational amplifiers are often used to construct these circuits for designing controllers. Most work can be done with simulation software. There is a useful software named falstad can be used to do the simulation. It is a web page which can used conveniently for simulating. An example is shown in figure 2.

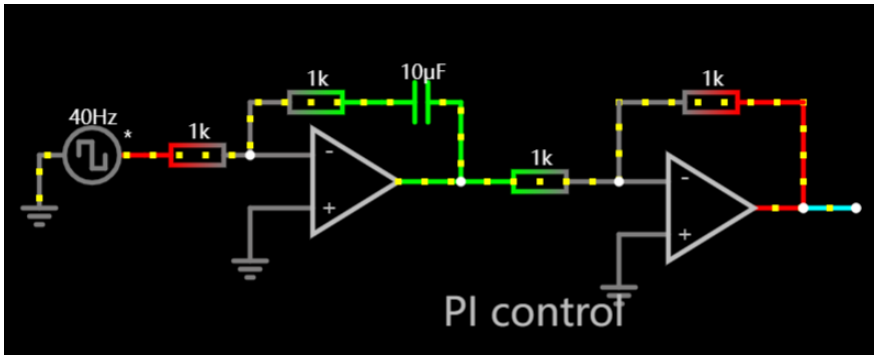


**Fig. 2** PID Controller Design

## 3. Automotive Systems and Control Challenges

### 3.1. Overview of Automotive Systems

Automotive systems refer to the various subsystems and components integrated into automobiles to ensure their proper functioning, performance, and safety. These systems work together to control different aspects of the vehicle's operation, including propulsion, steering, braking, comfort, and safety features. Some common automotive systems include:

Power System: This system includes the engine, transmission, and related components that generate and transmit power to propel the vehicle.

Chassis System: The chassis system encompasses the frame, suspension, steering, and wheels, which provide structural support, stability, and control over the vehicle's movement.

Electrical and Electronics System: This system comprises the vehicle's electrical architecture, including the battery, wiring, sensors, control units, and communication networks. It controls various functions such as lighting, climate control, entertainment, and advanced driver-assistance systems (ADAS) [3].

Braking System: The braking system is responsible for slowing down or stopping the vehicle. It includes components like brake pads, rotors, calipers, hydraulic systems, and electronic control systems like anti-lock braking systems (ABS) and electronic stability control (ESC).

Safety Systems: These systems are designed to enhance occupant safety and prevent accidents. Examples include airbags, seat belts, pre-crash sensing systems, adaptive cruise control, lane departure warning, and collision avoidance systems.

Fuel and Exhaust Systems: These systems handle fuel storage, delivery, and combustion, as well as the removal of exhaust gases. They include components like fuel tanks, fuel injectors, exhaust pipes, catalytic converters, and emission control systems.

HVAC System: The Heating, Ventilation, and Air Conditioning (HVAC) system controls the temperature, airflow, and air quality within the vehicle's cabin, ensuring passenger comfort.

Infotainment System: The infotainment system provides multimedia, communication, and connectivity features, including audio systems, touchscreen displays, navigation systems, Bluetooth connectivity, and smartphone integration.

These are just a few examples of automotive systems, and modern vehicles incorporate a wide range of technologies and subsystems to deliver enhanced performance, efficiency, comfort, and safety [4].

### 3.2. Control Challenges in Automotive Systems

Modern automotive systems consist of numerous interconnected subsystems and components. These systems have complex interactions and feedback loops, making the design and optimization of control strategies more challenging. Besides, Automotive systems face various uncertainties and changing conditions, resulting in the need for fast and accurate control [5].

#### 3.2.1 Engine Control using PID.

Engine idle control has always been a difficult point, the traditional PID control system due to the simple structure, it is difficult to play a precise control role, not easy to meet the modern people's higher requirements for environmental protection and energy saving.

#### 3.2.2 Vehicle Dynamics Control using PID.

Autonomous driving has emerged as a hot research field in recent years, but its full implementation is still pending due to challenges in achieving dynamic equilibrium. Traditional PID algorithm is widely used to control the movement of vehicles due to its simple structure. However, its dynamic characteristics have many limitations. Significantly advancing autonomous driving technology

requires upgrading and refining the PID algorithm to better regulate dynamic characteristics. Fuzzy control can be used as a solution. Fuzzy controller and PID controller can form a fuzzy PID controller, which takes the deviation of rate as input to obtain fuzzy variables. After parameter tuning, the corrected parameters can be applied to the system. This method can acquire faster response time, better dynamic characteristics.

#### 3.2.3 Active Suspension Control using PID.

The suspension is a significant part of automobiles. It provides cushioning when vehicles pass through uneven ground and ensures that the wheels move within a fixed angle, ensuring stable steering to maintain good contact with the ground. However, traditional suspension is different to control according to the real time situation of road surface, so there are more challenges.

## 4. PID Control Solutions in Automotive Systems

To solve these problems, some improved algorithms based on PID have been taken, which can bring better dynamic performance or make the system respond faster and more accurately.

### 4.1. PID Control for Engine Management Systems

#### 4.1.1 Idle Speed Control

Idling state is an important working condition of vehicle engine, which is closely related to the emission and energy consumption of automobiles. To solve the long response time and excess of the control during the adjustment process, PID control can be used to ensure the engine is working in appropriate condition, it is necessary to adjust, and correct different load movements based on the control demands of the electronic throttle to effectively meet the idle tracking control requirements. In addition, with self-tuning scaling factor, we can get satisfactory control of idle speed [6].

#### 4.1.2 Throttle Control

Throttle is a gate that controls the entry and exit of air into the engine. It is directly related to the energy supply of automobiles. Optimizing the throttle can reduce energy use, thereby reducing emissions and pollution. Due to the limitations of traditional integer order PID controllers, their performance to some extent cannot meet the requirements. Optimization can be achieved through improvements, using adaptive constrained control to further improve. He Youguo and other authors mentions algorithm which provides possibilities for further development [7]. As a consequence, the system has a fast and accurate response.

### 4.2. PID Control for Vehicle Stability Systems

The explanation for car stability refers to the ability of a vehicle to quickly restore its original driving state and direction after external interference during driving, which is closely related to safety of human beings.

ABS is a system used to prevent a car from locking up during braking. The phenomenon of lockup refers to the phenomenon of wheel slip when a car brakes at high speeds, where the braking force of the braking system is greater than the friction force of the road on the tires. To prevent the phenomenon, ABS was invented. Adaptive fuzzy PID control is suitable for ABS due to its robustness and control accuracy. This system can calculate and control the slip rate of the car, so that the vehicle can smoothly decelerate to zero in the shortest possible time [8].

### 4.3. PID Control for Active Suspension Systems

Although the structure is simple, PID has many problems for the complex situation faced by suspension control, as mentioned earlier. To this end, single neurons and neural networks can be combined with traditional PID to make up for their shortcomings in the face of mutations in a simple structure [9].

#### 4.3.1 Vertical and Lateral Dynamics Control

The purpose of vertical and lateral dynamics control is keeping the car running on a planned trajectory. The information is transmitted through sensors, and then some algorithms are upgraded, such as the Linear–quadratic regulator based on "feedforward +feedback", to achieve optimal lateral control [10]. In addition, a two-layer structure based on PI controller is used to ensure the accuracy and robustness of longitudinal speed control. With the help of these, safe and intelligent driving can be achieved.

#### 4.3.2 Adaptive Damping Control

Air suspension is widely used in some vehicles, and its adjustable performance is good, which can effectively improve the comfort performance of vehicles. The smoothness and handling stability of the interconnected air suspension can be achieved by adaptively adjusting the damping coefficient of the shock absorber to achieve a reasonable balance to improve the overall performance of the vehicle.

## 5. Performance Evaluation and Optimization

Due to the long history of the PID system, there are inevitably some defects that cannot meet people's higher demand for control. Therefore, it is necessary to optimize and adjust it on this basis to improve the system's performance.

### 5.1. Evaluation Metrics for PID Control in Automotive Systems

Due to the high real-time and safety requirements of automotive systems, many factors should be considered during the control process. Firstly, the response rate of the system should be as fast as possible, which requires appropriate *Kp* parameters. The second point is the accuracy and stability of the response, minimizing overshoot within the allowable range. Thirdly, the system should have robustness and can still function normally in the face of uncertain disturbances. Only by meeting these requirements can automotive be made safe and reliable [11].

### 5.2. Performance Limitations and Trade-offs

Although PID controllers are versatile and effective in many applications, they do have certain performance limitations and trade-offs. Firstly, PID controllers can introduce oscillations or instability in the system if not properly tuned. The proportional gain (*Kp*) determines the system's response speed, but high gains can lead to overshoot and oscillations. The derivative gain (*Kd*) can reduce oscillations but can also amplify noise in the system. Achieving stability while maintaining desired performance is a trade-off. Secondly, Responsiveness and Settling Time: PID controllers aim to minimize the error between the setpoint and the actual value. Higher gains can lead to faster response times, reducing settling time. However, this may increase overshoot or cause oscillations. Balancing the speed of response with overshoot is a trade-off, and system requirements and characteristics should be considered. Thirdly, Integrator Windup: Integrator windup can occur when the integral action accumulates a large error due to saturation or limitations in actuator output. This can cause overshoot and slow response when the saturation is removed. Anti-windup techniques, such as output saturation or derivative kick prevention, can help mitigate this issue.

### 5.3. Optimization Techniques for PID Tuning

PID controllers are widely used in control systems to regulate and stabilize processes. Proper tuning of PID parameters is crucial to achieve optimal control performance. Several optimization techniques can be employed to determine the optimal values for the PID controller parameters. Here are some commonly used optimization techniques for PID tuning:

Model-Based Optimization, Genetic Algorithms and Particle Swarm Optimization, Ziegler-Nichols Method, manual Tuning, gradient-Based Optimization,

Frequency Response Methods, and simulation and Iterative Methods. It is worth mentioning that the choice of optimization technique depends on factors such as the complexity of the system, availability of mathematical models, computational resources, and the desired control performance. Often, a combination of these techniques is used to fine-tune PID parameters and achieve the best control performance for a specific system.

### 5.3.1 Model-based Optimization

This technique involves utilizing a mathematical model of the system to optimize the PID parameters. The model can be derived from first principles or identified from system data. Various optimization algorithms, such as model predictive control (MPC) or genetic algorithms, can be used to search for optimal PID parameters that minimize an objective function, such as tracking error, control effort, or other performance criteria [12].

### 5.3.2Genetic Algorithms

Genetic algorithm is a method of simulating the evolution of organisms in nature, using computers to simulate mutations and cross these biological phenomena, in order to obtain better individuals and meet their needs. The first step is to encode, such as using binary. Assuming the range of parameters is from u1 to u2, with a binary length of k, the representation method for each individual I is shown in Equation (4) and (5).

$$m = \frac{U2-U1}{2^k-1} \tag{4}$$

$$I = U1 + n * m \tag{5}$$

The second step is to set the parameters, the maximum evolution algebra. As for group size, cross probability, probability of variation, etc. The third step is to determine the fitness of individuals in the population, and then obtain the most suitable results through genetic manipulation. Genetic algorithm is a series of search algorithms inspired by natural evolution theory. By imitating the process of Natural selection and reproduction, genetic algorithms can provide high-quality solutions to various problems involving search, optimization and learning. At the same time, they are similar to natural evolution, so they can overcome some of the obstacles encountered by traditional search and optimization algorithms, especially for problems with a large number of parameters and complex mathematical representations.

## 6. Conclusion

PID control technology, as part of classical control theory, can still play an important role in automotive control systems. Although there are some defects in engine control, dynamic control, etc., PID can still be used as the core solution by introducing fuzzy algorithms and other algorithms to improve optimization.

In future automotive systems, PID technology will still play an important role. PID control is a classic feedback control algorithm that can be used to adjust various parameters in automotive systems to achieve stable and precise control. The role of PID technology in future automotive systems includes, but is not limited to, engine control, braking system, suspension, stability control. As far as I am concerned, intelligent driving is undoubtedly the most important research direction, perhaps with the continuous upgrading and improvement of PID technology, this technology will soon be put into use.

In conclusion, PID technology will continue to play an important role in future automotive systems, improving vehicle performance, safety and comfort through precise parameter regulation and control. With the development of autonomous driving and electric vehicle technology, PID control will also be combined with other advanced control algorithms to jointly drive the progress of the automotive industry.

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