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PID Control and Simulation Analysis of a Servo Motor for Intelligent Guide Machinery

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Abstract:

This study primarily focuses on the enhancement and improvement of guiding robots, aiming to enable these devices to provide precise navigation and timely obstacle avoidance, thereby ensuring the travel safety of individuals with disabilities. Traditional guiding robots predominantly emphasize obstacle avoidance as their main function, without considering features such as route re-planning. Additionally, the slow response rate of conventional robots is one of their significant drawbacks, often failing to provide a high level of safety for individuals with disabilities during their travels. This research concentrates on addressing the issue of slow response rates by integrating a proportional-integral-derivative (PID) control algorithm into the guiding robots. The intention is to accelerate the navigation speed of the robotic system, allowing it to respond more swiftly to real-time situations, thereby enhancing the safety of individuals with disabilities while traveling. The outcome of this research is the integration of PID technology with traditional guiding robots, resulting in an improved response time of approximately 1-2 seconds, enabling the robots to react more quickly in complex environments. The emphasis of guiding robots lies in rapid and accurate navigation, and the incorporation of the PID algorithm can effectively improve their response times, further ensuring the travel safety of individuals with disabilities.

Keywords: PID control, Guide technique, Global positioning system, Intelligent robot

1. Introduction

In recent years, the application scenarios of PID-based guiding technology have become increasingly diverse, and its value has gradually risen. In public transportation settings such as bus and subway stations, PID-based guiding technology can dynamically adjust navigation paths in real time, assisting visually

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impaired individuals in locating boarding points and exits while avoiding crowds and obstacles. In complex environments like large shopping malls, museums, and airports, PID control can monitor the position and orientation of visually impaired individuals in real time, providing dynamic navigation guidance to ensure their safe arrival at their destinations. In smart home environments, PID-based guiding technology can interact with smart devices to offer navigation and safety alerts within the home, helping visually impaired individuals better adapt to their domestic surroundings.

Furthermore, there are numerous articles related to guiding technology. In Yuan's research, it is mentioned that guiding devices can be integrated with head-mounted devices to transmit environmental data in real time, providing safety assurance for the travel of visually impaired individuals [1]. In Wen's study, they designed an intelligent guiding dog utilizing an Arduino microcontroller, which can replace the guiding role of real guide dogs and further enhance and update its functionalities [2]. In Zhou's research, the KANO model is employed to prioritize user demands for guiding products, centering on user needs to ensure the safety of visually impaired individuals during their travel [3]. In Lai's study, it is mentioned that research on guiding assistance has been initiated in various countries around the world, focusing primarily on three areas: cane-type mobility aids, wearable mobility aids, and mobile mobility aids. They also conducted research on Mecanum wheel vehicles [4]. In Wang's research, a guiding cane embedded with an STM32 microcontroller is designed using a multi-sensor integrated intelligent system, effectively overcoming the limitations of traditional guiding canes [5]. This innovative cane incorporates multiple functions, enabling visually impaired individuals to walk safely with the assistance of the guiding cane while traveling alone.

The issues with guiding systems lie in their inability to adjust promptly based on the environment, resulting in long system response times that hinder timely corrections. This delay decreases the safety factor for individuals with disabilities during travel. By utilizing PID control algorithms, the response time of guiding systems can be reduced to approximately 1 second. This article focuses on discussing the improvements in mechanical response time and obstacle avoidance accuracy achieved through PID control algorithms, ultimately providing a safer travel experience for individuals with disabilities.

2. Analysis of the status quo of guide technology and satellite positioning technology

2.1 Introduction to Guiding Technology and Existing Issues

Guiding technology is an essential means of assisting visually impaired individuals in improving their daily lives and ensuring safe mobility. This technology encompasses various forms, including guide glasses, guide dogs, electronic guiding devices, and guiding robots. These technologies aim to enhance the mobility and safety of visually impaired individuals by integrating different sensors and algorithms to provide navigation, obstacle avoidance, and environmental perception functions.

However, existing guiding robots primarily focus on the development of guiding functionalities and have not adequately considered the potential spatial positioning of objects and the user's state. Although many cities have constructed tactile paving, these pathways are often obstructed by various items, leading to challenges and safety hazards for visually impaired individuals.

Currently, guiding methods predominantly rely on guiding robots and guide dogs. However, guiding robots are costly, complex to manufacture, and fail to allow users to intuitively perceive real-time environmental conditions and sudden situations, thereby limiting the widespread application and effectiveness of guiding technology [6]. Future guide robots need to be more considerate and intelligent, able to adapt to different environments and user needs.

2.2 Function realization of guide machinery

2.2.1 Obstacle Detection and Avoidance

The system is capable of real-time detection of obstacles in the path, such as walls, trees, and pedestrians, and can take appropriate measures, including stopping, detouring, or advising the user to change direction.

2.2.2 Path Planning

Current intelligent transportation systems can collect and process data from sensors, cameras, and GPS devices in real time. Researchers employ machine learning and big data analysis techniques to instantly recognize traffic flow, accidents, and other conditions, allowing for dynamic adjustments and responses. This real-time capability significantly enhances the flexibility and effectiveness of traffic management while taking into account environmental changes, such as pedestrian movement, traffic conditions, and road surface conditions. Furthermore, the system can predict potential obstacles or hazards based on historical data and real-time information, providing users with optimal travel plans.

2.2.3 Environmental Recognition

The system utilizes cameras and sensors to identify road signs, traffic signals, store signage, and other elements, providing informative feedback to enhance the user's environmental awareness.

2.2.4 Real-time Localization

Through GPS or other positioning technologies, the system can track the user's location in real time, assisting them in confirming their current position and destination.

2.3 Required Technologies for Functional Implementation

Matthew noted that the device can leverage satellite navigation technology, in conjunction with screen magnification and speech synthesis technologies, to provide route navigation and way finding information for visually impaired passengers [7]. At the same time, in previous research, Li's research found that by using phase beam forming technology using both the transmitting array and the receiving array, electronically controlled beam scanning forms a fan scan of directly detected objects [8], the system can effectively detect the surrounding environment, promptly avoid obstacles, and adjust routes as necessary. Additionally, PID control technology can significantly shorten response times. When an obstacle is detected nearby necessitating a route change, the PID technology calculates the direction of adjustment based on the deviation and replans the route accordingly. Furthermore, PID technology plays a crucial role in velocity control. By sensing the nearby environment through sensors, the system can determine the optimal speed suited for the current conditions and continually adjust to prevent potential safety risks.

3. Method

3.1 Introduction to PID Control Technology

PID control technology is a widely used feedback control method in industrial control systems. It involves real-time monitoring of the system's output and adjusting based on a set target value (also known as a reference value) to achieve precise control of process variables. The core components of a PID controller include Proportional control, Integral control, and Derivative control. Fig. 1 provides a visual representation of the PID control concept.

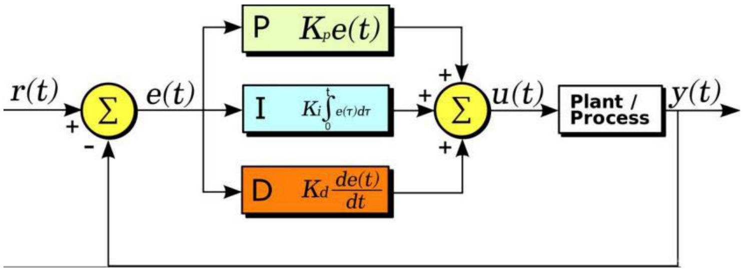

Fig. 1 PID algorithm flow chart [9].

3.2 Proportional, Integral, and Derivative Analysis

Proportional Control (P)

Proportional control adjusts the output based on the current error, which is defined as the difference between the target value (set point) and the actual value (process variable). The primary purpose of proportional control is to reduce the error; however, it may lead to the presence of steady-state error.

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

where, $u(t)$ is the output of the controller, $e(t)$ is the current error, and Kp is the proportional gain.

Integral control (I): The accumulation of past errors eliminates steady-state errors. Integral control can improve the accuracy of the system, but it may cause the system to respond slowly or produce overshoot.

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

where, Ki is the integral gain.

Differential control (D): adjusts for the rate of change of the error to predict future error trends. Differential control can improve the response speed of the system and reduce overshoot, but it is sensitive to noise.

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

where, Kd is differential gain.

3.3 PID technology design process and optimization system method

According to the PID control formula

$$u(t) = Kpe(t) + Ki\int_0^t e(t)dt + Kd\frac{de(t)}{dt} \tag{4}$$

In Guo's study, it is mentioned that the PID control algorithm is used to adjust the horizontal motion of the intelligent car [10], to accurately track the path. The algorithm defines the error as the lateral deviation between the center of the vehicle and the center of the track. This deviation is corrected by adjusting the motor using Pulse Width Modulation (PWM) output (PWM(D)). Properly tuning the proportional, integral, and derivative components ensures the stability and responsiveness of the vehicle during high-speed operation. Specifically, while turning, adjusting the proportional coefficient Kp based on the curvature of the lane lines enables the vehicle to drive smoothly and accurately follow the path. Additionally, similar to position correction, speed regulation can also be achieved

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through the PID algorithm, allowing for a quicker adjustment of speed rates and precise adaptation to the desired velocity.

3.3.1 Research Tools (Octave Image Analysis and Falstad Simulation Computer Analysis)

The response time of the system under PID control is shorter than that achieved through pure proportional or derivative control, enabling the mechanical system to respond quickly to changes in the surrounding environment and make necessary adjustments. The use of Octave provides a visual representation of this accelerated response rate. Furthermore, the Falstad simulation tool can illustrate the response rate of the motor under the PID algorithm. Fig. 2 shows an image simulated using the Falstad tool, and Fig. 3 shows the acceleration of response time under PID control.

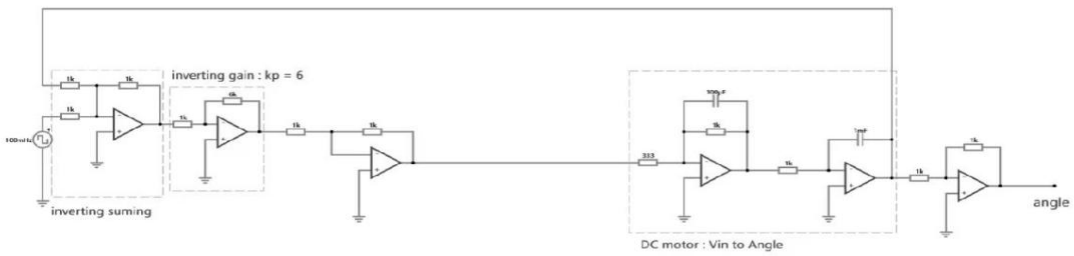

Fig. 2 Falstad tool simulates computer images. (Photo/Picture credit: Original)

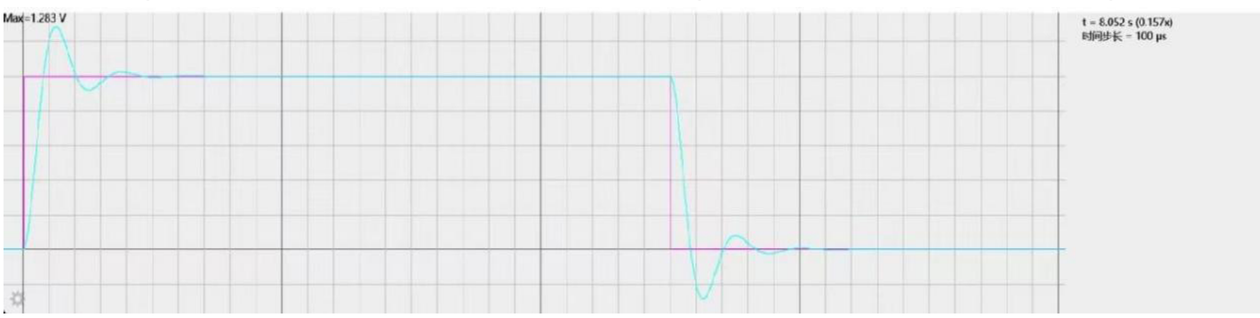

Fig. 3 The acceleration of response time under PID control. (Photo/Picture credit: Original)

3.3.2 System research process

First, the PID algorithm is performed using the STM32 microcontroller. In Cao's study, fuzzy control can be used in the initial test, although the machine is prone to wobble during the tracking process [11]. Then the PID algorithm is added to check whether there is an error by using the data transmitted by the sensor. When the route deviates from the established route of the system, the error will be transmitted to the PID control system, and then the system will calculate the error and transmit it to the PWM signal to adjust the motor, the speed, and the direction of operation. Meanwhile, in Geetanjali Rathee's research, sensors can be used to sense the surrounding environment and provide efficient and safe travel for people with disabilities by avoiding obstacles and adjusting speed and direction [12]. If there are obstacles around or on the way forward, the data returned by the sensor will be adjusted in time after calculation by the PID control system. Fig. 4 shows a related flow chart.

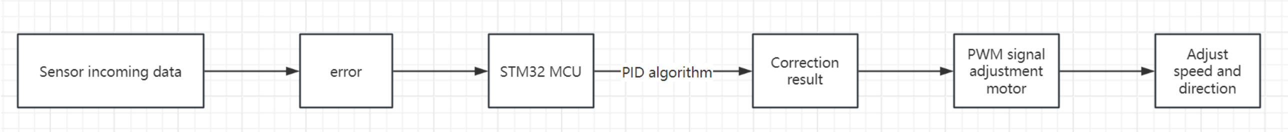

Fig. 4 Corresponding flow chart of the system. (Photo/Picture credit: Original)

4. Results and Discussions

4.1 Optimization of Speed Response Effects of PID in the System

Before the implementation of the PID algorithm, the mechanical response exhibited significant delays when encountering obstacles, resulting in an inability to adjust speed in a timely manner and, consequently, the failure to evade obstacles effectively. In Fig. 5, the blue line represents proportional control, while the red line indicates PID control. Fig. 6 illustrates the response under derivative control. It is evident that the response time of the system under PID control is shorter than that achieved through pure proportional or derivative control, with an improvement of approximately 1 second in response time.

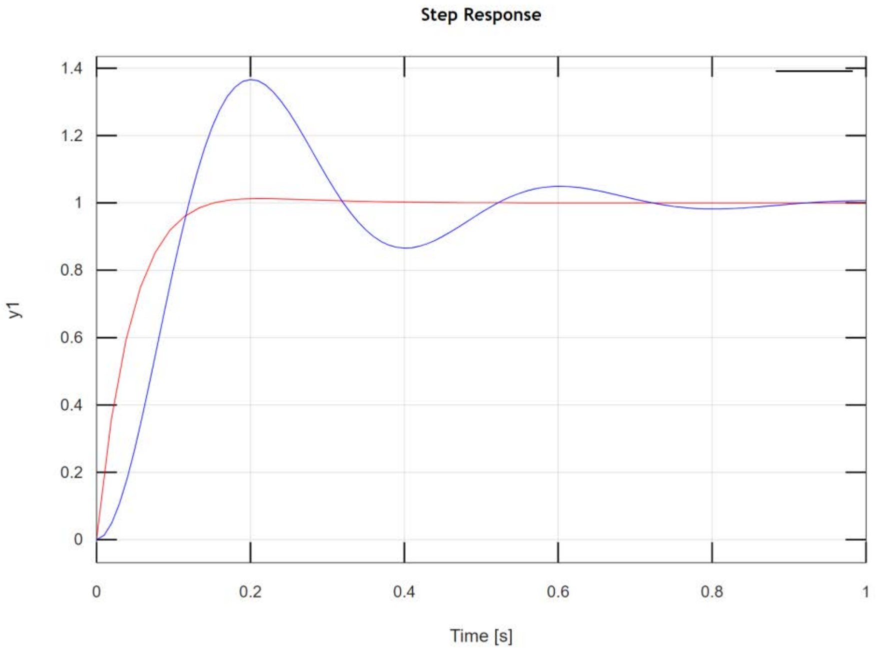

Fig. 5 The response time of PID control and proportional control increases. (Photo/Picture credit: Original)

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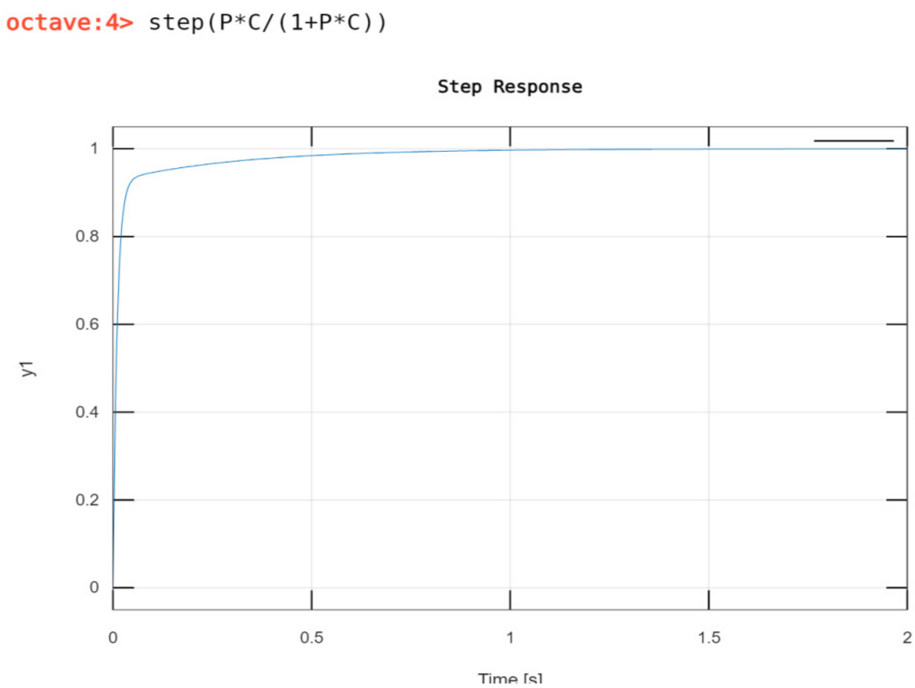


Fig. 6 Differential control. (Photo/Picture credit: Original)

As shown in Fig. 7, octave tool is used to simulate the speed adjustment response time after adding PID control, which reduces by about 2s, greatly shortening the adjustment time of the system, and providing safer travel for the disabled.

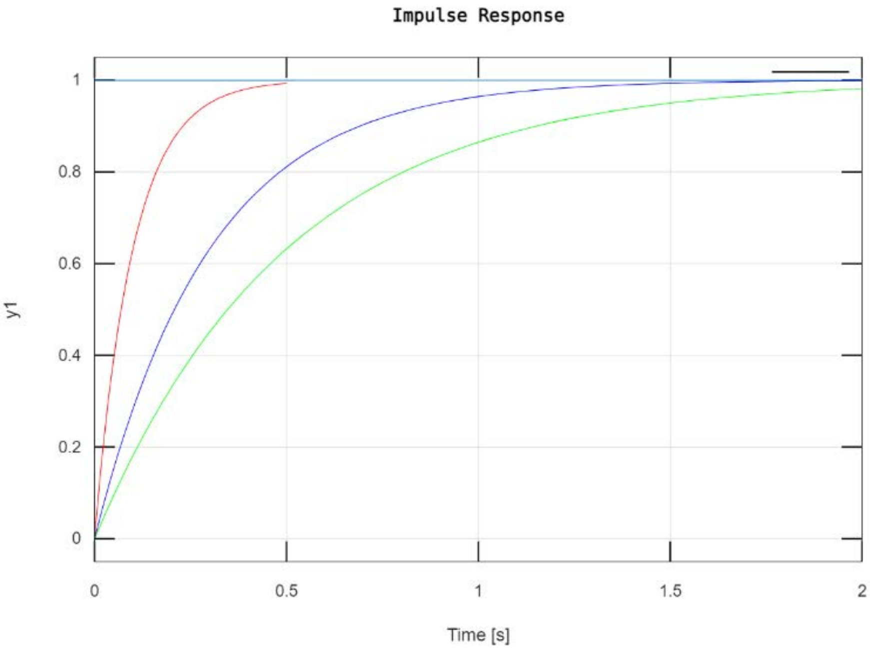


Fig. 7 Optimization of response time after adding PID control to the system. (Photo/Picture credit: Original)

4.2 Optimization of Position Correction Response Effects of PID in the System

The optimization effects of position response are similar to those of speed response; this experiment focuses solely on the integration of the PD algorithm. Prior to the implementation of the PD algorithm, the mechanical response exhibited significant delays when encountering obstacles, resulting in an inability to adjust position in a timely manner and consequently failing to achieve rapid obstacle avoidance. Using the Falstad tool, a simulation of the system after the integration of PD control was generated, as shown in Fig. 8. The response time for position adjustments is illustrated in the comparison between Figs. 9 (a) and (b), indicating an improvement of approximately 1 second in response time, thereby enhancing the system's obstacle avoidance capabilities. Additionally, the overshoot is reduced compared to pure proportional control, with nearly no overshoot occurring. The settling time has also improved by approximately 1 second, thereby increasing the safety factor for individuals with disabilities during travel. Subsequently, based on the data returned from the sensors, calculations are performed to determine the existence of errors, allowing for control of the motor to the appropriate speed and position.

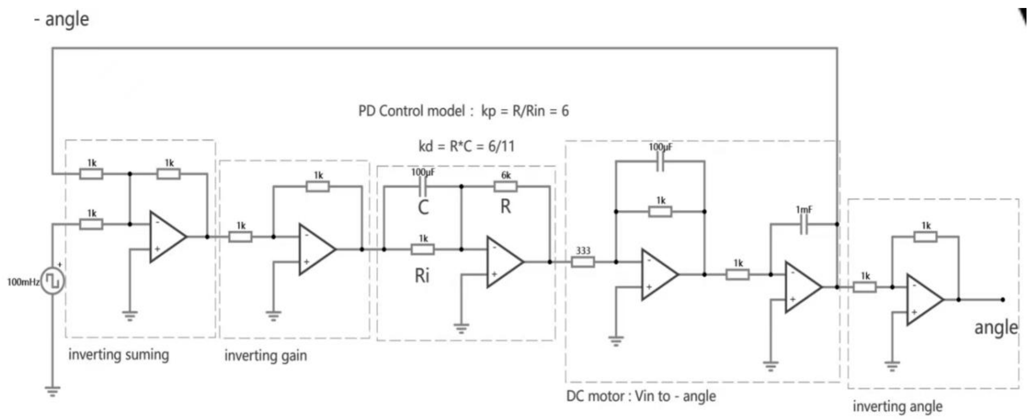
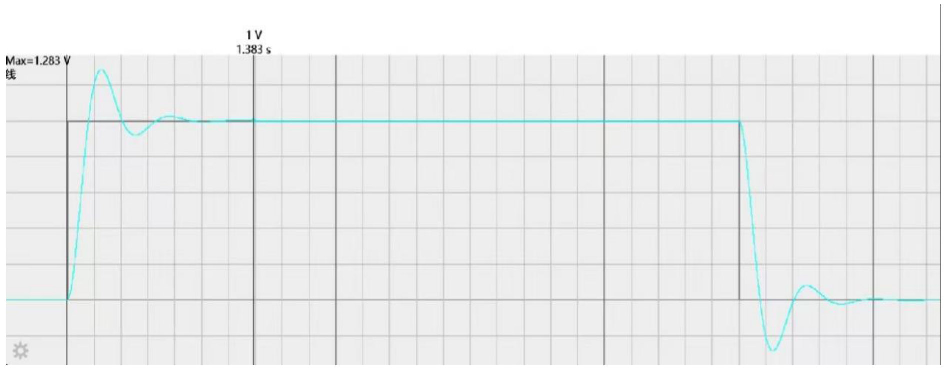
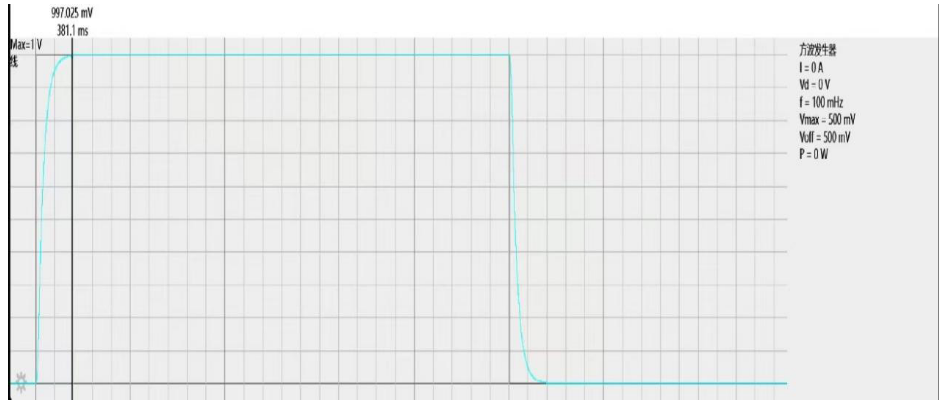


Fig. 8 Circuit design of PD control system. (Photo/Picture credit: Original)



(a)



(b)

Fig. 9 Comparison of proportional control and PD control. (a) Proportional Control; (b) PD Control. (Photo/Picture credit: Original)

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5. Conclusion

This paper discusses the application of PID control in the motor control of electric vehicles. PID control is a widely adopted control technology that enables precise regulation of motor speed and overall performance based on feedback signals. By continuously monitoring and adjusting control parameters, PID control optimizes motor operation and enhances performance, improves response time by about 1-2s, and the system adjustment time is increased by about 1 second. Due to its effectiveness, it can be utilized to improve the response accuracy and speed of assistive mobility devices for individuals with disabilities. The accuracy and reliability of PID control contribute to ensuring timely responses to the surrounding environment, allowing individuals to adjust their motor speed and direction promptly, thereby enhancing their travel safety. As the demand for mobility among individuals with disabilities continues to rise, PID control plays a crucial role in ensuring their safety.

However, despite the improvements in motor response times and the enhanced safety it provides, PID control has certain limitations. It requires precise parameter tuning, necessitating specialized knowledge for calibration, which can be time-consuming. Additionally, the associated costs can be high. Furthermore, due to the indirect relationship between inputs and outputs, PID control struggles to handle complex nonlinear systems. To overcome these limitations, further exploration of advanced control technologies, such as fuzzy control and adaptive control algorithms, is necessary to enhance the control accuracy and adaptability of motion control systems. In the future, building upon the precision of PID control coefficients and integrating multiple algorithms could further ensure the safety of individuals with disabilities during travel.

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