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Research on the application of automatic control theory in automatic driving technology

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Abstract. Autonomous driving technology has been widely used and studied in depth in recent years, and has become a hot field in the automotive industry. As one of the core methods to realize automatic driving, automatic control theory provides an important theoretical basis and practical guidance for automatic driving systems. This paper aims to explore the application of automatic control theory to autonomous driving and analyze its potential impact on improving driving safety, comfort and efficiency. This paper first introduces the basic principles and components of the autonomous driving system. Among them, automatic control theory plays an important role in decision-making and execution. Secondly, this paper discusses the specific application of automatic control theory in automatic driving. These include PID controller-based vehicle stability control, model predictive control (MPC) for path planning and trajectory tracking. These applications enable autonomous driving systems to respond in real time to environmental changes and maintain vehicle stability and safety. Finally, the paper discusses the challenges and future directions of automatic control theory in autonomous driving. Future research should focus on further improving the robustness and adaptability of automatic control algorithms to cope with complex driving scenarios and uncertainties. To sum up, automatic control theory plays an important role in automatic driving and has broad application prospects. Through continuous improvement and innovation, automatic control theory will make an important contribution to the realization of safer, more efficient, and more intelligent autonomous driving technology.

Keyword: Autonomous Driving, Automatic Control Theory, Model Predictive Control, Robustness Challenges.

1. Introduction

As a revolutionary innovation, autonomous driving technology is leading the automotive industry towards a safer, more efficient and intelligent future. With the rapid development of computer technology and sensor technology, the automatic driving system has become the key to the realization of driverless cars [1]. In the process of realizing automatic driving, automatic control theory is widely used, which provides real-time and accurate control and decision-making capabilities for the system.

This thesis will be divided into the following sections for discussion. First, we will introduce the basic principles and components of the autonomous driving system so that readers can have a comprehensive understanding of the technology. Secondly, we will discuss in detail the specific application of automatic control theory in automatic driving, including vehicle stability control, path planning and trajectory tracking, state estimation, etc. Then, we will discuss the challenges and future directions of automatic control theory in autonomous driving. Finally, we will summarize the main points of this paper and look forward to the importance and application prospects of automatic control theory in the development of autonomous driving technology in the future.

Through the research in this paper, we expect to further promote the application of automatic control theory in the field of automatic driving and provide useful enlightenment and guidance for the realization of safer, more efficient, and more intelligent automatic driving technology.

2. Fundamentals of autonomous driving technology

2.1. Sensing and Sensing Fusion

Autonomous driving systems perceive the surrounding environment by using various sensors such as cameras, lidar, radar, and ultrasonic sensors. These sensors collect and acquire information around the vehicle, such as road markings, obstacles, pedestrians, vehicles and traffic signals, etc. Perception fusion is the integration and processing of data from different sensors to obtain a comprehensive and accurate understanding of the environment.

2.2. Maps and Location

Autonomous driving systems rely on high-precision maps and positioning systems to provide accurate information about the vehicle's current location and surrounding environment. Maps can include details such as road topology, lane lines, traffic signs and restrictions, while positioning systems use GPS, inertial navigation systems or other sensors to determine the exact location of the vehicle.

2.3. Perception Data Processing and Object Recognition

In autonomous driving technology, perception data processing and target recognition are key links. They are responsible for extracting useful information from sensor data around the vehicle and identifying and understanding various targets and obstacles on the road. Perceptual data processing refers to the processing and analysis of raw data obtained from various sensors (such as cameras, lidar, radar, etc.). These sensors can provide different types of data about the vehicle's surroundings, such as images, point clouds, and distance information. Target recognition refers to identifying and classifying various target objects on the road in sensory data, such as vehicles, pedestrians, traffic signs, road boundaries, etc.

2.4. Path planning and decision-making

Based on the perceived environmental information and target recognition results, the automatic driving system needs to perform path planning and decision-making to determine the next driving path and action. Path planning algorithms take into account multiple factors, such as traffic rules, traffic conditions, safety, and efficiency, to formulate an optimal driving strategy.

2.5. Control and Execution

After the decision is made, the autonomous driving system needs to implement control commands to achieve accurate control and operation of the vehicle. Control algorithms and controllers are used to precisely control the acceleration, braking, steering, etc. of the vehicle. The actuators and various control components of the vehicle, such as the electric drive system, braking system, and steering system, work in harmony to achieve a predetermined driving behavior.

The automatic control theory is widely used in the decision-making and execution of automatic driving technology. Automatic control theory provides methods such as system modeling, controller design, and system analysis for designing control strategies for automatic driving systems. By analyzing vehicle dynamics and environmental characteristics, a mathematical model can be established to describe the behavior of the autonomous driving system, and then an appropriate controller can be designed to achieve the desired driving behavior. Automatic control theory can also be applied to path planning and trajectory tracking to achieve accurate control and execution of vehicles. Path planning involves determining the optimal travel path for a vehicle, while trajectory tracking involves controlling the vehicle on the planned path and accurately tracking the desired trajectory. Secondly, the automatic control theory provides various control algorithms and technologies, such as PID controller, model predictive control, etc., to achieve precise trajectory tracking and dynamic control. The autonomous driving system needs to accurately estimate the state of the vehicle, such as position, speed, attitude, etc., to support decision-making and control. The filtering algorithms in automatic control theory, such as Kalman filter and extended Kalman filter, can be used to fuse and process sensor data, so as to realize accurate estimation of vehicle state. Automatic control theory can also be applied to collision avoidance and safety control in automatic driving technology. By monitoring the surrounding environment of the vehicle and predicting the movement of other objects in real time, the autonomous driving system can adopt corresponding control strategies to avoid potential collisions.

3. Vehicle Stability Control Based on PID Controller

Vehicle stability control based on a PID (Proportional, Integral, Derivative) controller is a common control method used to improve vehicle stability and handling performance under different driving conditions. The PID controller implements stability control by adjusting the vehicle's steering input (such as steering angle or braking force) according to the error between the current state of the vehicle and the desired state. Stability control first needs to perceive the current state of the vehicle, such as sideslip angle, lateral speed, lateral acceleration, etc. This can be estimated and measured by vehicle dynamics models and sensor data such as gyroscopes, accelerometers, etc. The control system needs to set a target state, that is, the desired behavior of the vehicle. For example, in side slip angle control, the goal is to control the side slip angle of the vehicle within a safe range to avoid loss of control or sideslip due to excessive side slip angle. The control system determines the direction and magnitude of the adjustment control input by comparing the error between the current state and the target state. Error is usually defined as the difference between the current state and the target state [2].

Proportional control is the first component of a PID controller. It scales the control input in the form of a proportional gain according to the magnitude of the error. Proportional control allows the vehicle to respond quickly to errors, but can result in overshoot or oscillation. Equally important is integral control, which adjusts the control input based on the integral of the error. The integral controller accumulates the error to eliminate the steady-state error of the system and improve its stability. Derivative control is the third component of the PID controller. It adjusts the control input according to the rate of change of the error. The differential controller can predict the future trend of the error and improve the stability of the system by reducing the rate of change of the control input [3].

The PID controller weights and adds the results of proportional, integral and differential control to obtain the final control output. This control output is used as a steering input to the vehicle, such as steering angle or braking force. By continuously adjusting the control output according to the error, the PID controller can make the vehicle gradually approach the target state and keep it stable. It should be noted that the parameters of the PID controller (proportional gain, integral time constant, and differential time constant) need to be adjusted and optimized according to the specific vehicle and control requirements to obtain good control performance and stability.

In general, PID controller-based vehicle stability control utilizes an error feedback mechanism to adjust the vehicle's manipulation input through proportional, integral, and differential control according to the error between the vehicle's current state and the target state to achieve the stable driving behavior.

4. Path Planning and Trajectory Tracking Based on Model Predictive Control (MPC)

4.1. Fundamentals of MPC

Model Predictive Control (MPC) is a control method widely used in path planning and trajectory tracking. It achieves the goal of path planning and trajectory tracking by establishing a dynamic model of vehicle driving and predicting vehicle behavior in a period of time in the future [4].

MPC first needs to establish a dynamic model of the vehicle, describing the vehicle's motion equations and constraints. This model can be a model based on physical principles, or an empirical model obtained through data fitting. Secondly, path planning and trajectory tracking need to set goals, including the desired vehicle driving path and trajectory. These goals can be set by advanced decision-making algorithms or manually. MPC then converts the path planning and trajectory tracking problem into an optimization problem. The goal of an optimization problem is to minimize a predefined performance metric, such as the deviation from a desired trajectory, the rate of change of a control input, etc. At the same time, the optimization problem also needs to satisfy the dynamic model and constraints, such as vehicle dynamics constraints, obstacle avoidance, etc. Based on the established dynamics model, MPC generates multiple possible trajectories by predicting the vehicle's behavior over a period of time in the future. These trajectories include information such as the position, velocity, and acceleration of the vehicle. According to the objectives and constraints of the optimization problem, MPC will select the optimal trajectory. After selecting the optimal trajectory, MPC will apply the calculated control input (such as steering angle, braking force) to the vehicle to achieve the goal of trajectory tracking and path planning. Target. At this point, MPC enters the next time step to perform prediction and optimization again.

At the same time, MPC also has the property of a real-time update: MPC is an iterative process that continuously updates the control input at each time step Over time, the difference between the vehicle's actual and predicted trajectory is fed back into the MPC controller to adjust future control inputs.

By using MPC for path planning and trajectory tracking, vehicles can achieve more accurate trajectory tracking and path planning based on dynamic models and the ability to predict future behavior. MPC can comprehensively consider vehicle dynamics, environmental constraints and performance indicators, and select the optimal control input through optimization problems, so as to improve the handling performance and safety of the vehicle.

4.2. Improvement effect of lateral controller based on MPC design on stability (cited)

The experimental simulation and verification experiments carried out on the Carsim-Simulink joint simulation platform in "Path Tracking Control of Unmanned Vehicles Based on MPC and PID" written by Zhou Yipeng and Yang Wei can be concluded: at the limit of 20 m/s Under speed conditions, the maximum lateral error of the unmanned vehicle using the MPC+dual PID control method provided in this paper is 0.085 m, while the maximum lateral error of the LQR method can reach 0.181 m. The MPC+double PID ratio LQR method provided in this paper can improve the lateral control accuracy by 53% in the limit speed condition [5].

The simulation results show that the MPC+double PID method provided in the literature can guarantee a high tracking accuracy for the path tracking of the unmanned vehicle. From the lateral error, heading error and speed tracking error, it can be seen that the method provided in the literature can ensure better stability and accuracy in the path tracking control of unmanned vehicles, and can improve the driving speed of the vehicle in the longitudinal speed control. At the same time, it also proves that MPC in the automatic control theory has certain effects on the stability of automatic driving.

5. Problems and Challenges

5.1. Robustness and Security Challenges

Robustness refers to the ability of a system or algorithm to remain stable and reliable under different circumstances. Autonomous driving systems must be able to work in a variety of uncertain and complex environments, including varying weather conditions, road conditions and the behavior of other vehicles. Therefore, ensuring the robustness and safety of automatic control systems is an important challenge. Future development directions include more powerful perception and decision systems, and more effective fault detection and fault-tolerant control methods. In order to ensure the maturity, stability and safety of autonomous driving technology.

5.2. Multi-objective optimization challenge

An autonomous driving system needs to consider multiple goals simultaneously, such as safety, comfort, fuel efficiency, and traffic efficiency. These objectives may conflict with each other, requiring multi-objective optimization. This leads to the contradiction and collapse of automatic driving. Therefore, future development directions include developing more complex control strategies and optimization algorithms to achieve trade-offs and balances among multiple objectives.

5.3. Real-time and computational complexity challenges

The automatic driving system needs to make decisions and control under real-time requirements. Since the autonomous driving system involves a large amount of sensor data processing and calculation, as well as complex decision-making and planning algorithms, it faces the challenges of computational complexity and real-time performance. The actual road contains various unknown factors, and any move will change the real-time algorithm. Therefore, autonomous driving technology must be able to quickly process various information so that drivers and passengers are always in a safe environment. Future development directions include methods such as efficient algorithm design, hardware acceleration, and distributed computing to improve the computing performance and real-time performance of the system.

5.4. Legal and Ethical Challenges

Autonomous driving technology raises a series of legal and ethical issues, such as the distribution of responsibilities, privacy protection, road traffic regulations, etc [6]. Especially the liability issue. It has become extremely difficult to hold the driver accountable after a traffic accident, because of the emergence of autonomous driving technology. In order to enable the early emergence of autonomous driving technology, the government and judicial departments should consider and legislate these issues in advance. These issues need to be addressed and regulated as the technology evolves to ensure the safety and social acceptance of autonomous driving technology. Future development directions include formulating relevant laws and regulations, establishing industry standards, and promoting public education.

6. Conclusions

This paper studies the application of automatic control theory in automatic driving technology. First of all, this paper analyzes and explains the principle of automatic driving technology, and analyzes the steps of perception, processing, planning and decision-making, and execution if the car needs to carry out automatic driving. Secondly, this paper focuses on analyzing the absolute effect of automatic control theory on automatic driving technology in decision-making and execution steps. Including the use of PID controller, using its three links of proportional integral differential to improve stability. Including the introduction of MPC (Model Predictive Control) theory for path planning and trajectory tracking in autonomous driving technology. At the same time, the simulation experiments in "Path Tracking Control of Unmanned Vehicles Based on MPC and PID" were cited to prove that the introduction of the MPC model can improve the stability of the automatic driving system. Finally, this paper analyzes the challenges that future automatic control theory will encounter in the use of automatic driving technology, including four possible problems: safety challenges, real-time challenges, multi-objective challenges, and moral and legal challenges. It also provides reassurance about countermeasures and future efforts.

To sum up, automatic control theory plays a vital role in automatic driving technology. The automatic control theory plays an indispensable role in the decision-making and execution steps of the driving technology and improves the stability and safety of the technology. However, there are still many problems and challenges to be solved in the future, and autonomous driving technology still needs further development and experiments.

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