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A study on the key technologies and existing challenges in the development of autonomous vehicles

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Abstract. As an emerging means of transportation, autonomous driving has great development potential and application prospects. This paper investigates relevant issues of autonomous vehicles, aiming to explore the technical principle and implementation method of autonomous driving and evaluate its performance and effect in road traffic. By analyzing the existing related research results and practical experience, this paper conducts an in-depth study on key technologies of autonomous vehicles, including sensor and sensing systems as well as decision-making and control systems. Besides, the paper also summarizes the ethical and safety problems in the course of autonomous driving development and puts forward a deep learning-based control strategy for autonomous driving. This strategy has high accuracy and stability in different scenarios and can effectively improve the safety and performance of autonomous vehicles. To sum up, this paper carries out in-depth research on autonomous vehicles and tries to propose innovative solutions in key technical fields. This study provides reliable theoretical and technical support for the development and application of autonomous vehicles and promotes progress and innovation in the field of transportation.

Keywords: autonomous vehicles, technical principle, deep learning, control strategy, security.

1. Introduction

With the rapid development of science and technology and the increasing demand for traffic safety and travel efficiency, autonomous vehicles are regarded as an important representative of future transportation modes. By introducing advanced sensor and sensing systems as well as decision-making and control systems, autonomous vehicles can drive autonomously, having comprehensive environmental perception, decision-making reasoning, and precise control capabilities [1].

This paper aims to systematically study the related technical principles and implementation methods of autonomous vehicles and evaluate their performance and effect in road traffic. Through the comprehensive analysis of the existing related research results and practical experience, this paper studies sensor and sensing systems as well as decision-making and control systems of autonomous vehicles, and on this basis, puts forward the existing challenges and corresponding solutions to autonomous vehicles in the development process.

This study has important theoretical and practical significance. First of all, as a new technology, autonomous driving is of great significance to be further studied in order to promote innovation and development in the field of transportation. Secondly, an in-depth study of the technical principles and implementation methods of autonomous vehicles will help improve their performance, thus

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contributing to the realization of the goals of intelligent transportation systems. Finally, by evaluating the safety and performance of autonomous vehicles, this study can provide a scientific basis for the government and enterprises to formulate relevant policies and strategies.

2. The development of autonomous vehicles

The development of autonomous vehicles can be traced back to the early 1950s. At that time, scientists began to explore automatic driving technology. Early automatic driving technology mainly relied on mechanical and electronic equipment, such as mechanical trackers and electronic compasses.

With the continuous development of science and technology, autonomous vehicles have developed rapidly in recent decades. In the 1960s, engineers began to research and develop vehicle prototypes that can drive automatically. However, due to the limitation of computing power and sensing technology at that time, these prototypes still had many difficulties and challenges.

In the 1980s, with the rapid development of computer technology, autonomous driving technology made a great breakthrough. Researchers began to introduce systems based on computer vision and sensor technology to provide necessary information and real-time data for autonomous vehicles. These systems can detect and identify traffic signs and vehicles on the road, and process and analyze them through algorithms, so as to realize autonomous navigation and driving of vehicles.

As time goes by, there are more and more experiments and research and development (R&D) of autonomous vehicles. Many large technology companies and automobile manufacturers have joined the competition of autonomous driving technology. They have invested a lot of time and money in the R&D of autonomous driving algorithms and systems. At the same time, experimental vehicles are also tested in various road environments and scenes to verify the feasibility and practicability of these technologies.

In the experimental and R&D stage, researchers and engineers have done a lot of testing and verification. First, they use the simulation platform and the actual environment to simulate and evaluate the performance and safety of autonomous vehicles. In this way, researchers can find and solve potential problems in advance to ensure the stability and reliability of autonomous vehicles on the actual road.

At the same time, experiments and R&D also involve a large number of test vehicles and test sites. Researchers choose different road conditions and weather conditions to conduct various tests on autonomous vehicles, including complex scenes such as straight driving, turning, and overtaking. Through these experiments, researchers can collect a large amount of data to analyze and optimize the decision-making and control system of autonomous vehicles. In addition, they will also conduct experiments on sensors and sensing systems to ensure that they can accurately perceive the surrounding environment.

Cooperation is very important in the experimental and R&D stages. Scientific research institutions, automobile manufacturers, and technology companies have established close cooperative relations to jointly promote the progress of autonomous vehicles. By sharing resources and experience, they can speed up the process of technology R&D and commercialization.

In short, the initial exploration of autonomous driving technology is a process full of challenges and opportunities. By introducing computer vision and sensor technology, researchers make autonomous vehicles more intelligent and reliable. The experiment and R&D stage of autonomous vehicles is very important, and lays the foundation for the development of autonomous driving technology. Through a lot of testing and verification work, researchers can continuously optimize the performance and safety of autonomous vehicles and solve the challenges that arise. With the continuous progress of technology, it is believed that autonomous vehicles will become an important part of the future transportation system.

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3. The technical principle of autonomous vehicles

3.1. Sensors and sensing systems

The sensors and sensing systems of autonomous vehicles are the key components to realize autonomous navigation and environmental awareness. The sensor system includes laser radar, camera, radar, and other equipment, which is used to collect the information around the vehicle [2]. In autonomous vehicles, laser radar is a commonly used sensor, which calculates the distance and shape of an object by emitting a laser beam and measuring the time it takes for the laser to reflect from the object. The camera is used to shoot images on the road and detect and identify road signs, vehicles, and pedestrians through image recognition technology. Radar can help vehicles perceive static and dynamic obstacles around them. Sensors play a vital role in the perception system of autonomous vehicles. They acquire and process information about the surrounding environment of vehicles through different technologies.

The sensing system is another important part of autonomous vehicles, which uses the data provided by sensors to understand and perceive the surrounding environment. By analyzing and processing the sensor data, the sensing system can determine the road geometry, identify different types of traffic participants, and predict their behaviors and intentions. For example, when an autonomous vehicle drives into an intersection, the sensing system can judge the state of traffic lights by analyzing the images provided by the camera, and then decide the driving direction and speed of the vehicle. The perception system can also detect and predict the trajectories of other vehicles and pedestrians by analyzing radar data, so as to make corresponding safety responses.

The accuracy and reliability of sensors and sensing systems directly affect the driving safety and effect of autonomous vehicles. Therefore, R&D personnel constantly strive to improve the sensor technology and the accuracy and performance of the sensor, in order to cope with various complex road conditions and environmental changes. For example, laser radar can improve the recognition accuracy and tracking performance of surrounding objects by increasing the density of the laser beam and improving the algorithm. At the same time, the algorithm of the sensing system is constantly optimized and improved to improve the ability of understanding and predict the environment.

In a word, sensors and sensing systems are important components of autonomous navigation and environmental awareness for autonomous vehicles. They provide key sensing functions for autonomous vehicles by collecting and analyzing information around vehicles. It is one of the important technical challenges to realize the commercial application of autonomous vehicles to continuously improve the accuracy of sensors and the reliability of sensing systems. With the continuous development and progress of technology, it is believed that the performance of sensors and sensing systems will continue to improve, providing strong support for realizing safer and smarter autonomous vehicles.

3.2. Decision-making and control system

The decision-making and control system of autonomous vehicles is the core technology to realize its autonomous driving function. The system continuously collects, analyzes, and processes the environmental information obtained by sensors and monitors the vehicle status in real time, so as to make decisions and control driving according to the current road conditions. Among them, the decision-making module is mainly responsible for real-time road analysis and target detection according to the data provided by the perception system, judging obstacles, traffic signs, and vehicles in the surrounding environment, and predicting their behavior. The control module controls the steering wheel, brake, and throttle of the vehicle according to the output of the decision-making module, so as to realize accurate lateral and longitudinal control.

Road analysis is one of the key steps in the decision-making module. Through deep learning and computer vision analysis of the environment in front of the vehicle, the system can identify information such as lane lines, road signs, and road boundaries, and then determine the driving path and vehicle driving planning. At the same time, the target detection module can identify vehicles,

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pedestrians, and obstacles in the surrounding environment, providing important references for vehicle safety decision-making. These decision results will be passed to the control module to perform corresponding operations.

After obtaining the output of the decision-making module, the control module changes the motion state of the vehicle by adjusting the steering wheel angle and braking pressure and throttle opening of the vehicle in real time. Among them, the lateral control is mainly realized by the rotation of the steering wheel. According to the deviation between the target path and the vehicle position, autonomous vehicles can carry out accurate road maintenance, including lane maintenance and lane change. The longitudinal control mainly adjusts the speed and acceleration of the vehicle by controlling the throttle and brake, so as to ensure a safe distance from the preceding vehicle and realize a smooth acceleration and deceleration [3].

The key to decision-making and control systems is real-time and reliability. In order to achieve rapid decision-making and precise control, autonomous vehicles usually use high-performance computing platforms and real-time operating systems to process massive perceptual data and execute complex algorithms. At the same time, in order to ensure the reliability of the system, the decision-making and control system should have multi-level redundancy and fault-tolerant mechanism to deal with sensor failures, algorithm errors, and unexpected situations.

Generally speaking, the decision-making and control system of autonomous vehicles is the core technology to realize its autonomous driving function. Through continuous optimization and development, the decision-making and control system will provide better protection for the safety, reliability, and comfort of autonomous vehicles, and further promote the wide application and market development of autonomous driving technology.

4. Challenges of autonomous vehicles and corresponding solutions

4.1. Legal and moral issues

The development of autonomous vehicles has brought a series of legal and moral problems, which is a challenging task. First of all, a major legal and moral issue is the definition of responsibility [4]. When a traffic accident happens, who should bear the responsibility is always something people will discuss. Some agree that it is the responsibility of the vehicle manufacturer while others believe that it is the responsibility of the vehicle owner or the driver himself. Nowadays, drivers need to obey traffic rules and be responsible for their actions. However, when the vehicle changes from manual operation to automatic driving, the responsibility problem becomes complicated. Since self-driving vehicles have the ability of independent decision-making and operation, responsibility is a complex problem to be solved when there is a traffic accident.

Secondly, autonomous vehicles also involve issues of user privacy and data security. In order to achieve autonomous driving, vehicles need to collect a large amount of data and process and analyze it through the cloud. These data include internal and external information about the vehicle, which may involve the driver's personal privacy. Therefore, how to ensure the security and privacy of these data is an urgent problem to be solved. At the same time, how to prevent these data from being abused and misused is also an important legal and moral consideration.

In addition, autonomous vehicles have also caused a series of moral and ethical problems. For example, in an emergency, autonomous vehicles may need to make choices, for instance, whether to hit obstacles to avoid hitting pedestrians or to hit pedestrians to protect passengers' safety. These selective decisions involve ethical and moral standards. How to ensure that the automatic driving system can make these decisions fairly and follow social values has become a problem that needs attention.

Therefore, it is urgent to solve the legal and moral problems of autonomous vehicles. This requires the joint efforts of the government, automobile manufacturers, technical experts, and all walks of life. The government needs to clearly stipulate the responsibility, data security, and privacy protection of autonomous vehicles in legislation; automobile manufacturers need to establish a reliable automatic

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driving system and ensure its compliance; technical experts need to strengthen research to make the automatic driving system more reliable and safe; all sectors of society need to have full discussions and debates to reach a consensus to ensure the rational and responsible development of autonomous driving technology. Only by fully considering and responding to legal and moral issues can the sustainable development of autonomous vehicles be promoted.

4.2. Safety and reliability issues

The safety and reliability of autonomous vehicles is also a very critical issue. The instability of technology and loopholes in the system may lead to serious safety accidents and traffic chaos [5].

In order to improve the safety and reliability of autonomous vehicles, researchers have adopted many innovative solutions. First of all, they constantly improve and update sensors and sensing systems to improve the vehicle's perception of its surrounding environment. The update of the sensor system ensures that vehicles can accurately identify and understand various objects on the road, including other vehicles, pedestrians, and obstacles. The development of this advanced perception system enables autonomous vehicles to better adapt to the complex traffic environment and respond accordingly.

Secondly, the improvement of decision-making and control systems is also an important step to improve the safety and reliability of autonomous vehicles. Using advanced algorithms and technologies, researchers have designed a system that can make decisions quickly and accurately and a control system that can accurately control the running of vehicles. These improvements ensure that autonomous vehicles can run more stably and reliably in various complex traffic scenes and reduce accidents.

In addition, strengthening the research on the legal and moral issues of autonomous vehicles can provide better guidance for the improvement of safety and reliability. These issues include the interaction between autonomous vehicles and other vehicles and pedestrians, the distribution of responsibilities and privacy protection. Researchers actively cooperate with legal and ethical experts to discuss and formulate relevant laws and ethical standards to ensure the normal operation and social acceptance of autonomous vehicles.

In a word, the improvement of the safety and reliability of autonomous vehicles is inseparable from the continuous improvement of sensors and sensing systems, the optimization of decision-making and control systems, and the full study of legal and moral issues. The implementation of these solutions will lay a solid foundation for the commercial application of autonomous vehicles and provide a positive impetus for the development of intelligent transportation systems in the future.

5. Conclusion

After in-depth research and exploration on the related issues of autonomous vehicles, this paper summarizes the technological exploration and research and development process of autonomous vehicles, and deeply studies the sensors and sensing systems as well as decision-making and control systems of autonomous vehicles, but these key technologies still need to be further optimized and improved. For example, in the complex and changeable traffic environment, the perception ability and decision-making ability of autonomous vehicles are still facing challenges, and more accurate and reliable algorithms and models are needed to improve their performance. Secondly, legal and moral issues are important considerations for the development of autonomous vehicles [6]. At present, the laws, regulations, and ethics of autonomous vehicles are not perfect. It is necessary to strengthen the research and formulation of relevant laws, regulations, and ethics while developing technology to ensure the safety and legitimacy of autonomous vehicles.

Based on the above research, future research can be carried out from the following aspects. First of all, the sensors and sensing systems as well as decision-making and control technology of autonomous vehicles can be further optimized and enhanced to improve their performance and safety. Secondly, the research and formulation of laws, regulations, and ethics of autonomous vehicles can be strengthened to provide a more reliable and legal environment for the application and development of

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autonomous vehicles [6]. In practice, the practical application and verification of autonomous vehicles can be further developed to verify and evaluate the performance and feasibility of autonomous vehicles. At the same time, it can also strengthen the collaborative research between autonomous vehicles and other means of transportation and infrastructure, and promote the seamless docking and optimization of autonomous vehicles and transportation systems.

In short, as a new mode of transportation, autonomous vehicles have great development potential and application prospects. This study provides an important reference and basis for promoting the development and application of autonomous vehicles by deeply exploring the technical principles and implementation methods of autonomous vehicles. Future research and practice will further improve the key technologies, laws, regulations, and ethics of autonomous vehicles, and promote the safety, reliability, and popularization of autonomous vehicles.

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