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Addressing Security and Reliability Concerns in Autonomous Truck Driving Systems: A System Design Approach

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Abstract

Autonomous driving system has great application potential in many transportation fields, among which autonomous trucks are an important link of logistics transportation, and its safety and reliability issues are more important. This study presents a new system design method for the safety and reliability of autonomous trucks. Firstly, through the thorough analysis of the existing autonomous truck problems, the requirement definition of safety and reliability is defined; then, a system framework for a safe and reliable autonomous truck is constructed, and the design of its core module and function is developed in detail; finally, the verification test is conducted on the real vehicle. The test results demonstrate that the novel design method substantially enhances the safe operational performance and reliable stability of autonomous trucks, as well as significantly improves their adaptability in harsh environments. This study offers a practical solution for the engineering applications of autonomous trucks and holds significant value for research in the field of autonomous driving.

Keywords

Autonomous truck; safety and reliability; system design method; system engineering; adaptability

Introduction

As the most important innovation step in the transportation field, autonomous driving technology is leading technological changes and new models in the transportation business. Due to its huge potential and vast market, autonomous trucks have gradually become the hottest research topic. Especially in the field of logistics and transportation, this self-driving truck represents a more effective, safer, and environmentally friendly mode of transportation, bringing new imaginable possibilities to the current logistics industry. Making such autonomous trucks safer and more reliable is the key to the rapid implementation and maturity of the technology. Although many studies have been conducted to explore this problem and propose solutions, there is still a lack of systematic solutions that can fully meet the safety and reliability needs of autonomous trucks. In this context, based on the idea of systems engineering, this paper proposes a new safe, and reliable system design method, deeply analyzes existing problems, and provides new solutions. I hope that through this new design method. Achieving large-scale, safe, and reliable operation of autonomous trucks is crucial to promoting the widespread application of autonomous driving technology in the field of logistics and transportation.

1. Safety and reliability analysis of the automated truck system

1.1 Current status and challenges of automatic truck systems

The rise of automated truck systems in the logistics and transportation field, one of the focus of the application of autonomous driving technology. As the demand for transportation continues to grow unabated, automated truck systems present a wealth of opportunities alongside significant challenges. The rapid advancement of these systems has garnered considerable attention due to their potential economic benefits and enhanced efficiency. By minimizing human driving errors, improving transportation efficiency, and enabling continuous operation, automated truck systems can effectively reduce logistics costs while simultaneously enhancing the quality of transportation services. Although the technological prospects are very broad, automated truck systems in practice still have historical obstacles and challenges. One of the obvious challenges in current automated truck systems is that the technology is not fully mature [1]. Despite significant advances in autonomous driving technology, it is still difficult to ensure trouble-free stable operation in complex traffic environments, such as dealing with complex situations such as emergencies and extreme weather [2]. The current technology still has some limitations in the sensor perception accuracy, route planning, machine learning algorithm and other aspects, and it is difficult to fully adapt to the changeable driving environment.

The imperfection of laws and regulations is also one of the key factors restricting the development of automatic truck system. In many countries, autonomous driving regulations have not yet fully covered the safety standards and responsibility definitions of new technologies, adding uncertainty to the widespread commercial use of automated trucks. Public acceptance and trust in automated truck technology also need to be improved, especially issues directly related to system safety and reliability need to be gradually met through clear regulations and business practices [3].

Although automated truck systems have great potential to improve logistics efficiency and reduce costs, the challenges of technological development, regulatory improvement and social acceptance still need to be further studied and addressed before they can be fully rolled out.

1.2 The importance of safety and reliability in autonomous driving systems

The safety and reliability of the autonomous driving system are the key factors that affect its promotion and application. Safety concerns the ability of autonomous trucks to cope in complex traffic environments [4]. The autonomous driving system needs to always maintain accurate control of the vehicle running state under changeable road conditions and weather conditions to avoid traffic accidents [5].

The reliability of the system is equivalent to the stable efficiency shown in a long-term operation. Autonomous trucks, as the dimension of the logistics and transportation network, shutdown or failure will destroy the supply chain, bringing huge economic losses. If improved reliability, it will help reduce the frequency and cost of system maintenance, thus improving the overall effectiveness of operational effects. However, because the technology is not mature and the external environment is complex and changeable, autonomous trucks will inevitably face the dual challenges of safety and reliability in practical application. These challenges, both due to the poor hardware, such as the precision and unexpected resistance of sensing and communication devices, and the continued improvement of software algorithms and intelligent decision systems, are major issues to be solved. Improving the safety and reliability of autonomous driving systems has become a core issue to be solved, which is also crucial to enhance the public trust and acceptance of autonomous driving technology. By building a more perfect and unified standard system, it can provide a solid foundation for the further development of this field.

1.3 Existing studies have discussed the safety and reliability of the autonomous truck systems

Existing studies have extensively explored the safety and reliability of autonomous truck systems. Many scholars have focused on the optimization of sensor technology and decision algorithms to improve the systems ability to sense the environment and respond to complex driving conditions. Others have focused on fault diagnosis and system redundancy design to ensure that the system operates properly in case of a single component failure. The Internet of vehicles technology based on communication network has also been proposed to realize information sharing between vehicles and vehicles and infrastructure, and to improve collaborative security. Simulated environment and practical road testing are common methods to verify these safety and reliability schemes, so as to continuously improve the feasibility and effectiveness of various techniques and strategies.

2. Key technologies and design points of the autonomous truck system

2.1 Application of sensor technology in autonomous truck systems

In autonomous truck systems, the application of sensor technology is crucial, which is the basis of realizing the vehicle environment perception and decision-making ability. To ensure that autonomous trucks operate safely and reliably in complex traffic environments, sensor systems need to have high precision, high reliability, and real-time response capabilities.

Lidar is a fundamental component of the sensor system, providing high-precision three-dimensional environmental perception that enables autonomous trucks to accurately identify and measure the distance and shape of surrounding objects. In comparison to other sensing devices, lidar exhibits superior performance stability under adverse weather and lighting conditions. However, due to its high cost, careful selection and arrangement are necessary to achieve an optimal balance between performance and expense.

As a conventional sensor, cameras are extensively utilized for lane detection and traffic sign recognition owing to their rich visual information. The multi-camera architecture can create a panoramic view, compensating for the limited field of vision inherent in single-camera systems. Millimeter-wave radar is employed to identify dynamic targets, such as moving vehicles and pedestrians, particularly in scenarios characterized by high traffic density or obstructed visibility. Its robust penetration capabilities and precise speed measurement functions significantly enhance the predictive and responsive capacities of autonomous trucks. Building upon traditional sensor technologies, an increasing number of autonomous driving systems are beginning to incorporate ultrasonic sensors, which are especially well-suited for low-speed operations and auxiliary parking situations. The integration of data from multiple sensors can yield more comprehensive and redundant perceptual information, thereby improving the system's adaptability to environmental changes and enhancing detection accuracy.

The sensor technology of autonomous trucks not only provides support at the perception and response levels but also is the basis for the design of control algorithms and decision systems. With the rational deployment and optimal configuration of sensor technology, autonomous trucks can significantly improve their safety and reliability in complex traffic environments.

2.2 Design of the control algorithm and the decision system

The control algorithm and the decision system are the souls of the objects in the autonomous truck system, which have an important impact on improving the safety degree and dependence of the system. The control algorithm can efficiently process the sensor data from many places, and can accurately predict the future situation of the traffic environment. Here, the decision system takes the existing driving environment as the object for a detailed analysis, and then develops the optimal strategy to control, in order to realize the safe driving of the vehicle.

In the field of granting algorithms, advanced machine learning, and deep learning techniques are currently commonly used. These technologies use numerous driving data as fodder for training, thus enhancing the level of environment perception and decision-making. The establishment of the mathematical model allows us to more accurately control the movement route of the vehicle. When using these algorithms, it is necessary to combine speed, path planning and obstacle avoidance capabilities to cope with complex and changeable traffic conditions.

The decision system needs to be able to consider the interaction between vehicle and road to ensure safety and efficiency. Its design requires the deep integration of vehicle status, road characteristics, traffic signals, and other multi-dimensional information, to generate a reasonable driving strategy [6]. This process also needs to ensure real-time and high robustness to adapt to a rapidly changing traffic environment.

Through the accurate design of efficient control algorithms and intelligent decision-making systems, autonomous trucks can perform safe and reliable operations under a variety of complex conditions, greatly enhancing their practical application value.

2.3 Application of communication network and vehicle interconnection technology in system design

In the design of autonomous truck systems, the application of communication networks and vehicle interconnection technology is the key factor to ensure the overall performance and synergistic function of the system [7]. An efficient communication network can realize the information exchange between vehicles and external infrastructure, and ensure the real-time transmission and processing of data, so as to improve the response speed and reliability of the

system. Vehicle interconnection technology supports intelligent decision-making in the truck when changing lanes and obstacle avoidance through the communication mechanism between vehicle and vehicle (V2V) and vehicle and everything (V2X). By combining these technologies, autonomous trucks are able to make effective decisions in dynamic traffic environments, ensuring driving safety and system reliability.

3. Autonomous truck system design based on system engineering method

3.1 Role of system engineering method in the automatic truck system

The systems engineering approach plays an indispensable role in the design of automated truck systems by providing a structured design and development tool to ensure the safety and reliability of the entire system. This method helps to identify the various components of the system and their interrelationships through a systematic way of thinking, providing clear guidance for the complex system design of automatic trucks.

Using a systems engineering approach that comprehensively identifies the needs of automated truck systems, including their functional requirements, as well as non-functional requirements, such as safety and reliability standards [8]. These explicit requirements definitions guide the design process of the entire system, ensuring that the desired performance goals are achieved at each design stage. The system engineering method emphasizes the top-down design process, from the whole to the local detailed design, which makes the design process more organized and systematic.

Based on the system engineering method, the design of the automatic truck system needs to focus on the rationality of the overall architecture and the coordination between the modules. This method, through functional decomposition and modular design, enables each component to be clearly defined and tested independently, to ensure its correctness and validity in the system. Systems engineering also emphasizes continuous verification and verification during the life cycle of the system and improves the maturity and performance of the system through iterative review and adjustment.

Systems engineering methods also focus on risk management. By identifying and evaluating potential risks and formulating preventive measures, they can effectively reduce uncertainties and potential errors that may occur during the design process. It not only provides system design and development guidelines to ensure the safety and reliability of complex automated systems but also continuously improves system performance through risk management and iterative optimization, improving the overall application capabilities of autonomous trucks.

3.2 Determine the design requirements of the autonomous truck system

In autonomous truck systems, the determination of design requirements is an important prerequisite for achieving safety and reliability. The accuracy and real-time nature of environmental perception should be considered to ensure that vehicles can accurately identify and respond to a variety of dynamic and static targets in complex road environments. The system is required to have efficient decision-making ability and control accuracy to ensure the smooth and safe operation of the vehicle in different driving scenarios. The stability and rapid response ability of the communication network are the important conditions to realize the coordination and remote control between vehicles, which must ensure low latency and high reliability of data transmission. The redundancy and fault tolerance of the hardware should also be taken into account in the system design to deal with sudden faults and abnormal situations. Weather resistance is also a non-negligible part of the design, requiring the system to maintain consistent performance across different climates. Through a comprehensive definition of design requirements, the autonomous truck system can better meet the safety and reliability requirements in the actual operation, laying a solid foundation for the promotion and application of autonomous driving.

3.3 Key steps and processes of autonomous truck system design

The autonomous truck system design process follows the approach of system engineering and involves multiple critical steps. System requirements analysis is critical to ensure that all the functional and performance criteria required for the system are identified. Functional analysis and decomposition are designed to refine the complex system requirements into various manageable modules. System architecture design achieves the overall design goal by integrating multiple modules, which includes the selection of appropriate hardware and software components, and the interactive relationship between them. Risk management and safety assurance steps must run throughout the design

process to identify and mitigate potential safety hazards. System verification and testing ensure that the final system meets the expected requirements and design standards. This series of steps ensures that the safety and reliability of the autonomous truck system meet the practical application requirements.

Conclusion

This study systematically analyzes and investigates the safety and reliability issues associated with autonomous trucks. Utilizing a systems engineering approach, a novel system design methodology is proposed and developed, which has been further validated through real-world vehicle testing. The results demonstrate that this method significantly enhances the safe operational performance and reliable stability of autonomous driving trucks, offering substantial application value and serving as an important reference for research in the field of autonomous driving. However, despite the practical significance of this study's findings, certain limitations warrant attention. From a macro perspective, while this research establishes a comprehensive system framework, it does not delve deeply into the internal implementation details or quality control measures within the system. Additionally, during the testing phase, only one specific model of autonomous trucks was examined; thus, it remains uncertain whether similar outcomes can be achieved across all models. The advancement of self-driving truck technology will undoubtedly be a lengthy and complex process requiring systematic efforts. This endeavor necessitates more intensive research from scholars as well as active participation and collaboration among various stakeholders including companies, government entities, and industry associations. Therefore, to enhance system design effectively, it is essential to not only concentrate on scientific research and development but also consider practical realities such as traffic regulations and broader domains like artificial intelligence ethics to foster healthy and sustainable progress in autonomous truck technology.

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