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Research on autonomous driving technology in intelligent transportation systems

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Abstract. The convergence of scientific and technological advancement with the acceleration of urbanization has resulted in a notable intensification of the issue of traffic congestion. In this context, the development of autonomous driving technology has emerged as a pivotal area of focus for future transportation systems. Therefore, this paper presents a review of the current status of automatic driving technology in intelligent transportation systems, based on methods such as literature, data analysis and case studies. Furthermore, it delves into the evolution, applications, challenges and solutions of automated driving technologies in intelligent transport systems, and presents forward-thinking insights into the future development of intelligent transportation. As autonomous driving technology continues to evolve, the integration of deep reinforcement learning and other advanced technologies will facilitate the advancement of intelligent vehicle human-machine collaborative decision-making technology. It is imperative that the construction technology of safety-critical scenarios be reinforced in order to enhance the interpretability of algorithmic models and the real-time nature of scenario generation. All parties need to collaborate to promote the innovation and improvement of autonomous driving technology, achieve widespread application and sustainable development, and create a better travelling environment.

Keywords: Intelligent Transportation System, Autonomous Driving Technology, Application Cases, Problems, Future Prospects.

1. Introduction

In recent years, automated driving technology has made remarkable progress, especially in core areas such as perception, decision-making, and control, which has led to an expansion of its applications in across various fields. Despite these advances, significant challenges remain in areas such as handling complex environments, high-precision map coverage, data protection, and establishing unified safety testing standards. It is evident that further research is required on the following fronts: human-machine cooperative decision-making, the generation of safety-critical scenarios and sensor fusion technologies. The paper reviews and analyzes the recent developments in autonomous driving technology and the components and features of intelligent transport systems, including system frameworks, perception systems, sensor technologies, positioning and navigation, and vehicle-to-object (V2X) communication. In addition, it delves into practical applications in the field of urban public transportation and logistics, and explores the current status of autonomous driving technology in intelligent transportation systems.

The proposed solutions aim to serve as a reference for traffic management authorities and automobile manufacturers, with the potential to stimulate innovation and facilitate advancements in autonomous driving technology, enhance the overall quality of intelligent transportation systems, and contribute to the creation of a more convenient, efficient, and safer travel environment.

2. Overview of Intelligent Transportation System and Autonomous Driving Technology

2.1. Intelligent Transportation Systems and Their Components

Intelligent Transportation Systems (ITS) are comprehensive transportation management frameworks designed to operate extensively and integratively, which are characterized by their real-time, accurate, and efficient functionality, covering a broad range of components, as shown in Table 1. Sotiris posits that ITS represents a confluence of intelligent technology, wireless communication, automation, and computing technologies. It not only enhances the support provided to transportation management but also extends the range of service delivery. Leonidas then further defines intelligent transportation by its key attributes: timeliness, efficiency, stability, data sharing, and extensibility [1].

Table 1. ITS Components and Their Roles

Ingredient	Functions
Communication System	Enabling information interaction between vehicles and other vehicles and infrastructure (e.g., traffic signals, roadside units) to improve traffic efficiency and safety.
High Precision Maps	Providing detailed road maps and related information to help vehicles with location and route planning.
Intelligent Traffic Management System	Monitoring and managing the entire traffic system to optimize traffic flow, reduce congestion and improve road safety.
Connected Vehicle Technology	Enabling vehicles to communicate with each other, share information, realize cooperative driving, and improve traffic efficiency.
Data analysis and processing systems	Collecting and analyzing traffic data to provide support for traffic management and decision-making, and optimizing the operation of the traffic system.

2.2. Foundation of Automatic Driving Technology

The foundation elements of automatic driving technology encompass both the system framework and the perception system. The system framework is divided into three mian parts: perception, control, and execution. And the sensing system, which includes environmental sensing, interior sensing, and driver sensing, is primarily aimed at ensuring safety, improved passability, and economic comfort. These goals are mainly achieved through the use of sensors, positioning and navigation technologies, and V2X communication [2]. Sensor technologies are employed to detect various aspects such as the driving path, surrounding obstacles, and the driving environment. The leading sensing technologies include vision, laser, and radar. For positioning and navigation, which provide global positioning and other critical functions, commonly used technologies include satellite positioning and inertial navigation systems. V2X technology facilitates information exchange between vehicles and other entities, with Dedicated Short-Range Communications (DSRC) being the predominant wireless communication technology [3].

2.3. Synergy Between ITS and Autonomous Driving

The integration of ITS and autonomous driving technology constitutes a mutually reinforcing dynamic. ITS provides essential infrastructure and environmental support for autonomous driving, enhancing its effectiveness. For instance, high-precision maps and real-time traffic data enable self-driving vehicles to optimize route planning and decision-making. Intelligent traffic signals can communicate directly with autonomous vehicles, offering real-time signal status and countdowns, allowing for more precise control of speed and vehicle maneuvers. Conversely, advancements in autonomous driving technology drive the evolution of ITS. In terms of traffic efficiency, autonomous vehicles can collaborate closely through V2V communication, facilitating convoy driving, reducing vehicle spacing, and increasing road capacity. Regarding traffic safety, autonomous driving reduces issues related to human factors, such as fatigue and illegal driving, thereby decreasing the frequency of traffic accidents. Additionally, autonomous vehicles generate extensive real-time data, such as vehicle trajectories, speeds, and road conditions, that can be leveraged by traffic management authorities to refine traffic planning and management strategies.

3. Applications of Automatic Driving Technology in Intelligent Transportation System

3.1. Application in Urban Public Transportation

In the field of urban public transportation, the application cases of self-driving technology are increasing. For example, the proposed self-driving bus line program to be operated in Ningbo includes Digital Bus Line 1 and Leisure Business Travel Line 1, which uses L4-level self-driving vehicles to provide more convenient and efficient travel services for the public [4]. Additionally, the United States, Japan, and Europe are actively advancing autonomous driving in public transportation. Various types of self-driving buses have emerged, including those operating in dedicated right-of-way scenarios, conventional buses for open road environments, and feeder or micro-circulation buses for small-scale, low-speed routes. These different models address diverse travel demands, improving both operational efficiency and service quality within public transportation systems [5].

Self-driving buses are outfitted with an array of advanced sensors that can provide comprehensive real-time data on vehicle operation. To analyze this data, a multivariate Long Short-Term Memory (LSTM) neural network binary classifier model is employed, converting trajectory data into indicators of vehicle stability, efficiency, and safety. This facilitates real-time tracking and monitoring of vehicle performance [6]. To ensure safe and smooth trajectories for buses entering and exiting harbor-type stops, Zhang Wenhui develops motion trajectory equations based on Ackermann’s steering principle. This model incorporates constraints for obstacle avoidance, kinematics, and start/end positions, and uses fifth-degree polynomial curves to define the safe trajectory. The model’s feasibility and validity are validated through both simulations and real-vehicle road tests [7].

The application of automatic driving technology in the field of urban public transportation is gradually expanding, which brings new opportunities for improving the efficiency of bus operation and service quality. The self-driving bus can realize accurate arrival and stopping, intelligent route planning and efficient operation scheduling, reduce the influence of human factors on bus operation, and improve the reliability and punctuality of the bus system. At the same time, self-driving buses can also provide passengers with a more comfortable and safer travel experience, enhancing the attractiveness and competitiveness of the bus system.

3.2. Application in Logistics and Transportation

In logistics and transportation, the application of autonomous driving technology is highly significant. For instance, in a college environment, logistics robots are deployed across dormitory areas, office spaces, cafeterias, and residential zones, following designated routes to automate parcel delivery [8]. At Nanning Normal University, for example, the courier delivery cart known as Small Savage Donkey calculates its route based on the delivery address and scheduled times. It delivers parcels directly to student dormitory buildings according to reservation information and notifies recipients via text messages or other means to collect their deliveries.

In addition, Germany in the field of logistics and transportation of autonomous driving technology has also made significant progress. Germany is actively promoting the development and application of autonomous transportation technology, and autonomous driving technology has a broad prospect in the field of road freight transportation. For example, in 2019, DB Schenker, MAN Truck&Bus and the School of Applied Sciences at Fresenius University in Germany successfully completed a pilot project on truck queuing. The test proved that the truck queue system has obvious advantages in improving transportation safety, alleviating the driver gap and reducing costs [9]. In addition, Germany also actively promotes the introduction of automatic driving policies and laws, which establishes a good legal and policy environment for technology research and development and application, and promotes the healthy development of automatic driving technology in the field of logistics and transportation.

The integration of autonomous driving technology in logistics and transportation significantly advances distribution efficiency, cost reduction, and the overall intelligence of logistics operations. Autonomous vehicles facilitate all-weather, uninterrupted transportation, enhancing both operational efficiency and punctuality. Moreover, this technology mitigates labor and operational costs, thereby increasing the economic viability of logistics enterprises. Through sophisticated path planning and optimization, autonomous driving technology contributes to reduced energy consumption and lower emissions, aligning with the objectives of sustainable and green logistics.

4. Realistic Dilemmas and Solutions for the Application of Autonomous Driving Technology

4.1. Reliability of Sensors

In adverse weather conditions, such as heavy rain, fog, or snow, the optical and electromagnetic signals critical to autonomous driving sensors can experience significant interference, resulting in a significant reduction in recognition accuracy. In nighttime conditions, insufficient illumination further impairs the sensors' ability to accurately capture and differentiate surrounding objects. Additionally, in complex traffic scenarios, such as road construction, congestion, or emergency situations, the influx of variable and unpredictable environmental data may exceed the processing capacity of the sensors. This can adversely affect the vehicle's capacity for precise environmental perception, posing substantial risks to driving safety. To mitigate these challenges, substantial investment in sensor research and development is essential, including advancing optical and radar sensors to enhance their resistance to interference and extend their detection range. Moreover, integrating multiple sensor technologies, such as LIDAR, cameras, and millimeter-wave radar, can provide complementary strengths, improving overall system robustness and accuracy in diverse conditions.

4.2. Coverage and Data Protection of High-Precision Maps

At present, there are significant limitations in the coverage of high-precision maps, especially in some remote areas and emerging urban areas, where the lack of high-precision maps brings obstacles to the application of autonomous driving. Moreover, the collection of high-precision maps involves detailed information about urban roads, including geographic coordinates, road shapes, traffic signs, and other sensitive data, which not only involves the issue of personal privacy, but also relates to national security. Therefore, the scope of high-precision map collection should be further expanded under the strict supervision of the government and related departments. The government should formulate clear policies and regulations to ensure that the collection is legal and orderly. At the same time, strict data protection mechanisms should be put in place to strengthen norms for encrypted data storage, access control, and transmission security, to ensure that map data are properly protected during the entire process of collection, processing, and use, and to prevent data leakage and misuse.

4.3. Difficulties in Safety Testing and Verification

Currently, safety testing standards and methods for autonomous driving systems are in a phase of continuous development and refinement. Scientific, rigorous and appropriate testing standards should be established, which require a comprehensive assessment of various factors such as the vehicle's reaction time, its ability to detect and recognize various obstacles, and its stability under different driving conditions. The creation of standardized testing procedures is complicated by the diverse technical architectures and performance characteristics of various manufacturers and systems, making it challenging to ensure fair and comparable assessments. Additionally, extensive and large-scale road testing demands substantial human, material, and time resources, and can disrupt normal public road

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use. To improve testing efficiency and reduce reliance on public roads, it is crucial to establish unified standards and specifications that clearly define testing requirements and methodologies. Additionally, leveraging simulation technology to create diverse and complex virtual traffic scenarios can facilitate comprehensive testing of autonomous driving systems. This approach allows for extensive evaluation in a controlled environment, addressing a wide range of scenarios without the constraints and disruptions associated with on-road testing.

5. Forward-Looking Thinking on the Future Development of Intelligent Transportation

With the continuous development of science and technology, autonomous driving technology will play an increasingly important role in intelligent transportation systems. Deep reinforcement learning and other technologies are expected to make breakthroughs in areas such as adaptive driving strategy generation, providing more intelligent and flexible decision-making capabilities for autonomous driving. The application of multimodal human-computer interfaces and new decision intent conduction technologies (e.g., brain-computer interfaces) will promote the development of human-machine collaborative decision-making technologies for intelligent vehicles, making the driving process safer and more efficient. In addition, the integration of artificial intelligence, big data, cloud computing and other technologies will provide stronger support for autonomous driving, such as achieving more accurate road condition prediction and optimized path planning [10].

In the future, the human-machine collaborative decision-making technology will develop in the direction of the common development of multi-level technology, the continuous improvement of human-computer interaction level, and the continuous innovation of collaborative methods. The innovation of multimodal human-computer interface will make the interaction between drivers and vehicles more natural and convenient, and the application of deep reinforcement learning will improve the system's intelligence level and decision-making ability, providing better support and suggestions for drivers [11]. At the same time, the development of human-machine collaborative decision-making technology will help to improve the safety and reliability of the transportation system and reduce the occurrence of traffic accidents. Additionally, future advancements in safety-critical scene construction should emphasize the use of real-world data to enhance the interpretability of algorithmic models and the real-time generation of scenarios. By gathering and analyzing extensive real-world data, more accurate models can be developed, improving the prediction and response to potential safety risks [12]. Furthermore, the advancement of reliable obstacle detection methods will be crucial. Reinforcement deep learning techniques can enhance obstacle recognition and detection through continuous learning and optimization, thereby reducing both misjudgments and missed detections [13].

6. Conclusion

This paper assesses the implementation of autonomous driving technology and ITS in urban public and logistics transportation, highlighting practical challenges and proposed solutions. Key issues include sensor accuracy, high-precision map coverage, data protection, and safety testing. Addressing these challenges will require increased R&D investment, enhanced regulation, and targeted measures. Future advancements will be driven by deep reinforcement learning and multimodal human-machine interfaces, which will enhance collaborative decision-making in autonomous vehicles. Additionally, improved construction of safety-critical scenarios will enhance model interpretability and real-time scenario generation.

However, there are limitations in the comprehensive assessment of autonomous driving technology’s adaptability to different regions and complex environments, and in exploring its integration with emerging technologies. Future research should expand to include diverse environmental testing and a deeper investigation into how autonomous driving technology integrates with artificial intelligence, big data, and other emerging technologies to uncover innovative application scenarios. Future research will enhance the adaptability of autonomous driving technology in varied environments, improve integration with intelligent transportation systems, and incorporate emerging technologies to boost performance and safety.

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