Review of Autonomous Driving Technology in Intelligent Transportation Systems

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Abstract: The main problems in transportation are traffic accidents, increasingly slow traffic flow, and pollution. It requires huge infrastructure investments in traditional transportation systems to solve. The advent of autonomous driving techniques with intelligent transportation systems (ITS) can overcome these problems. This paper investigates the integration of autonomous driving technology with intelligent transportation systems (ITS) and explores the latest case studies and research findings on this integration. The purpose is to emphasize the crucial role of merging autonomous driving technology with ITS in-boosting transportation efficiency, ensuring road safety, and fostering sustainability. The study delves into innovations such as intelligent traffic management systems and autonomous logistics distribution vehicles. Key findings highlight the potential of this integration to enhance traffic safety, and efficiency, and reduce congestion and accidents. However, unresolved challenges persist in system integration, data correlation, and hazard detection. The paper concludes by emphasizing the transformative potential of autonomous driving within ITS while proposing future research directions to address these challenges.

Keywords: Autonomous Driving Technology, Intelligent Transportation Systems.

1. Introduction

The accelerating pace of urbanization and the continuous growth in traffic demand have exposed the inadequacies of traditional transportation systems. The rising incidence of traffic accidents presents significant economic, environmental, and human challenges, particularly in developing countries, where the vehicle population is projected to outpace the growth of transportation infrastructure. To address these challenges, Intelligent Transportation Systems (ITS) have been proposed as a solution to mitigate traffic congestion, reduce accident frequency, and alleviate environmental pollution. The rapid advancement of technologies such as the Internet of Things (IoT), big data, and cloud computing has provided robust support for the development of ITS [1,2]. As a result, many countries and regions have successfully implemented advanced ITS to improve transportation efficiency and management.

Autonomous driving technology in ITS offers tremendous potential for revolutionizing transportation. Researchers suggest that integrating these technologies could lead to the creation of intelligent traffic management systems, comprehensive vehicle-road coordination, and significant improvements in traffic safety, efficiency, energy conservation, and emission reduction [3,4,5]. Furthermore, this integration is expected to drive coordinated industrial advancements across the automotive, information technology, and transportation sectors. Autonomous driving is positioned to

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be one of the most transformative innovations of the near future. With breakthroughs in key technologies such as computer vision, machine learning, and path planning, autonomous vehicles now have the capability to perceive their environment, make informed decisions, and execute those decisions with high precision [6,7]. The introduction of these vehicles has generated considerable consumer interest, leading to a rapid increase in demand for advanced assisted driving features. This growing demand is pushing automakers to accelerate the development and deployment of autonomous driving technologies. The societal impact of autonomous driving is anticipated to be profound; for example, estimates suggest that only 15% of the current number of vehicles may be necessary in the future, and one-quarter of the existing parking space could suffice [8]. Moreover, autonomous driving is expected to significantly reduce accident and fatality rates, with additional benefits including an average annual reduction of 38 hours in commuting time per individual and an estimated savings of 1.3 trillion dollars for the U.S. economy [9]. The widespread adoption of autonomous driving technology promises substantial societal benefits.

This paper reviews recent case studies and research findings on the integration of autonomous driving technology with ITS, with a focus on innovations such as intelligent traffic management systems and autonomous logistics distribution vehicles. The paper also explores the technical and operational challenges and how autonomous driving could reshape urban transportation.

2. Technological Foundations

2.1. Autonomous Driving Technology

The autonomous driving vehicle is an intelligent connected car that achieves autonomous driving through a computer system. Autonomous driving systems rely on the cooperation of artificial intelligence, visual computing, radar, monitoring devices, and global positioning systems so that computers can achieve vehicle-road cooperation without the active operation of people. With the rapid advancements in deep learning and artificial intelligence [10], significant progress has been made in computer vision, robotics, and natural language processing. This technological leap has paved the way for the development of sophisticated autonomous vehicles, which rely heavily on deep learning-based decision-making architectures. These architectures encompass various components, including perception and localization, high-level path planning, behavior arbitration, and motion controllers.

At the core of autonomous driving, the first step is for the vehicle to comprehend and localize itself within its surrounding environment. This is achieved through the integration of IoT frameworks [11], which draw upon diverse disciplines within computer science, such as sensor technology, computer vision, artificial intelligence, and communication technology. Once localized, the vehicle utilizes convolutional and recurrent neural networks, along with deep reinforcement learning paradigms, to perceive its driving scene and plan a continuous path. This path is then refined by the behavior arbitration system, which determines the appropriate actions for the vehicle to take based on its current state and surroundings. Finally, a motion control system is employed to reactively correct any errors that may arise during the execution of the planned motion, ensuring a smooth and safe driving experience.

2.2. Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) is road-vehicle systems that applies advanced communication, information, and electronics technologies designed to enhance the safety, efficiency, and reliability of road transportation [12]. By leveraging these technologies, ITS aims to minimize road accidents, optimize traffic flow, and facilitate real-time monitoring, control, and management of the transportation network. At its core, ITS operates through a complex ecosystem of interconnected

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and heterogeneous entities, including vehicles, roadside units (RSUs), traffic signs, traffic lights, network nodes, and servers. These entities collaborate seamlessly, leveraging data captured by various sensors to inform and refine the transportation system's operations. Central to ITS's efficacy is the utilization of Vehicular-to-Everything (V2X) communication technologies [13]. This holistic approach to communication enables a seamless exchange of information between all stakeholders involved in traffic control, monitoring, and management, thereby enhancing traffic efficiency and ensuring the timely delivery of critical data.

Within the ITS framework, there are four primary subsystems that facilitate communication and collaboration [14]. Personal ITS Subsystem provides users with access to ITS applications through personal devices, enabling them to receive real-time traffic updates, route guidance, and other relevant information. Vehicle ITS Subsystem is equipped with advanced sensors and communication capabilities, which collect data about the vehicle's status and its surrounding environment. It communicates this information to the driver, aids in decision-making, and can even partially or fully control the vehicle in emergency situations. The central ITS Subsystem serves as the backbone of the ITS network and is responsible for maintaining, monitoring, and providing functionality to all ITS applications. It processes and analyzes data from various sources to inform traffic management decisions and optimize the overall performance of the transportation system.

Roadside ITS Subsystem collects information about traffic flow and road conditions, controls roadside equipment such as traffic signals, and communicates with vehicle ITS subsystems to provide and receive vital information. Coordinating with vehicles and other roadside units contributes to the smooth flow of traffic and enhances road safety. These subsystems form a powerful and interconnected network that harnesses the power of technology to revolutionize the way we move through our cities and on our highways.

3. Applications of Autonomous Driving in ITS

3.1. Traffic Management Systems

Traffic Management Systems (TMSs) integrate communication, sensing, and processing technologies to aggregate traffic data from various sources [15]. With the advent of autonomous driving in Intelligent Transportation Systems (ITS), TMSs now focus on dynamic speed adjustment, minimizing intersection wait times, identifying congestion, and offering intelligent routing options. This improves traffic flow, reduces delays, and enhances road safety. Papageorgiou et al. (2007) provided an overview of traffic flow modeling advancements, highlighting route guidance systems and control mechanisms in road networks [16]. Djahel et al. (2014) reviewed technological advancements in TMSs, exploring the potential of smart cars and social media in congestion detection and mitigation [17]. Shahgholian and Gharavian (2018) examined traffic assignment implementation, focusing on optimizing networks through the strategic deployment of traffic actuators [18]. Their research emphasized the importance of real-time monitoring in achieving efficient traffic flow.

3.2. Vehicle-to-Everything (V2X) Communication

Autonomous vehicles necessitate robust sensing and communication capabilities with various road users, including pedestrians, other vehicles, and roadside infrastructure. Intelligent Transportation Systems (ITS) facilitate this interconnectivity, enabling seamless communication between vehicles, pedestrians, networks, and infrastructure. A pivotal concept in this realm is Vehicle-to-Everything (V2X) communication [19], which represents the cutting-edge integration of Information Technology (IT) and Artificial Intelligence (AI) principles. V2X communication algorithms, particularly those leveraging supervised learning, can be instrumental in categorizing roadside obstacles such as pedestrians, sidewalks, or electrical towers. This classification is vital for ensuring safe and efficient

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navigation. Autonomous driving in ITS represents a groundbreaking technology, enabling vehicles to operate independently, navigating roads with minimal human intervention. At the core of autonomous driving lies V2X communication, which governs the interplay between vehicles, infrastructure, and networks. This technology is continually advancing, fueled by Artificial Intelligence, which enhances its capabilities and ensures safer, more efficient roadways for all.

3.3. Automated Logistics and Delivery

The seamless integration of autonomous delivery vehicles into urban logistics systems signifies a monumental leap toward constructing smarter, more streamlined, and highly efficient supply chains. At the forefront of this revolution are advanced technologies such as artificial intelligence (AI), machine learning, and deep learning algorithms, which endow these vehicles with exceptional self-diagnostic and autonomous decision-making abilities. This autonomy drastically reduces the dependency on human labor [20], enabling a paradigm shift in the logistics industry. The advent of smart logistics powered by automation offers unparalleled opportunities for enhancing competitiveness, streamlining operations, and minimizing errors. As Flechsig, Anslinger, and Lasch (2022) insightfully point out, the disparity in the adoption of robotic process automation (RPA) between the private and public sectors underscores the necessity for tailored strategies that cater to the unique needs and challenges of each domain [21], with implications that extend to both research endeavors and organizational practices. Benzidia, Ageron, Bentahar, and Husson (2019) underscore the urgency of anticipating and nurturing new competencies and knowledge bases essential for effectively orchestrating and managing automated logistics workflows involving autonomous guided vehicles (AGVs) [22]. Their research highlights the profound transformation that AI- and robot-driven logistics can bring about, revolutionizing operational efficiency, minimizing human errors, and ultimately, strengthening the competitive stance of businesses operating in this rapidly evolving landscape. Empirical evidence from case studies and current deployments of autonomous delivery vehicles underscores the viability and tangible benefits of this technology in practical settings. By alleviating traffic congestion, reducing carbon emissions in urban centers, and enhancing customer satisfaction through swifter, more dependable deliveries, the integration of autonomous vehicles with ITS into urban logistics is revolutionizing the very fabric of goods transportation and distribution. This evolution promises a future where logistics operations are smarter, more agile, and better equipped to meet the demands of a dynamic global marketplace.

3.4. Enhanced Safety and Accident Prevention

The application of autonomous driving in intelligent transportation systems holds immense potential for enhancing safety and preventing accidents, transcending the limitations posed by human factors. Road accidents, a persistent threat to public safety, are often fueled by human errors such as overspeeding, driving under the influence, disobeying traffic rules, and misjudgments of other road users' movements. Even seasoned drivers can falter, especially in emergencies or adverse weather conditions. Autonomous driving, conversely, endeavors to mitigate these hazards by entrusting the driving task to sophisticated vehicles armed with robust algorithms and cutting-edge technologies. Core to its safety prowess lies the capability to avert collisions with all road users, pedestrians, and cyclists alike, even in intricate and perilous scenarios. This is facilitated by the seamless integration of Collision Avoidance Systems (CAS) in autonomous driving with ITS, which meticulously analyzes sensor data in real-time to preempt and respond to potential threats. Advanced Driver Assistance Systems (ADAS) form the cornerstone of enhancing autonomous vehicle safety [23].

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4. Challenges and Future Directions

4.1. Technical and Operational Challenges

Ensuring the safe and efficient operation of transportation systems involves overcoming challenges in system integration, data correlation, and hazard detection. The diversity and lack of standardization in data sources complicate integration, while IoT introduces issues in managing numerous connected devices. Effective data management and correlation are needed to prevent false positives, and autonomous vehicles must balance data update frequency with timely hazard detection. Advanced algorithms and machine learning are crucial for addressing these challenges, enabling vehicles to adapt and operate safely in complex urban environments. Ongoing research is essential for realizing the full potential of autonomous driving within intelligent transportation systems.

4.2. Emerging Technologies

Fifth Generation (5G) mobile technology represents a significant leap in network capabilities, enabling the rapid development of autonomous and connected vehicles (ACVs). With its high-speed, low-latency communication, 5G allows ACVs to communicate seamlessly with each other, infrastructure, and the cloud, supporting real-time decision-making and improving road safety. The integration of 5G with AI enables vehicles to analyze data from sensors and cameras to navigate complex traffic, adapt to conditions, and avoid hazards. This synergy also powers advanced features like adaptive cruise control, autonomous braking, and lane-keeping, optimizing traffic flow and reducing congestion. Together, 5G and AI are transforming intelligent transportation systems, creating safer and more efficient roadways.

4.3. Potential for Urban Mobility Transformation

The integration of autonomous driving within Intelligent Transportation Systems (ITS) promises to transform urban mobility, enhancing efficiency, safety, and sustainability. Powered by AI, autonomous vehicles can navigate complex environments using sensors, computer vision, and machine learning, optimizing traffic flow and reducing congestion without human intervention. By analyzing real-time and historical data, AI improves signal timing, predicts traffic patterns, and suggests alternative routes, increasing overall system efficiency. Beyond transportation, AI also optimizes logistics operations, streamlining supply chains and reducing costs. In ITS, AI enables real-time incident detection, adaptive routing, and dynamic signal control, enhancing both safety and performance. As autonomous technology advances, it will reshape urban landscapes, creating smarter, greener, and more connected cities.

5. Conclusion

The integration of autonomous driving technology with Intelligent Transportation Systems (ITS) has greatly improved traffic management. Leveraging AI, visual computing, radar, and communication technologies, Traffic Management Systems (TMSs) can now dynamically adjust speeds, reduce intersection delays, mitigate congestion, and offer smarter routes, enhancing traffic flow, reducing delays, and improving road safety. This paper highlights the transformative potential of this integration in boosting transportation efficiency, safety, and sustainability. Key innovations like V2X communication enhance connectivity between vehicles, pedestrians, and infrastructure, enabling real-time coordination. Autonomous delivery vehicles have also revolutionized urban logistics, reducing congestion and emissions. Additionally, integrating Collision Avoidance Systems (CAS) with autonomous driving can significantly reduce road accidents. While progress has been made,

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challenges remain in system interoperability and hazard detection in complex environments, necessitating further research to ensure safe and efficient autonomous vehicle operations.

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