



Research and application of new technologies for smart vehicles

Do Van Dung^{1*}, Phan Nguyen Qui Tam¹, Nguyen Van Tong Em², Nguyen Dinh Nhat¹

¹HCMC University of Technology and Education, HCMC Society of Automotive Engineering

²Nam Can Tho University

*Corresponding author: dodzung@hcmute.edu.vn

DOI: 10.64632/jsde.eng.1.2026.718

ABSTRACT

Received: Sep 18, 2025

Revised: Oct 2, 2025

Accepted: Oct 30, 2025

Keywords: 5G, ADAS, AI, AioT, smart vehicles

The rapid advancement of technology has paved the way for the evolution of smart vehicles, which are poised to revolutionize the transportation industries. This study introduces the latest research and applications of emerging technologies in smart vehicles, focusing on areas such as advanced driver-assistance systems (ADAS), AioT (Artificial Intelligent of Things) for vehicle-to-everything (V2X) communication, artificial intelligence (AI), 5G connectivity, sensor integration, connectivity, and autonomous driving capabilities. It examines how these innovations integrate sensors, machine learning, and real-time data processing to enable features such as adaptive cruise control, collision avoidance, and predictive maintenance. Additionally, the article discusses challenges in implementation, such as cybersecurity risks, regulatory frameworks, and ethical considerations, while highlighting real-world applications and their impact on transportation systems. By providing a comprehensive overview of current trends and future directions, this study aims to inform stakeholders and guide the strategic implementation of smart vehicle technologies in the automotive industry.

1. INTRODUCTION

The rapid evolution of smart vehicles is transforming the automotive industry, ushering in an era of enhanced safety, efficiency, and connectivity through the integration of cutting-edge technologies. From autonomous driving and vehicle-to-everything (V2X) communication to

advanced driver-assistance systems (ADAS), the application of innovations such as artificial intelligence (AI), sensor fusion, 5G/6G networks, and edge computing is redefining the future of mobility. These technologies enable vehicles to perceive their surroundings, make real-time decisions, and interact seamlessly with other

vehicles, infrastructure, and networks, paving the way for intelligent transportation systems. This article explores the latest research and applications of new technologies in smart vehicles, highlighting their potential to revolutionize urban mobility, reduce environmental impact, and improve road safety, while addressing the challenges and future directions for widespread adoption.

2. MATERIALS AND METHODS

This study reviews a systematic approach to identifying, selecting, and analyzing research studies related to technologies and applications in the field of intelligent transportation systems. The primary data sources include IEEE Xplore, Science Direct, ACM Digital Library, Springer, and several other specialized research platforms. The search process employed specific keywords such as "intelligent transportation," "intelligent transportation applications," "intelligent transportation technologies," and "intelligent transportation architecture" to narrow down the search results to the most relevant publications. The inclusion criteria required the articles be published between 2000 and 2025, written in English, and available for full-text download.

Publications that did not primarily focus on applications, architectures, or technologies for intelligent transportation were excluded at the title and abstract screening stage to ensure the relevance and accuracy of the selected dataset. Furthermore, a backward reference search was conducted by analyzing the citations within the selected articles to identify additional relevant studies. This approach not only strengthened the comprehensiveness of the data collection, but also facilitated the construction of a holistic overview of the technological evolution and

emerging trends within the domain of intelligent transportation systems over the past two decades.

3. RESULTS AND DISCUSSION

In this section, we provide an in-depth analysis of various architectures, communication protocols, and frameworks that have been employed in the development of intelligent transportation systems (ITS) and their associated applications. We also examine the current landscape, highlighting both the prevailing challenges and emerging opportunities that shape this rapidly evolving field.

Our discussion encompasses a diverse range of technologies integrated into ITS, including invehicle sensor networks, the application of Artificial Intelligence of Things (AIoT) for Vehicle-to-Everything (V2X) connectivity, and the utilization of advanced 5G and 6G networks to support smart mobility initiatives. Additionally, we explore novel advancements in Advanced Driver-Assistance Systems (ADAS), the incorporation of cutting-edge technologies into autonomous vehicles, and the implementation of artificial intelligence and machine learning models within smart vehicle ecosystems.

Finally, we present a case study focusing on the technological innovations underpinning electric scooter-sharing systems, providing practical insights into how these developments are being translated into real-world urban mobility solutions.

3.1 Sensor fusion in smart vehicles

3.1.1 Definition and importance

Sensor fusion stands as a cornerstone of smart vehicle technology, integrating data from multiple sources-cameras, LiDAR, radar, ultrasonic sensors, and inertial measurement

units (IMUs) to create a comprehensive and reliable model of the vehicle's environment. The necessity of this integration arises from the inherent limitations of individual sensors in capturing the unpredictable dynamics of real-world driving. Cameras offer high-resolution visual data for object classification (e.g., identifying pedestrians or traffic signs) but struggle in low light or adverse weather like heavy rain. LiDAR provides precise 3D mapping for obstacle detection but falters in fog and remains costly. Radar excels in long-range detection and performs well in harsh weather, yet it lacks the detail needed for fine-grained analysis. Ultrasonic sensors are effective for short-range tasks like parking, while IMUs track vehicle motion but cannot sense external objects.



Figure 1. Sensor fusion intelligently processes raw data from different sensing devices to determine vehicle surroundings like lane markings, pedestrians, cyclists, vehicles, and street signs

(Source: Ahmad, 2023)

By combining these sensors, smart vehicles achieve redundancy and accuracy, compensating for individual weaknesses to enable advanced driver-assistance systems (ADAS) and fully autonomous navigation (Yeong et al., 2021; Eskandarian, 2012; Ahmad, 2023). For example, Tesla's Autopilot fuses camera and radar data for

cross-validation, while Waymo's self-driving systems integrate LiDAR, radar, and cameras (CLR fusion) to ensure 360° environmental awareness across diverse scenarios.

3.1.2 Fusion techniques and algorithms

Sensor fusion employs three primary methodologies to integrate data: High-Level Fusion (HLF), Low-Level Fusion (LLF), and Mid-Level Fusion (MLF). HLF processes data independently at each sensor before combining results, such as fusing LiDAR-detected obstacles with camera-classified objects; it is computationally efficient but risks missing low-confidence detections. LLF merges raw data—like LiDAR point clouds with camera pixels—for deeper integration and higher accuracy, though it demands significant computational power and precise calibration. MLF strikes a balance by extracting features (e.g., edges from images, speed from radar) before fusion, optimizing tasks like lane detection. Common algorithms underpinning these methods include Kalman filters, which estimate the state of dynamic systems by combining noisy data, Bayesian methods that use probabilistic models for integration, and deep learning neural networks that process complex sensor data for enhanced object recognition and prediction (Mitchell, 2007). The fusion process involves several steps: data alignment to synchronize time and space, filtering to reduce noise, integration to create a unified environmental representation, and object detection/tracking to monitor entities like vehicles or pedestrians.

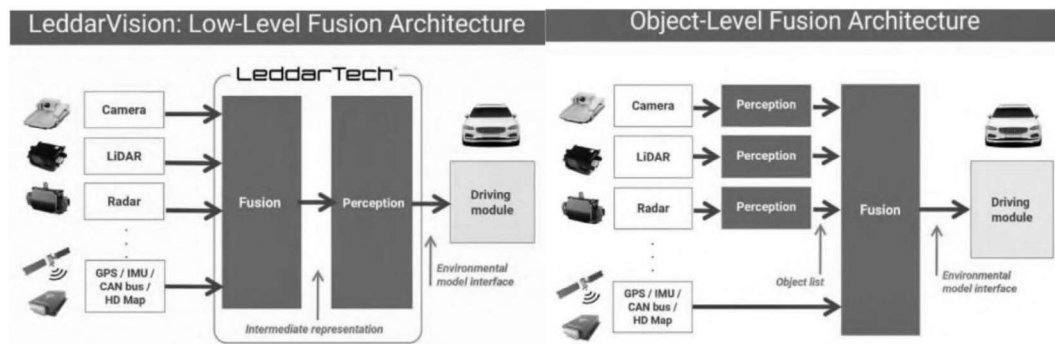


Figure 2. Comparison of Low-Level and Object-Level Sensor Fusion Architectures for AVs

3.1.3 Applications in smart vehicles

Sensor fusion drives critical functionalities in smart vehicles. In collision avoidance, radar's long-range detection pairs with camera-based object classification to identify hazards—such as sudden braking or pedestrians—and trigger evasive maneuvers.

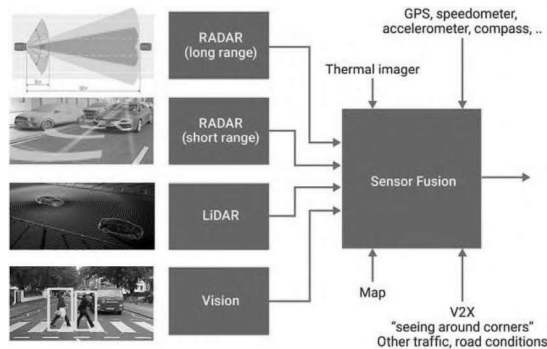


Figure 3. Applications of Sensor Fusion in Autonomous vehicles

Lane keeping & adaptive cruise control rely on fused camera and LiDAR data to ensure precise lane tracking and maintain safe distances from other vehicles, even in challenging conditions. Parking assistance integrates ultrasonic sensors and cameras to detect curbs and nearby obstacles with high accuracy. A novel application in urban navigation involves incorporating traffic surveillance cameras into vehicle systems, using mathematical localization with multi-anchor nodes to enhance perception in GPS-denied environments like tunnels,

significantly improving autonomy in complex urban settings.

3.1.4 Challenges and industry solutions

Despite its promise, sensor fusion faces several challenges. Computational complexity is a major hurdle, with smart vehicles processing up to 5.17 TB of data per hour, straining onboard systems with numerous sensors, as shown in Figure 4. Companies like Aptiv address this by miniaturizing hardware—shrinking cameras—and centralizing processing in domain controllers for efficiency. Calibration and synchronization are critical, as precise alignment of sensor data in time and space is required; this is managed through external GPS clocks and internal timestamping, though dynamic environments complicate the process. Environmental variability poses another challenge - snow, fog, or adversarial attacks (e.g., manipulated road signs) can deceive sensors in APTIV (2024). The industry counters this by training AI on diverse datasets like nuScenes (with 1.4 million annotated objects) and using simulation tools like CARLA to test edge cases. Data bias & overfitting, often due to poorly annotated datasets (e.g., 33% of Udacity Dataset 2 lacks labels), are mitigated by developing “small neural networks” optimized for specific tasks, reducing computational overhead while maintaining accuracy.

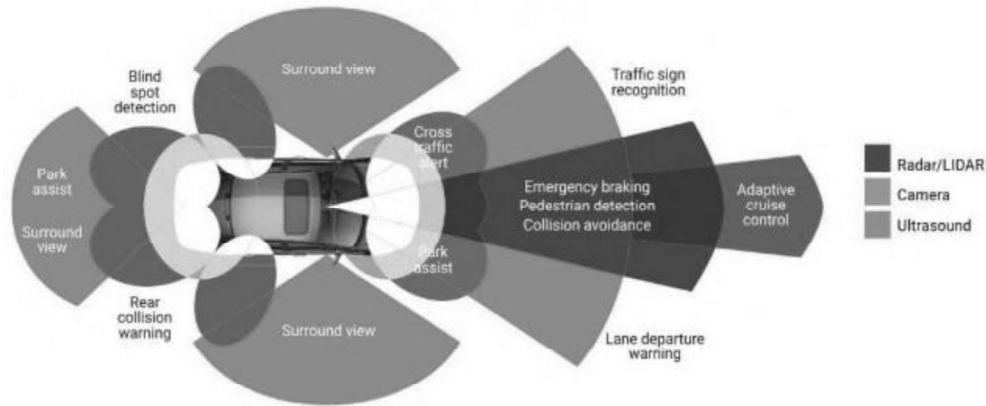


Figure 4. Sensors in vehicle collision avoidance system

3.1.5 Future research directions

The future of sensor fusion in smart vehicles points toward several promising directions. Edge AI aims to shift computation from cloud to onboard systems, reducing latency for real-time decision-making critical in dynamic driving scenarios in Manduva (2022). V2X communication, such as NR-V2X with 99.999% reliability and less than 3ms latency, will enable vehicles to share sensor data with infrastructure (e.g., traffic lights) and other vehicles, fostering a cooperative ecosystem for enhanced perception and coordination (Zhang et al., 2025). Standardization of protocols for sensor integration and data sharing is essential to streamline development and ensure interoperability across manufacturers. Additionally, expanding the integration of urban traffic cameras could provide an additional layer of environmental perception, particularly in complex urban corridors where traditional sensors may struggle (Hasanujjaman et al., 2023). As of 2025, sensor fusion remains a dynamic field, balancing technological ambition with practical implementation. Innovations in AI, edge

computing, and cooperative systems continue to bridge the gap between human and machine perception, driving the vision of fully autonomous, intelligent transportation systems forward (Nama et al., 2024).

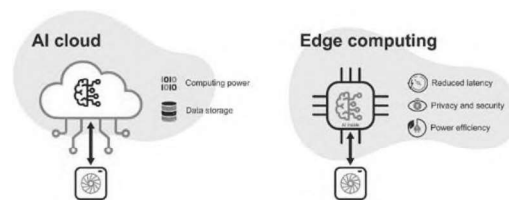


Figure 5. AI cloud and Edge computing

(Source: Nama et al., 2024)

3.2 Application of AI and Machine Learning in smart vehicles

The automotive industry is transforming through Artificial Intelligence (AI) and Machine Learning (ML) (Perez-Cerrolaza et al., 2024), driving advancements in smart vehicles. These technologies enable autonomous driving, advanced driver-assistance systems (ADAS), and personalized experiences by processing vast data, making real-time decisions, and adapting to dynamic environments, revolutionizing transportation, as shown in Figure 6.



Figure 6. AI and ML Solutions for the automotive sector

3.2.1 Role and function of AI and ML

AI and ML power smart vehicles with capabilities like autonomous driving, where AI processes sensor data (cameras, LiDAR, radar) to navigate and control vehicles, while ML learns from driving scenarios. ADAS features, such as lane-keeping and emergency braking, enhance safety. Predictive maintenance uses ML to foresee failures, cutting costs. NLP enables voice controls, and personalization adjusts settings to driver preferences. The process involves data collection from sensors, real-time processing, model training on large datasets, and continuous learning for improved accuracy.

3.2.2 Key technologies and benefits

Technologies like computer vision detect road elements, deep learning handles complex tasks, reinforcement learning optimizes strategies, and edge computing ensures real-time responses. Benefits include enhanced safety through faster hazard detection, improved efficiency in fuel and traffic management, convenience via autonomous features, and scalability with ongoing updates.

3.2.3 Key technologies and benefits

According by Rajapaksha et al., (2023) challenges involved data privacy, regulatory standardization, ethical decision-making in

accidents, and infrastructure needs like 5G networks. Future directions include explainable AI for transparency, collaborative learning among vehicles, and human-centric designs prioritizing safety and trust (Kamran et al., 2022; Rana & Khatri, 2024). As AI and ML evolve, they will redefine mobility, creating a safer, smarter, and more sustainable transportation ecosystem (Rao & Frtunikj, 2018).

3.3 Artificial Intelligence of Things (AIoT) for Vehicle-to-Everything (V2X)

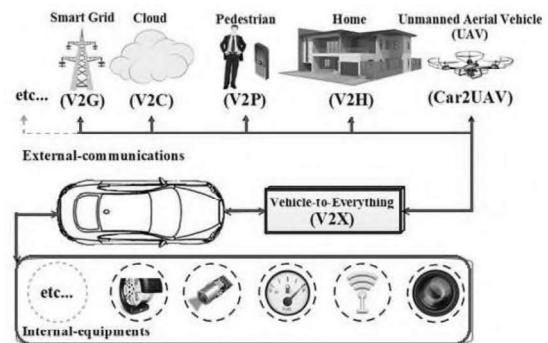


Figure 7. Vehicle to Everything (V2X) technology illustration

(Source: Babaghayou et al., 2021)

The fusion of Artificial Intelligence and the Internet of Things (AIoT) is revolutionizing Vehicle-to-Everything (V2X) communications (Babaghayou et al., 2021), enabling smarter, safer, and more efficient transportation systems. V2X encompasses vehicle-to-vehicle (V2V),

vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) interactions. AIoT integrates IoT's connectivity with AI's analytical capabilities to enhance real-time data processing, predictive analytics, and decision-making, paving the way for intelligent transportation systems (ITS) (Jnr, 2024; Xu et al., 2022).

3.3.1 Mechanisms and applications

AIoT employs IoT devices like sensors and cameras in vehicles and infrastructure, paired with AI algorithms to process data. It uses 5G for

low-latency communication, edge computing for real-time responses (e.g., V2V collision warnings), machine learning for behavior prediction (e.g., V2I traffic analysis), and automation for adaptive decisions (e.g., V2N rerouting). Applications include collision avoidance through obstacle detection (V2V, V2P), traffic optimization via smart signals (V2I), predictive maintenance using engine data (V2N), platooning for fuel efficiency (V2V), and improved navigation with real-time updates (V2N) (Tong et al., 2019).

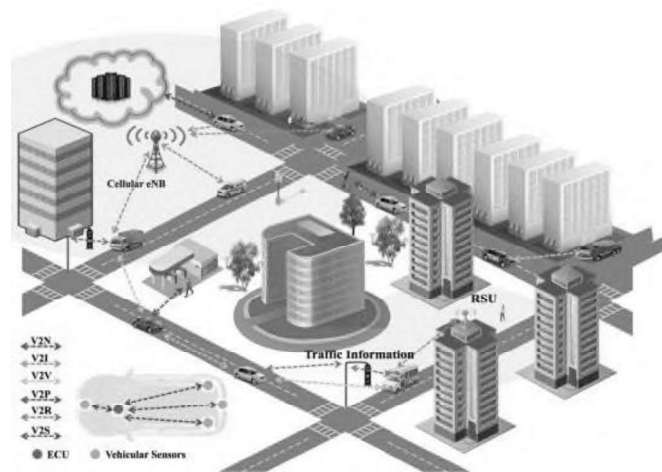


Figure 8. An overview of V2X scenario

3.3.2 Benefits and challenges

AIoT enhances safety with real-time hazard alerts, improves efficiency by optimizing traffic and fuel use, scales with growing networks, and elevates user experience through seamless services (Tong et al., 2019). However, it faces challenges like data privacy risks needing strong security, interoperability issues due to non-standardized protocols, latency in dense areas requiring 5G and edge solutions (Moubayed & Shami, 2020), high infrastructure costs, and ethical dilemmas in AI decisions.

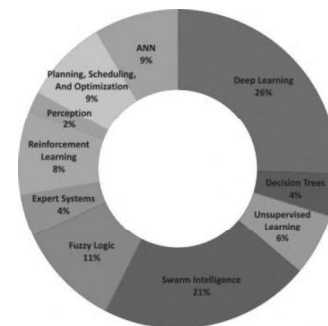


Figure 9. Percentage of AI techniques used in V2X applications

(Source: Tong et al., 2019)

3.3.3 Case studies and future research directions

Real-world examples include Singapore's V2I systems cutting congestion by 15-20% (Noor-A-Rahim et al., 2022), European platooning trials saving 10% fuel, and Japan's

V2P systems reducing pedestrian accidents. Future advancements will leverage 6G networks, federated learning for privacy, digital twins for simulations, standardized regulations for interoperability, and deeper integration with autonomous vehicles. While AIoT promises transformative benefits for V2X, addressing its challenges is key to unlocking its full potential in creating intelligent, connected transportation ecosystems (Noor-A-Rahim et al., 2022; Avci & Koca, 2024).

3.4 Application of 5G and 6G networks for smart vehicles

The emergence of 5G and the forthcoming 6G networks is reshaping the automotive industry by equipping smart vehicles with high-speed, low-latency, and reliable connectivity (Lucas-Estan et al., 2022).



Figure 10. Advanced use cases and services of NR-V2X

(Source: Bagheri et al., 2021)

These advanced wireless technologies are critical for enabling applications such as autonomous driving, vehicle-to-everything (V2X) communication, and real-time data processing, paving the way for a safer, more efficient, and interconnected transportation

ecosystem (Sakaguchi et al., 2021; Avci & Koca, 2024).

3.4.1 5G's Transformative role in smart vehicles

5G networks deliver ultra-low latency (as little as 1 millisecond), high bandwidth, network slicing for application-specific performance, and the capacity to connect up to 1 million devices per square kilometer. These capabilities support key smart vehicle applications: V2X communication - including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) - enhances situational awareness & traffic management (Noor-A-Rahim et al., 2022). Autonomous driving benefits from real-time data sharing for navigation and collision avoidance, while advanced driver-assistance systems (ADAS) gain from live updates on road conditions. Additionally, 5G enables remote vehicle control through teleoperation and enhances in-vehicle infotainment with streaming, augmented reality (AR) navigation, and cloudbased services (Appinventiv, 2024).

Top 5G Use Cases in the Automotive Industry

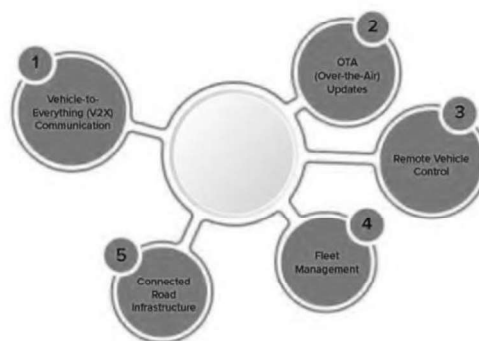


Figure 11. 5G use cases in the automotive industry

3.4.2 The future with 6G networks

Slated for commercial rollout in the 2030s, 6G will build on 5G's foundation (Deng et al., 2023), introducing terahertz frequencies for faster data rates, integrated AI for network optimization,

holographic communication for advanced displays, and improved energy efficiency. For smart vehicles, 6G promises hyper-connected autonomous systems with seamless coordination, digital twin technology for real-time monitoring and optimization, immersive AR/VR passenger experiences, and global connectivity even in remote regions, ensuring uninterrupted service (Lang et al., 2024).

3.4.3 Challenges and future pathways

Deploying 5G and 6G for smart vehicles faces hurdles: high infrastructure costs, spectrum allocation complexities, cybersecurity and privacy concerns, and the need for global standardization to ensure interoperability (Lang et al., 2024). Future efforts will focus on leveraging edge computing to minimize latency (Sakaguchi et al., 2021), using AI to enhance network performance, and prioritizing sustainable technologies to meet environmental goals. As 5G adoption grows and 6G approaches, these networks will redefine connected mobility, advancing autonomy, safety, and efficiency in smart vehicles and transforming how we travel.

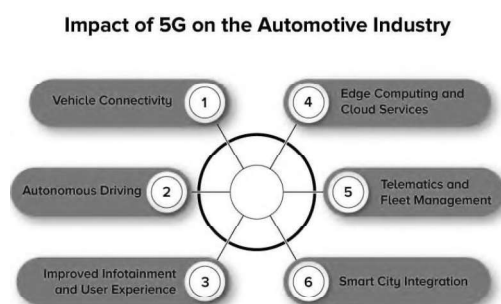


Figure 12. impact of 5G on the automotive industry

(Source: Appinventiv, 2024)

The integration of 5G and 6G networks into smart vehicles is transforming the automotive landscape, enabling unprecedented levels of connectivity, autonomy, and efficiency. These technologies are critical for realizing the full

potential of smart vehicles, from autonomous driving to enhanced safety and immersive passenger experiences. As 5G continues to expand and 6G emerges on the horizon, the future of connected mobility promises to be smarter, safer, and more sustainable, reshaping the way we travel and interact with our vehicles (Su et al., 2023).

3.5 New technologies in ADAS

Advanced Driver-Assistance Systems (ADAS) are undergoing a profound transformation, driven by the integration of cutting-edge technologies such as artificial intelligence (AI), sensor fusion, 5G connectivity, and augmented reality (AR). These innovations are enhancing vehicle safety, improving operational efficiency, and elevating driver comfort, positioning ADAS as a critical bridge between traditional vehicles and fully autonomous driving. By enabling features like adaptive cruise control (ACC), lane-keeping assistance (LKA), automated emergency braking (AEB), and real-time hazard detection, these technologies are reshaping the automotive landscape and paving the way for smarter transportation systems.

3.5.1 Innovative technologies powering ADAS

At the heart of modern ADAS is artificial intelligence, which processes vast amounts of sensor data for real-time decision-making. Deep learning models, such as convolutional neural networks (CNNs), excel in object detection, lane recognition, and pedestrian tracking (Janai et al., 2020), often achieving over 95% accuracy in optimal conditions. Sensor fusion complements AI by integrating data from multiple sources—lidar, radar, cameras, and ultrasonic sensors—to create a comprehensive and reliable

environmental map. Fusion algorithms, like Kalman filters, compensate for individual sensor limitations, ensuring robust performance in features like AEB, even in adverse conditions (Zhang et al., 2023; Khaleghi et al., 2013).

5G connectivity plays a pivotal role by providing low-latency, high-bandwidth communication essential for vehicle-to-everything (V2X) interactions. This enables real-time data exchange between vehicles (V2V), infrastructure (V2I), and other entities, enhancing situational awareness for applications like cooperative adaptive cruise control and intersection collision warnings (Bagheri., 2021). Augmented reality further improves driver engagement by projecting critical information—such as navigation cues, hazard alerts, and lane boundaries - onto heads-up displays (HUDs) (Khaleghi et al., 2013; Cheng et al., 2023), reducing distraction and improving reaction times. Lastly, edge computing supports time-sensitive ADAS functions by processing data locally, minimizing latency for tasks like sudden obstacle avoidance, with edge AI chips handling complex computations without constant cloud reliance (Sophia, 2025).

3.5.2 Applications, benefits, and challenges

These technologies enable a wide range of ADAS applications. Adaptive cruise control uses AI and sensor fusion to adjust vehicle speed based on traffic, while 5G-enabled V2V communication anticipates slowdowns for smoother flow. Lane-keeping assistance relies on cameras and AI to detect lane markings, with sensor fusion ensuring accuracy in poor weather or faded lines (Zhang et al., 2023). Automated emergency braking leverages radar, lidar, and AI to detect imminent collisions and apply brakes

faster than human reflexes, distinguishing real threats from false positives. Traffic sign recognition processes camera data to display speed limits and stop signs on AR HUDs, while driver monitoring systems use infrared cameras and AI to detect drowsiness or distraction, issuing alerts or slowing the vehicle if needed.

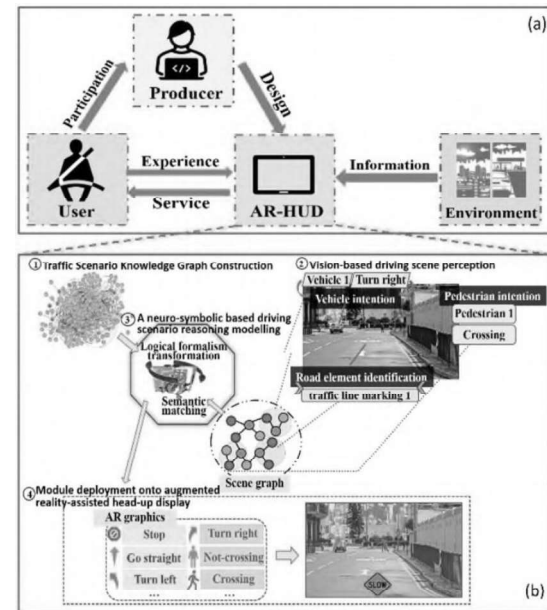


Figure 13. (a) co-creative value model and (b) cognitive intelligence framework

(Source: Liang et al., 2023)

The benefits are substantial: enhanced safety by mitigating human error (a factor in over 90% of crashes), improved efficiency with up to 15% fuel savings through optimized speed and routing, greater driver comfort via automation and AR interfaces (Liang et al., 2023), and scalability for future autonomy levels. However, challenges remain. High costs of components like lidar and advanced AI chips limit adoption in budget vehicles. Cybersecurity risks arise from increased connectivity, requiring robust encryption to protect against hacking. Regulatory inconsistencies across regions complicate deployment, while environmental factors like heavy snow can impair sensor performance

(Zhang et al., 2023), necessitating redundant systems. Additionally, consumer over-reliance on ADAS can lead to misuse or complacency, as seen in some high-profile incidents.

3.5.3 Case studies and future outlook

Real-world implementations highlight the transformative impact of these technologies. Tesla's Full Self-Driving (FSD) beta uses AI and camera-based vision for advanced lane-keeping and traffic-aware cruise control, logging millions of miles in testing. Bosch's partnership with Vodafone on 5G-based V2X systems has reduced urban collisions by 30% in trials through intersection warnings (Bosch, 2018). BMW's iNext models incorporate AR HUDs, displaying navigation and hazard alerts, improving driver response times by 20% in simulations (Winkler & Soleimani, 2025).

Looking ahead, the future of ADAS involves addressing current limitations and expanding capabilities. Advances in solid-state lidar and scalable AI chips will reduce costs, making ADAS accessible to mass markets.

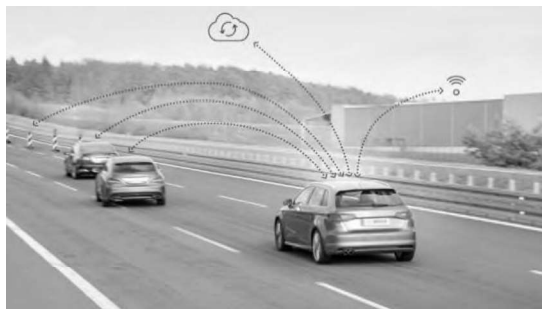


Figure 14. A multi-standard approach when it comes to V2X

(Source: Bosch, 2018)

The rollout of 6G networks will offer ultralow latency, enhancing V2X for real-time swarm intelligence in traffic coordination (Zhang et al., 2023). Explainable AI will improve transparency and trust, aiding regulatory compliance. Deeper

integration with autonomy will see ADAS evolve into Level 4/5 systems, while personalization will allow systems to adapt to individual driver preferences, optimizing safety and comfort. As these hurdles are overcome, ADAS will continue to evolve, playing a pivotal role in the transition to fully autonomous, intelligent transportation systems.

3.6 Application of new technologies for autonomous vehicles

The rise of autonomous vehicles (AVs) marks a transformative leap in modern transportation, propelled by cutting-edge technologies such as artificial intelligence (AI), advanced sensor systems, high-speed connectivity, and robust computing frameworks. These innovations enable vehicles to perceive their surroundings, make intelligent decisions, and operate with minimal human intervention, promising safer roads, reduced traffic congestion, and enhanced mobility for all. This article delves into the key technologies powering AVs, their practical applications, the challenges they face, and the future directions that could solidify their role in reshaping transportation ecosystems.

3.6.1 Key technologies driving autonomous vehicles

At the core of AV development is AI and machine learning (ML), which underpin critical functions like perception, decision making, and predictive analytics. Perception systems rely on AI to process data from an array of sensors - cameras, LiDAR, radar, and ultrasonics - to detect objects, recognize traffic signs, and predict pedestrian movements (Hasanujjaman et al., 2023).

Deep learning models, such as convolutional neural networks (CNNs), excel in real-time

image and video analysis, achieving high accuracy in identifying obstacles, as shown in Figure 15. For decision-making, reinforcement learning allows AVs to navigate complex scenarios like merging into traffic or handling

roundabouts by training on millions of simulated driving miles. Predictive analytics further enhances efficiency by analyzing historical and real-time traffic data to optimize routes and anticipate road conditions (Hossain et al., 2024).

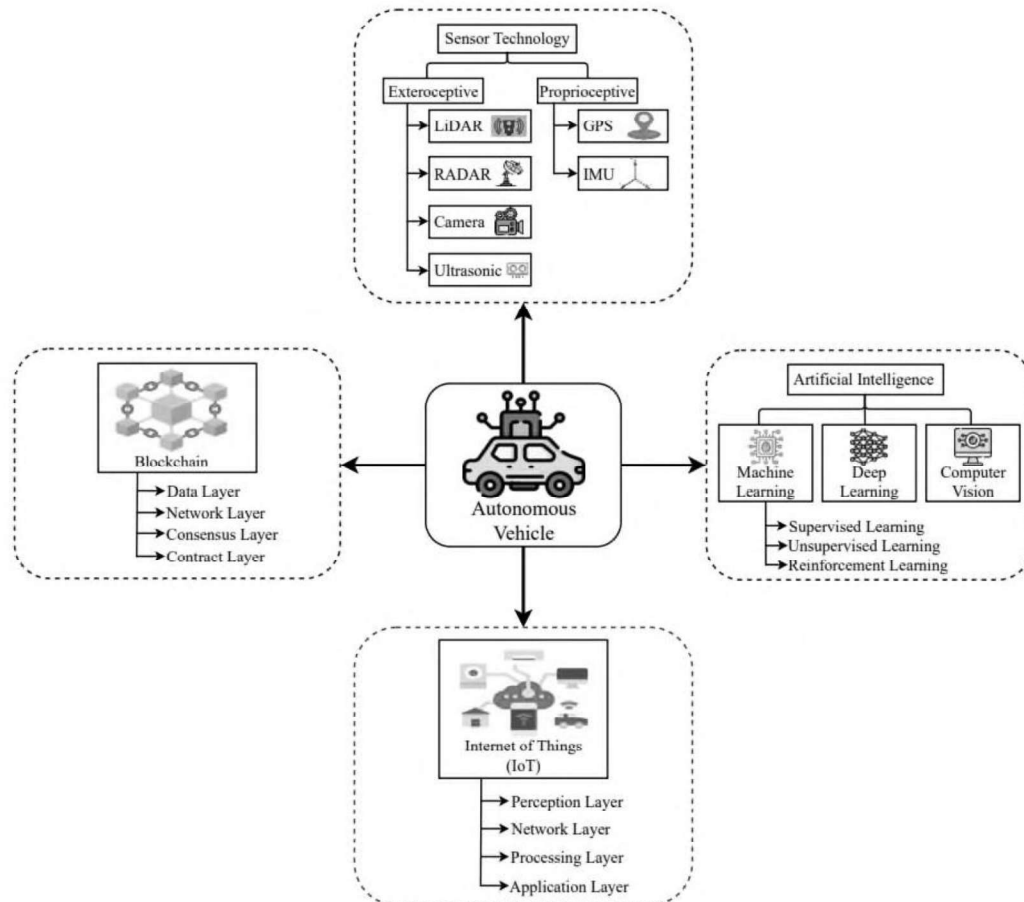


Figure 15. Framework for advanced technologies used in AVs.

(Source: Hossain et al., 2024)

Advanced sensor fusion is another cornerstone, integrating data from multiple sources to create a comprehensive 360-degree environmental model. LiDAR delivers high-resolution 3D mapping, radar ensures reliable detection in adverse weather, and cameras provide contextual details like traffic light colors.

Sensor fusion algorithms, such as Kalman filters and Bayesian networks, combine these inputs to eliminate blind spots and improve accuracy, ensuring robust performance even in challenging conditions (Wan & Van, 2000; Qi &

Moore, 2002). Connectivity, particularly through 5G and emerging 6G networks, plays a vital role in vehicle-to-everything (V2X) communication. 5G's ultra-low latency (under 1 millisecond) enables real-time data exchange between vehicles (V2V), infrastructure (V2I), and other entities, supporting applications like collision avoidance and traffic management. Looking ahead, 6G promises terahertz-frequency speeds and AI-integrated connectivity, ensuring seamless global communication for AVs.

Computing infrastructure also underpins AV functionality (Qi & Moore, 2002; Sadaf et al., 2023). Edge computing processes data locally using in-vehicle GPUs, reducing latency for time-critical tasks like emergency braking, while cloud platforms facilitate over-the-air (OTA) updates, fleet learning, and access to high-definition (Kamran et al., 2022) maps. HD mapping and localization technologies, combining GPS, inertial measurement units (IMUs), and SLAM (Simultaneous Localization and Mapping) algorithms, provide centimeter-level accuracy for navigation, even in GPS-denied environments like tunnels. Additionally, ethical AI and explainable AI (XAI) are being developed to make AV decision-making transparent, addressing complex ethical dilemmas such as prioritizing passenger versus pedestrian safety in

unavoidable accident scenarios (Panduru & Walsh, 2025; Vinoth & Sasikumar, 2024).

3.6.2 Applications, challenges, and future research directions

The applications of these technologies are vast and impactful. In ride-sharing, companies like Waymo and Cruise deploy autonomous taxis, reducing costs and improving accessibility in urban areas. In freight and logistics, self-driving trucks from firms like TuSimple and Embark optimize long-haul delivery, addressing driver shortages and boosting fuel efficiency. Public transportation benefits from autonomous shuttles and buses that enhance last-mile connectivity in smart cities, while AVs in disaster response navigate hazardous environments like wildfire zones to deliver supplies or evacuate civilians.

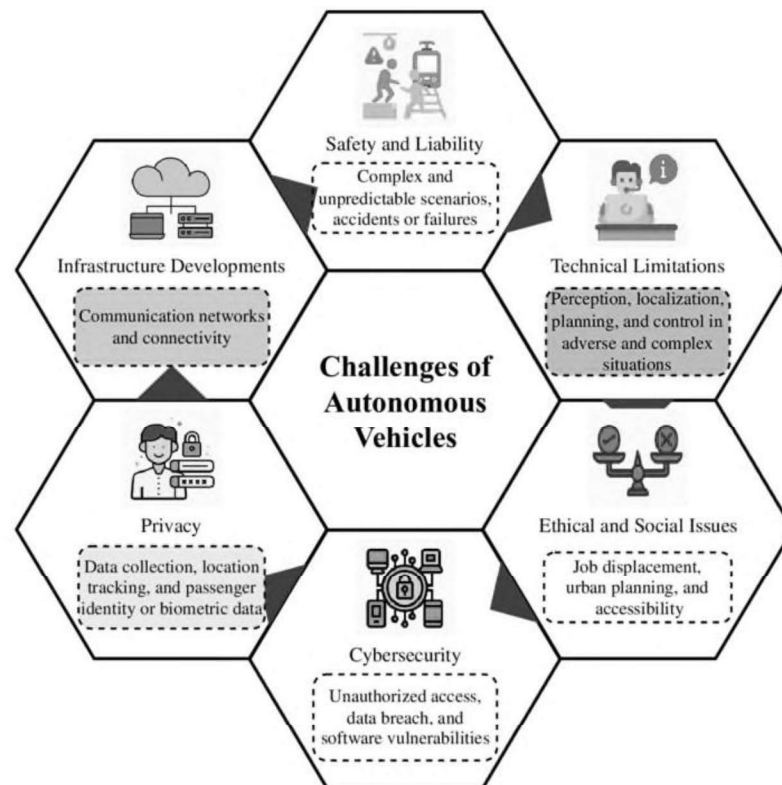


Figure 16. Current issues and challenges of autonomous vehicles

(Source: Hossain et al., 2024)

Despite their promise, AVs face significant challenges. Technical hurdles include sensor limitations - LiDAR struggles in fog, and cameras falter in low light - while cybersecurity risks loom large for connected vehicles, making them vulnerable to hacking and data breaches. Regulatory and legal frameworks remain inconsistent, with a lack of global standards for testing, liability, and insurance complicating deployment in Figure 16. Public trust is another barrier, as high-profile accidents, such as Tesla Autopilot incidents, fuel skepticism about AV safety. Infrastructure demands also pose challenges, as AVs rely on smart roads, widespread 5G coverage, and updated HD maps, which are not yet universally available.

Looking to the future, several research directions hold promise. Collaborative autonomy through swarm intelligence could enable AVs to share data and optimize traffic flow collectively. Quantum computing may solve complex optimization problems, like real-time route planning, faster than classical systems.

Sustainability efforts will integrate autonomy with (EV) platforms to reduce emissions, while improved human-AI interaction will focus on

intuitive interfaces to build passenger trust. As these technologies mature, autonomous vehicles will not only redefine how we travel but also reshape urban planning, logistics, and societal access to mobility, heralding a smarter, safer, and more efficient transportation future.

3.7 Case study: Technology in scooter-sharing systems

3.7.1 Background

Yandex, a leading Russian tech firm, launched its electric scooter-sharing service in Moscow in 2021 as part of its broader mobility offerings within the Yandex Go app. Targeting urban commuters, the service provides a sustainable solution for short-distance travel, addressing last-mile connectivity and reducing congestion. This case study explores the technologies behind Yandex's system and its impact on Russian transportation, with a focus on Moscow.

3.7.2 Technologies driving Yandex scooter-sharing

Yandex scooters leverage advanced tech for efficient operation. Yandex scooters have an improved IOT module of their own design in AK&M (2025) and Isik et al. (2023).

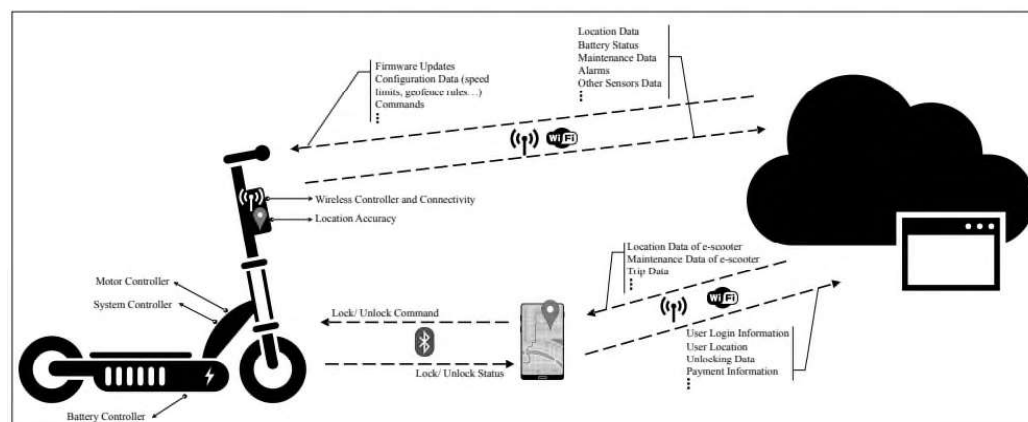


Figure 17. Shared E-scooter System Architecture

(Source: Isik et al., 2023)

IoT modules enable real-time tracking, remote locking/unlocking, and battery monitoring via 4G connectivity, linking scooters to central servers. High-precision GPS and geofencing ensure accurate positioning and restrict usage in prohibited zones (e.g., Red Square), aligning with local regulations. The Yandex Go app allows users to locate scooters, unlock them via QR codes, and pay per minute, displaying battery levels and costs.

AI predicts demand using historical data, weather, and events, optimizing scooter placement near high-traffic areas like metro stations. Smart battery management systems (BMS) with swappable batteries and AI-guided charging stations minimize downtime. Safety features include sensors to detect reckless riding and dynamic speed limits (10-15 km/h in crowded zones) enforced via geofencing, addressing Moscow's safety concerns.

3.7.3 Implementation and impact in Moscow

Launched with hundreds of scooters, Yandex positioned units near transport hubs to complement Moscow's public transit. Users access scooters via the Yandex Go app, park in designated zones, and benefit from integration with other services like ride-hailing. The system enhances last-mile connectivity, reducing taxi reliance around metro stations, cuts emissions with electric scooters, and encourages micromobility among young urbanites, who value affordability and speed. It also prompted Moscow to establish clearer scooter regulations, influencing other cities.

3.7.4 Challenges and future prospects

Challenges include Moscow's lack of bike lanes, forcing scooters onto busy roads or sidewalks, harsh winters limiting usage,

competition from firms like Whoosh, and maintenance costs due to vandalism in Interfax, 2022. Future plans involve expanding to cities like St. Petersburg, integrating autonomous tech for self-repositioning scooters, enhancing safety with features like collision detection, and partnering with municipalities for better infrastructure, such as dedicated lanes.

Yandex's scooter-sharing system, powered by IoT, AI, GPS, and mobile apps, showcases technology's role in transforming Russian urban mobility. It improves connectivity, reduces emissions, and aligns with sustainability goals, despite hurdles like infrastructure gaps. As Yandex innovates, its model offers a blueprint for scalable micromobility in Russia and beyond in Tarnovetckaia & Mostofi (2022).

4. CONCLUSION

The research and application of new technologies in smart vehicles mark a pivotal shift in the automotive landscape, driving unprecedented advancements in safety, efficiency, and connectivity. Innovations such as artificial intelligence, sensor fusion, 5G/6G networks, and edge computing have not only enabled autonomous driving and enhanced driver-assistance systems but also fostered a more integrated and sustainable transportation ecosystem through vehicle-to-everything communication. Despite their transformative potential, challenges like high implementation costs, cybersecurity risks, regulatory gaps, and infrastructure demands remain significant hurdles to widespread adoption. As ongoing research addresses these obstacles, future developments in collaborative autonomy, AI-driven networks, and scalable solutions promise to further refine smart vehicle capabilities.

Ultimately, the continued evolution of these technologies will reshape urban mobility, reduce environmental impact, and pave the way for a safer, smarter, and more connected future in transportation.

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