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REVIEW ARTICLE

Advancements, challenges, and implications for navigating the autonomous vehicle revolution

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ABSTRACT - The deployment of self-driving cars has significantly impacted society, offering several benefits such as better passenger safety, convenience, reduced fuel consumption, minimised traffic congestion and accidents, cost savings, and improved reliability. With the development of automated driving systems, autonomous vehicle technology has progressed from human-operated vehicles to conditional automation, utilising an array of sensors to constantly observe their surroundings for potential hazards. However, it is crucial to highlight that full autonomy has not yet been reached, and there are several problems involved with this revolutionary technology. This article explores the advancements, challenges, and implications inherent in the widespread adoption of autonomous vehicles. Recent advancements in sensor technology (cameras, RADARs, LiDARs, and ultrasonic sensors), artificial intelligence, the Internet of Things, and blockchain are just some of the topics covered in this article regarding autonomous vehicle development. These advancements are critical to evolving and incorporating autonomous vehicles into the transportation ecosystem. Furthermore, the analysis emphasises the considerable problems that must be overcome before self-driving cars can be widely adopted. These difficulties include security, safety, design, performance, and accuracy. Focused solutions such as increasing cybersecurity protections, refining safety standards, optimising vehicle design, enhancing performance capabilities, and assuring correct perception and decision-making are proposed to tackle these challenges. Lastly, autonomous cars have great promise for transforming transportation systems and improving a wide range of areas of our lives. Nevertheless, successful implementation requires overcoming existing difficulties and pushing technological innovation's limits. By solving these problems and capitalising on artificial intelligence, the Internet of Things, and blockchain breakthroughs, we can navigate the autonomous car revolution and realise its full potential for a safer, more efficient, and sustainable future.

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1. INTRODUCTION

Autonomous vehicles (AVs) are automobiles that can go from place to place without human intervention [1]. The promising technology of AVs is attributed to enhanced safety measures [2], traffic flow efficiency [3], and improved energy efficiency [4], which leads to a reduced environmental impact. According to statistical data, the annual number of fatalities from traffic accidents exceeds one million individuals, with human negligence being the predominant cause of such accidents [5]. The reliance on human-operated vehicles poses numerous challenges and limitations regarding safety, efficiency, and sustainability [6]. Also, the rapid expansion of automotive production has been linked to significant apprehension regarding escalating traffic congestion and accidents. So, governments worldwide have implemented measures such as enhancing traffic infrastructure, enforcing traffic regulations, and providing education to address traffic-related issues by allocating additional financial resources [7]. In addition, many research institutes have initiated projects to develop driver assistance and safety warning systems. However, AVs are the most recent trend in the automotive sector since they have the potential to replace human drivers, who are prone to errors and blunders when driving a vehicle [8]. Hence, implementing AVs on roadways is expected to mitigate accidents resulting from human error, thereby enhancing overall road traffic safety. Technological developments are hastening the development of self-driving vehicles. The evolution of advanced high-tech sensors, artificial intelligence, and other emerging technologies have pushed the limits of autonomous driving [9].

Moreover, decision-making is critical in developing autonomous systems [10]. The intelligence of a vehicle is determined by its capacity to autonomously generate robust decisions through the anticipation and evaluation of future outcomes. Nevertheless, AVs encounter inherent safety and security obstacles that necessitate resolution prior to their implementation for practical purposes [11]. Currently, ongoing research and development focuses on fully autonomous vehicles, with the ultimate goal of enhancing the safety and convenience of driving in the coming decades. Yet, the extensive implementation of autonomous vehicles encounters several obstacles that must be resolved. Technical issues include enhancing sensor accuracy and reliability, optimising algorithms for intricate driving situations, and establishing

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strong cybersecurity measures to prevent any hacking attempts [12]. Furthermore, ethical and legal factors, including determining liability in accidents and setting standards for the safe use of autonomous vehicles on public roads, must be taken into account [13].

This paper summarises the recent technological developments of AVs, the challenges, progress, and their proposed solution to gain full autonomy. However, the remaining portions of this paper are organised in the following order. Section 2 presents an introduction to AV with the SAE automation levels. Section 3 provides a comprehensive overview of advanced technologies for manufacturing autonomous vehicles, presenting the taxonomical framework. This section includes detailed sensor technology and their comparison, AI methods and their applications in AVs, especially Advanced Driver Assistance Systems. Moreover, the Internet of Things and blockchain technology have been described in Section 3. In addition, Section 4 describes the potential challenges for future research in AVs development. Furthermore, Section 5 highlights some outcomes of upcoming research on self-driving technology. Finally, Section 6 concludes the key findings, future directions, and valuable insights.

2. AUTONOMOUS VEHICLE AND ITS AUTONOMY

The concept of autonomous vehicles was proposed initially by science fiction writers who envisaged a fresh paradigm for the automotive industry: self-driving cars [14]. AV refers to a self-guided vehicle that can operate without human intervention. This mechanism employs computer technology for propulsion. AVs are currently facing a siege owing to their numerous benefits compared to traditional manually-operated vehicles [15]. Autonomous vehicles are projected to generate an estimated annual revenue of approximately 7 trillion dollars by 2050 [4]. The automobile industry is presently the focus of extensive research and public scrutiny, particularly in autonomous driving and Advanced Driver Assistance Systems (ADAS). Adopting AVs is a complex process involving various stages of development. It is expected that the full adoption of AVs will take some time and become more apparent as we approach the completion of the development process and overcome the current limitations. The method may require multiple iterations and simulations [16]. SAE International recommends six levels of vehicle automation, ranging from minimal to complete automation (Level 0 to Level 5) [17,18]. The vehicle automation levels are presented in Table 1.

Table 1. SAE levels of autonomy as defined in standard J3016 [17,18]

SAE Level	Definition	Description	Monitoring of the Driving Environment
0	No automation	The human driver controls steering, throttling, braking, and parking.	Human driver
1	Driver assistance	The automobile can execute certain control operations but not everywhere.	
2	Partial automation	The vehicle can manage steering, throttle, and braking functions autonomously. However, it is incumbent upon the driver to oversee the system and intervene in any malfunctions.	
3	Conditional automation	The vehicle observes the environment and notifies the driver if manual control is required.	Driving system
4	High automation	The vehicle is fully autonomous but only in specified applications.	
5	Full automation	Only the destination needs to be set by the driver. The car can adapt to any situation and make any necessary decisions.	

3. TECHNOLOGICAL ADVANCEMENTS OF AVS

Technological advancements in autonomous vehicles have driven their rapid development and progress in recent years. These AVs improvements encompass sensors, artificial intelligence, the Internet of Things, and blockchain. AVs leverage sophisticated sensor arrays, LiDAR, RADAR, cameras, and ultrasonic sensors to decorate environmental beliefs. Moreover, AI, especially machine learning, deep learning, computer vision, and fuzzy logic, permit AVs to interpret complex riding scenarios in real-time by continuously learning from data. Furthermore, the integration of IoT generation allows seamless connectivity between automobiles and infrastructure, enabling vehicle-to-vehicle and vehicle-to-infrastructure communication for more suitable situational consciousness and operational performance. Finally, blockchain technology offers capacity applications to secure data exchanges inside the AV environment, mitigate cybersecurity risks, and establish trust among stakeholders. Together, these advancements drive the development and deployment of AVs, enhancing safety, performance, and reliability on the street. However, some key technological advancements in autonomous vehicles have been shown in Figure 1.

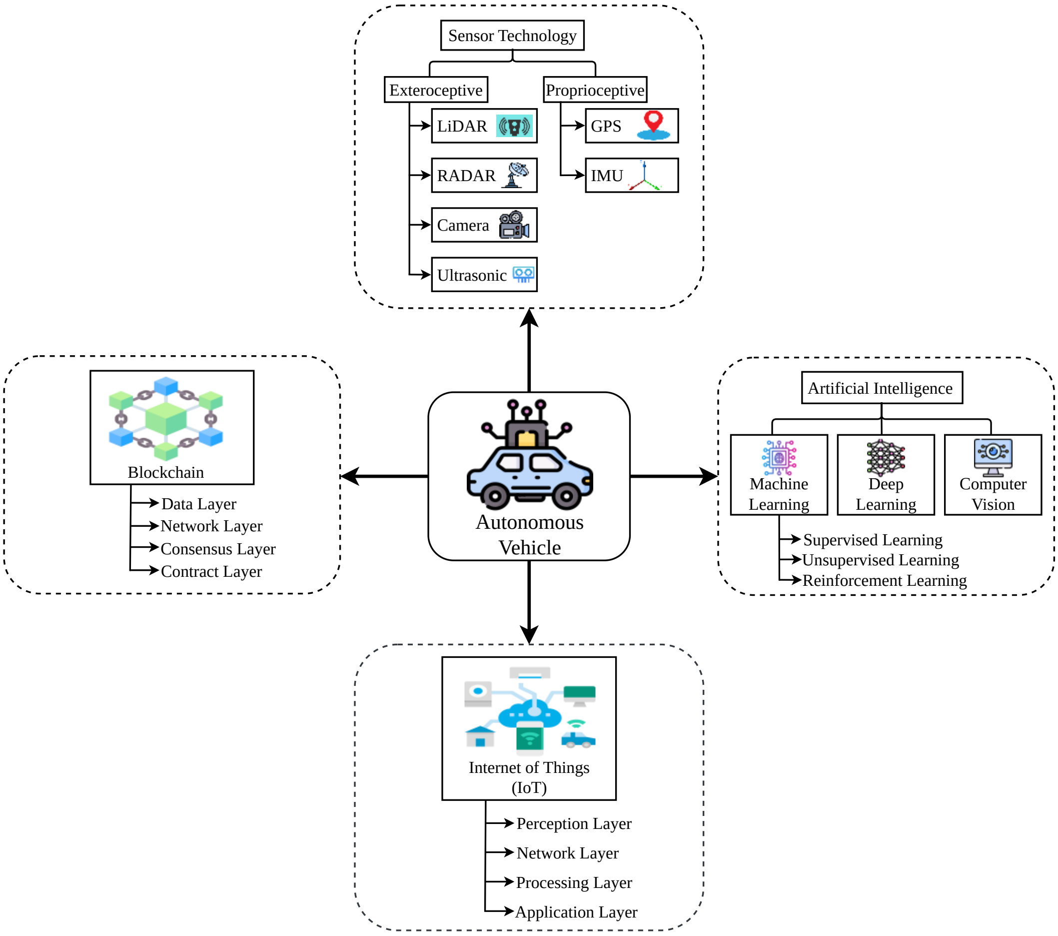

Figure 1. Framework for advanced technologies used in AVs

3.1 Sensor Technology

Autonomous vehicles rely heavily on sensor technology to gather information about their surroundings and behave appropriately. It works in conjunction with advanced algorithms and data processing systems. AVs use sensors to gather data about their surroundings, including the position of other vehicles, pedestrians, road conditions, and various objects [19]. The vehicle's decision-making algorithms then use this information to make appropriate decisions and navigate safely. Key sensor technologies utilised in AVs include the following:

3.1.1 Cameras

Cameras capture visual data from the vehicle's surroundings, providing valuable information about road signs, traffic lights, pedestrians, and other vehicles. Multiple cameras are strategically positioned on the vehicle to offer a comprehensive view of the environment. Computer vision algorithms process the camera images to detect and recognise objects, lane markings, and traffic signs [20]. Moreover, cameras play a crucial role in object recognition and understanding the visual context of the driving environment.

3.1.2 Light detection and ranging

LiDAR sensors analyse the reflected light to provide a very accurate three-dimensional representation of the area around the vehicle [21]. Also, these sensors provide high-resolution data about the distance, shape, and position of objects, allowing the vehicle to perceive its environment [18] accurately.

3.1.3 Radio detection and ranging

Radio-wave-activated detection and ranging or RADAR sensors locate nearby objects. They transmit radio waves and measure the time it takes for the waves to return from their target [22]. Moreover, RADAR sensors can determine the distance, relative speed, and direction of objects, even in adverse weather conditions. They are beneficial for detecting objects far away or obscured from the line of sight [23].

3.1.4 Ultrasonic sensors

Ultrasonic sensors employ acoustic waves to determine how far away obstacles are. They send out high-frequency sound waves and measure how long it takes for the sound waves to bounce back [24]. Ultrasonic sensors are commonly used for parking assistance systems and low-speed manoeuvring, providing a close-range object detection [25].

3.1.5 Inertial measurement units

Inertial measurement units consist of accelerometers and gyroscopes that measure the vehicle's acceleration, orientation, and angular rate. IMUs help determine the vehicle's position, velocity, and orientation changes [26]. The vehicle can better understand its movement and navigation by combining the data from IMUs with other sensors.

Table 2. Comparisons of mostly used sensors in AVs

Criteria \ Sensor	Camera [18,28]	LiDAR [28-30]	RADAR [28,30]	Ultrasonic [18,31]
Types	Monocular Stereo Infrared	Solid-state Infrared	Short-range Medium-range Long-range	N/A
Range	N/A	250 m	Short: 0.2-30 m Medium: 30-80 m Long: 80-200 m	0-20 m
Working Principle	Passive light sensors	Producing infrared or laser light pulses	Electromagnetic radiation	Sound waves
Usage	Produce a digital image of a covered region	For measuring distances, simultaneous localisation and mapping	To measure objects, distance, angle, and velocity; relative motion of detected objects	To measure the distance to an object
Distance Accuracy	Medium	High	High	High for close proximity objects
Cost	Low	High	Lower than LiDAR	Lowest
Availability	High	Low	High	High
Advantages	Sensitive to low-intensity lights	Robust in all kinds of environmental conditions	Not affected by foggy or rainy weather	Robust in adverse weather conditions
Disadvantages	Heavily affected by adverse weather conditions	Heavy and bulky in size	Cannot recognise the colour of targets	Heavily affected by disturbances in sound waves

3.1.6 Global positioning system

Global positioning system technology is often used for localisation and navigation in autonomous vehicles. GPS receivers collect signals from satellites to determine the vehicle's precise location, speed, and heading. While GPS provides global positioning information, it is usually combined with other sensors and mapping data for accurate localisation [31]. Various aspects of AV sensors and their significance have been depicted in Table 2. LiDAR and RADAR sensors, although costly, give very accurate results for long-range objects and generate high-quality 3D maps for navigation. On the other hand, cameras and ultrasonic sensors perform better for proximity objects, which are available at reasonable prices.

3.2 Artificial Intelligence

Artificial intelligence focuses on creating intelligent computer systems and devices [32]. AI involves developing and implementing advanced algorithms that enable autonomous vehicles to perceive, interpret, and respond to their environment without human intervention [33]. Moreover, it encompasses a range of techniques that empower AVs to autonomously navigate, make decisions, and adapt to various driving scenarios. As discussed below, machine learning, deep learning, computer vision, and fuzzy logic are some of the most popular AI methods to process AV sensor information.

Currently, researchers are mainly using deep learning techniques such as Artificial Neural Networks, Convolutional Neural Networks, Long Short-Term Memory, Autoencoder, etc., to recognise and classify objects [34], understand road conditions [35], detect obstacles [36], plan optimal routes [37], and make real-time decisions [38] to ensure safe and efficient operation of AVs. Also, some machine learning algorithms, like K-Nearest Neighbor, Decision Tree, etc., have been employed with ANN to develop AV security purposes [39]. However, Table 3 represents some recent AI works that have been done to enhance the safety and security of autonomous vehicles. Also, Table 3 implies that CNNs are the most effective AI methods for visual processing in AVs because of their ability to automatically learn and extract meaningful features from images and their robustness and efficiency.

3.2.1 Machine learning

The discipline of machine learning is concerned with creating and refining computational models and algorithms that facilitate the autonomous acquisition of knowledge and the generation of predictions or decisions without the need for explicit programming [40]. The process entails the utilisation of statistical methodologies and computational algorithms to educate models on annotated data and derive patterns or insights from the data [41]. By processing sensor data, ML algorithms enable AVs to perceive and interpret the surrounding environment, adaptive decision-making, predictive maintenance, etc., to ensure the safety of AVs [42].

3.2.2 Deep learning

Specialised area within the field of machine learning that employs artificial neural networks comprising multiple layers [41]. Deep learning algorithms can acquire hierarchical data representations, rendering them highly suitable for addressing intricate issues such as speech and image recognition, self-driving vehicles, and natural language processing [34]. Deep learning architectures generally comprise several layers of artificial neurons, where each layer is responsible for identifying particular patterns in the input data [43]. DL algorithms provide high accuracy in feature extraction from large amounts of data and are more robust to data variability [44].

3.2.3 Computer vision

Computer vision is a subfield of AI that facilitates extracting significant information from digital images, videos, and other visual inputs. This information can be utilised to make recommendations or take actions based on the extracted data. AI simplifies cognitive processes in computers, while computer vision empowers them to perceive, scrutinise, and comprehend their surroundings visually [45]. Traditional computer vision approaches rely primarily on 2D image information, which limits their ability to perceive depth accurately. This limitation can make it challenging to estimate distances, perceive the relative position of objects correctly, and make precise decisions in complex scenarios [46].

3.2.4 Fuzzy logic

It is a formal system that provides a mathematical structure for managing uncertain or imprecise information. In contrast to classical logic that relies on binary values of true or false, fuzzy logic permits the consideration of partial truths, encompassing values that span from 0 (entirely false) to 1 (wholly accurate) [47]. In AVs with low autonomy, fuzzy logic is extensively used to detect and understand driver behaviour using linguistic terms in real-road traffic environments [48].

Table 3. AI applications in autonomous vehicles

Authors	AI Techniques	Remarks
Alsadee et al. [39]	KNN + DT + LSTM + Deep Autoencoder	To detect cyber-attacks on the controller area network.
Vashisht et al. [49]	ANN	Traffic sign recognition.
Ray et al. [50]	CV + DL	Image segmentation and classification to improve fault tolerance
Hamad et al. [51]	ANN	To enhance the security and protect CAN from susceptible attacks.
Bellam et al. [52]	CV + CNN	Recognising and detecting traffic signs.
Nemadi et al. [53]	ANN	To ensure braking systems' safety by resolving thermal behaviour issues during disc braking.
Gorska et al. [54]	CNN	Development of an automatic pedestrian detection system in low-resolution thermal images.
Gullapalli et al. [55]	DQL	Controlling vehicle behaviour to avoid obstacles, walkers, and other vehicles.
Meftah et al. [56]	ResNet 50 DL	Obstacle avoidance strategy.
Andriyanov et al. [57]	CNN	Eye recognition system to prevent road accidents.
Rizianiza et al. [58]	Fuzzy Logic	Automatic braking system.
Khan et al. [59]	CNN	Lane detection method.
Chehri et al. [60]	CNN	Observation and identification of road signs in a snowy environment.
Chaitanya et al. [61]	CNN	Object and obstacle detection.
Vincent et al. [62]	CNN	Traffic sign classification.

3.3 Advanced Driver Assistance Systems

Advanced Driver Assistance Systems is a set of technologies that enhance the safety and performance of autonomous vehicles by providing assistance and automated features to the driver. Although ADAS is not fully autonomous driving, it forms an essential foundation for developing and deploying AVs [63]. ADAS utilises sensors such as cameras, LiDAR, RADAR, and ultrasonic sensors to perceive the vehicle’s environment by continuously gathering data about the surroundings [64]. The sensor data is then processed using AI algorithms to detect and classify objects, track their movements, and extract relevant features. After detecting objects, AVs can immediately use ADAS features for safety purposes (shown in Figure 2). For example, Guerrieri et al. [65] implemented deep learning in developing ADAS to ensure the safety of autonomous and rapid trams.

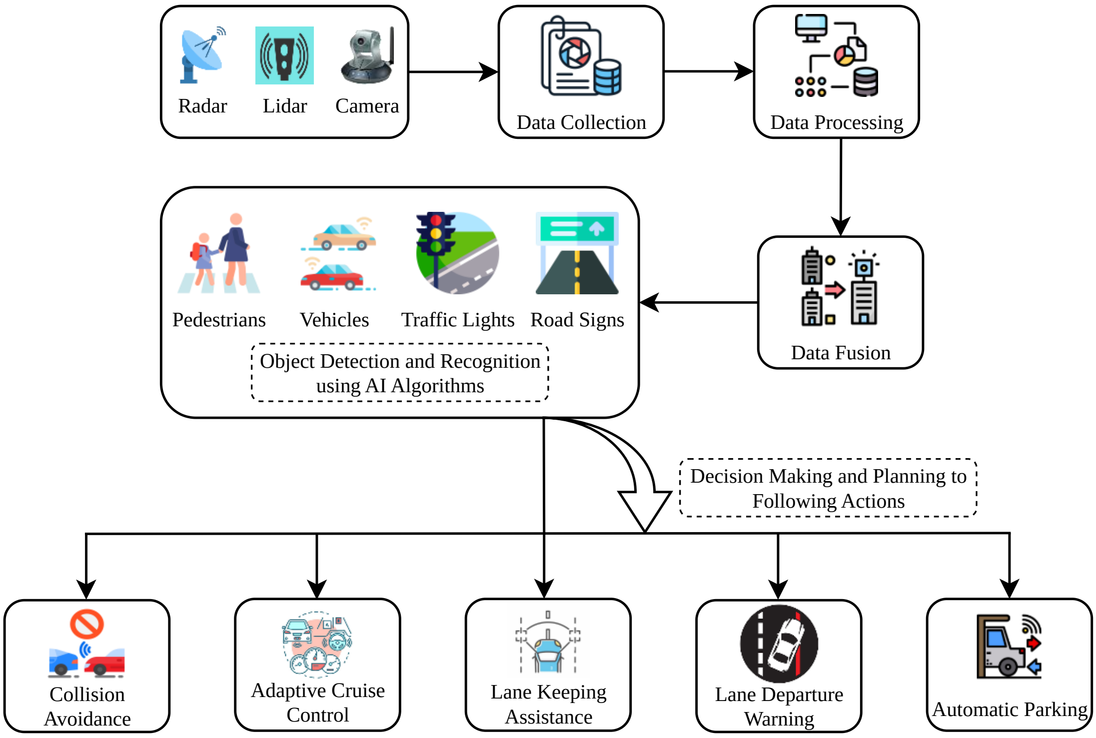

Figure 2. Illustration of ADAS for autonomous vehicles

The following are the primary features of ADAS:

3.3.1 Collision avoidance

ADAS systems include collision avoidance features to help prevent accidents. The forward collision warning systems use sensors and AI methods to detect the proximity of vehicles ahead and warn the driver if a potential collision is detected. Automatic emergency braking systems can apply the brakes by themselves if a collision is about to occur, but the driver does not respond to the warning [66]. Karthikeyan et al. [67] proposed the CNN algorithm to develop a collision avoidance system for AVs.

3.3.2 Adaptive cruise control

The system employs RADAR or LiDAR sensors to assess the distance to and speed of approaching vehicles. Vehicle speed is automatically adjusted to keep a safe following distance, and a full stop is possible if needed. It enhances comfort and safety by reducing driver fatigue and supporting smoother traffic flow [68]. LSTM techniques have been used by Yin [69] for the target selection of adaptive cruise control.

3.3.3 Lane departure warning and lane-keeping assist

Cameras or other sensors detect when a vehicle has drifted out of its lane without the driver's knowledge, and an alarm sounds [70]. Lane-keeping assist systems can also actively steer the vehicle back into the lane, providing gentle corrective action to help maintain proper lane position [71].

3.3.4 Automatic parking

It facilitates the manoeuvring of a vehicle from a traffic lane to a designated parking spot, which can be parallel, perpendicular, or angled [72]. The system autonomously performs the task without any external human intervention. Furthermore, the utilisation of data obtained from parking sensors, when inputted into the trained AI systems, can provide supplementary advantages to the safety of ADAS systems. Guo et al. [73] developed an automatic parking system based on CNN algorithms and achieved 34.83% less time than manual parking. In addition, using this AI-based parking strategy resulted in fewer parking errors being committed.

3.4 Internet of Things

The Internet of Things is crucial in autonomous vehicle research, development, and operation. IoT technologies enable seamless connectivity and communication between vehicles, infrastructure, and other devices, enhancing the capabilities and efficiency of driverless vehicles [74]. AVs are interconnected to exchange data from their onboard sensors and the mobile devices of pedestrians and cyclists, traffic sensors, parking detectors, and other sources. Nanda et al. [75] demonstrated an overview of AV communication layers with their associated properties and security threats based on IoT structure. The following section discusses the various layers of an IoT's typical structure.

3.4.1 Perception layer

The perception layer is responsible for capturing and processing data from various sensors and perception devices in AVs to gather information about the vehicle's surroundings, including road conditions, obstacles, pedestrians, and other vehicles [76]. The collected data is processed using computer vision, signal processing, and sensor fusion techniques to generate a comprehensive understanding of the environment. Cao et al. [77] presented a model based on multi-sensor fusion (camera and LiDAR) perception to save AVs from cyber-physical attacks.

3.4.2 Network layer

This layer focuses on the communication and connectivity aspects of the IoT. It involves Vehicle-to-Everything communication [78], which includes Vehicle-to-Vehicle, Vehicle-to-Infrastructure, Vehicle-to-Device, Vehicle-to-Network, and Vehicle-to-Pedestrian (presented in Figure 3). V2V communication enables vehicles to exchange real-time information with other nearby vehicles, such as position, speed, and intentions, to enhance cooperative driving and safety [79]. On the contrary, V2I is the interaction between vehicles and infrastructure, including traffic signals, road signs, and centralised control systems [80]. Suganthi et al. [81] employed IoT V2V and V2I to develop ADAS systems for vision-enabled lane changing. Furthermore, V2D facilitates the exchange of information between vehicles and smart devices, typically utilising the Bluetooth protocol. V2N communication is the two-way flow of information between vehicles across data networks such as LTE (Long-Term Evolution) and 5G. Finally, V2P communication refers to the capability of a vehicle to detect and perceive the presence of pedestrians in close proximity, encompassing individuals utilising bicycles, strollers, and wheelchairs [82]. The network layer ensures reliable and low-latency communication using wireless technologies like Wi-Fi, 5G, LTE, or other cellular networks.

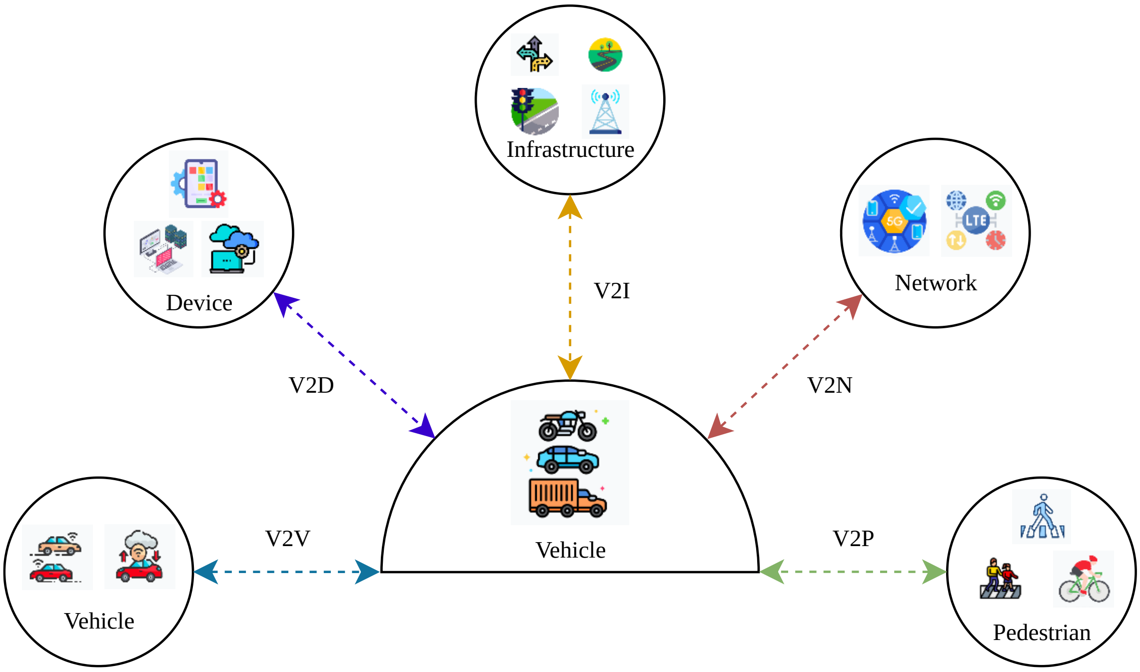

Figure 3. Vehicle-to-Everything communication scenario

3.4.3 Processing layer

The processing layer encompasses the cloud infrastructure and data processing capabilities within the IoT. It involves storing, processing, and analysing large volumes of data generated by autonomous vehicles. Cloud platforms store data and provide computational resources for data processing and analytics [83]. Advanced techniques such as big data analytics [84], machine learning, and artificial intelligence [85] are applied to extract valuable insights from the collected data. Furthermore, this layer enables real-time decision-making, predictive data analytics, and optimisation of autonomous vehicle operations. For example, Sharma et al. [86] described data analytics in AVs based on cloud and IoT.

3.4.4 Application layer

It is where the intelligence and functionalities of autonomous vehicles are realised. The layer involves developing and deploying applications and services that leverage the data and insights obtained from the processing layer. This layer includes various applications such as autonomous driving algorithms, collision avoidance systems, traffic management systems, and personalised user experiences [87]. The applications utilise the processed data and insights to make informed decisions, optimise routes, manage traffic, and enhance the driving experience [88].

3.5 Blockchain

Blockchain is a distributed and decentralised digital ledger that allows for the transparent and unchangeable recording of transactions across a network of computers. A chain of blocks is used to record and verify information or transactions. Using cryptographic hashes to connect one block to the next creates a permanent and unchangeable data record [89]. The distributed nature of blockchain refers to multiple computers, known as nodes, maintaining a copy of the blockchain, ensuring redundancy, and eliminating the need for a central authority [90]. The use of digital identities for various areas of vehicle management has been motivated by the maturing of blockchain technology and the increasing demand for AVs. Aybaz et al. [91] were to construct a framework for self-driving vehicles that can create reliable entities by merging decentralised ledgers and autonomous cars within the transportation system. This approach also aimed to offer a unified and accurate representation of information, thereby fostering public confidence. However, the blockchain has four layers [92], as depicted in Figure 4 and explained in detail.

3.5.1 Data layer

This layer focuses on managing and storing various data vehicles generate and their associated systems. It includes data related to vehicle telemetry, sensor readings, location information, maintenance records, and historical performance data [93]. The data layer ensures the security of this information and immutable storage by leveraging blockchain technology's decentralised and distributed nature. Zhu et al. [94] introduced vehicular crowdsensing intelligence to facilitate decentralised autonomous vehicle organisations. Each data entry or transaction is cryptographically signed and stored in a series of blocks, forming an immutable chain of data [95].

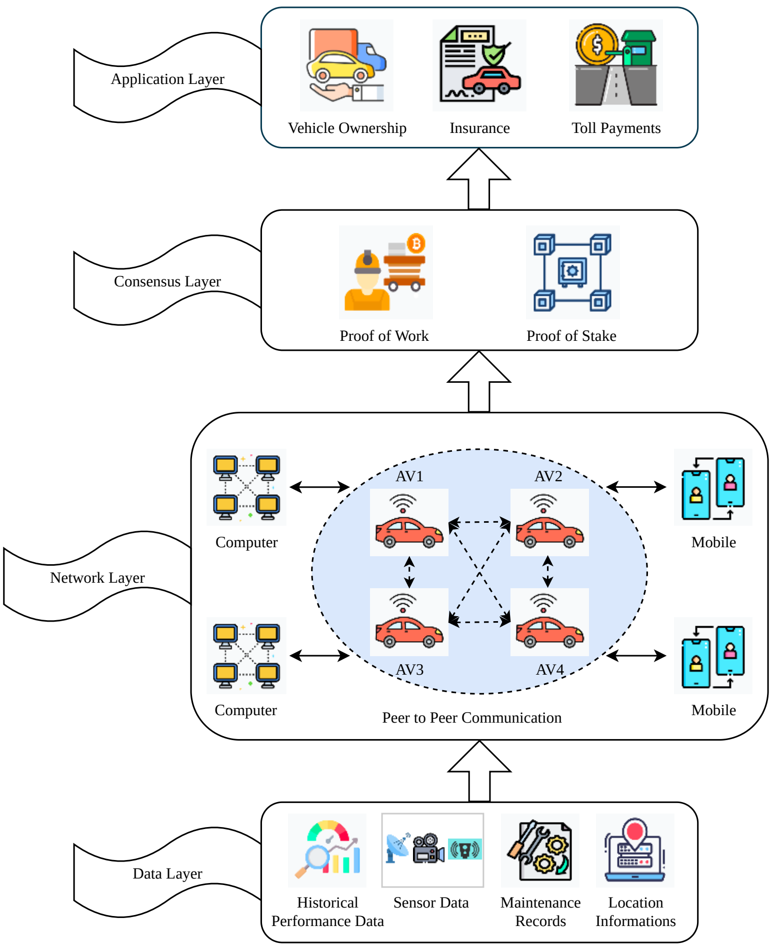

Figure 4. Blockchain architecture for autonomous vehicles

3.5.2 Network layer

The network layer facilitates the communication and connectivity between autonomous vehicles and other network participants in the blockchain ecosystem. It involves the peer-to-peer communication protocol that enables autonomous vehicles to interact with each other, infrastructure, and other entities in the network [96]. This layer utilises a decentralised network architecture, allowing vehicles to directly exchange information and transactions without relying on a central authority [97]. The network layer ensures secure data transmission and enables real-time communication between autonomous vehicles, enhancing their cooperative capabilities and overall efficiency. Kakkar et al. [98] proposed a safe and dependable data-sharing system for AVs using blockchain.

3.5.3 Consensus layer

The consensus layer is responsible for achieving agreement among network participants regarding the validity and order of transactions in the blockchain [99]. Consensus algorithms are essential in autonomous vehicles because they ensure accurate information communicated between vehicles. Proof-of-work, Proof-of-stake, and Practical Byzantine Fault Tolerance are examples of consensus algorithms used by distributed networks for transaction validation and verification [100]. Abubaker et al. [101] employed the proof-of-work algorithm to develop a decentralised blockchain-based mechanism for hiring AVs safely and reliably. The consensus layer ensures that all network participants agree on the state of the blockchain, making it resistant to tampering or malicious attacks.

3.5.4 Contract layer

The contract layer allows smart contracts to be executed and enforced within the blockchain infrastructure. Smart contracts are computer programmes that carry out predetermined activities when specific circumstances are satisfied [102]. Moreover, smart contracts can facilitate various functionalities, such as managing vehicle ownership, insurance, payments for charging or tolls, and autonomous driving permissions [103]. These contracts define the rules and conditions governing the interactions and transactions between entities within the autonomous vehicle ecosystem. Arunmozhi et al. [93] proposed an experimental design to implement smart contracts in AV supply chains. The contact layer enables transparent, secure, and automated execution of these smart contracts, ensuring trust and eliminating the need for intermediaries.

4. CHALLENGES, PROGRESSION, AND FUTURE DIRECTIONS

Autonomous vehicles have the potential to revamp the transportation sector completely, but there are still several serious obstacles (introduced in Figure 5) in the way of their broad adoption and implementation. Within the area of contemporary demanding situations surrounding AVs, top-notch emphasis is placed on safety and legal responsibility, technical barriers, ethical and social issues, cybersecurity, and privacy concerns. Concurrently, significant improvements are underway to mitigate those challenges. Nonetheless, substantial opportunities for future exploration persist, particularly in infrastructure development and AI aimed at fostering the adoption of AVs within the expanding automotive sector. The following are some of the present difficulties, recent developments, and potential future paths confronting AVs.

4.1 Safety and Liability

Safety remains critical in developing autonomous vehicles. Ensuring the reliability and robustness of autonomous driving systems, especially in complex and unpredictable scenarios, is a significant challenge. Inaccuracies in identifying pedestrians, traffic signals, and roadway signage can potentially cause significant accidents, resulting in fatalities for those impacted [104]. In addition, determining the liability [105] in the event of accidents or failures is another complex issue that needs to be resolved. As a consequence of the characteristics inherent to AVs, their passengers are likely to experience a state of relaxation, potentially resulting in reduced attentiveness toward traffic conditions. In circumstances where their focus is required, the period of opportunity for intervention may have already elapsed by the time they are prompted to take action. Hence, future research can focus on advancing AI algorithms to enhance AVs' efficiency, adaptability, and safety so they can operate in all possible situations.

4.2 Technical Limitations

Despite significant advancements, some technical limitations are required to be overcome. Autonomous vehicles face challenges in perceiving, localising, planning, controlling, and predicting information in complex and dynamic environments, particularly in adverse weather conditions, deteriorated road conditions, construction zones, or unmapped areas [106]. Therefore, developing robust and reliable sensor technologies, AI algorithms, and data processing capabilities to handle these scenarios is a key challenge. With AVs' massive data, research will focus on effective data management, storage, and analytics [107]. It includes developing efficient algorithms for real-time data processing, developing data fusion techniques to combine information from various sensors, and utilising data-driven insights to improve vehicle performance, traffic management, and urban planning. Furthermore, Milford et al. [108] described some critical technical challenges in their research, including the hardware and software of AVs. Researchers can develop more robust and accurate perception systems by exploring emerging sensor technologies to overcome these issues.

4.3 Ethical and Social Issues

Autonomous vehicles raise complex ethical and social questions. For example, decision-making algorithms must navigate difficult moral choices when harm may be unavoidable [109]. In addition, Wang et al. [110] described the challenges of social and ethical decision-making in AVs and provided recommendations to overcome the challenges. Furthermore, considerations such as job displacement, urban planning, and accessibility must be addressed to mitigate negative societal impacts [111]. Moreover, addressing ethical dilemmas [112] that AVs may encounter, such as making decisions in no-win situations where harm is unavoidable (e.g., choosing between two potentially dangerous outcomes). There is enormous scope to conduct in-depth research on AVs' societal and ethical implications to address concerns, establish guidelines, and inform policy decisions.

Figure 5. Current issues and challenges of autonomous vehicles

4.4 Cybersecurity

As autonomous vehicles become more connected and reliant on data exchange, the risk of cybersecurity threats increases. Safeguarding against potential cyber-attacks, including unauthorised access, data breaches, or remote control of vehicles, is essential to ensure the integrity and safety of autonomous systems. Lim et al. [113] assessed the cybersecurity and privacy issues associated with AVs for developing smart and sustainable cities. Also, Kukkala et al. [114] reviewed significant automotive cyber-attacks and presented AI-based solutions to overcome future challenges.

4.5 Privacy

Autonomous vehicles collect a vast amount of data about their surroundings and passengers. Safeguarding the privacy of this data [115], ensuring that it is collected and retained only for necessary purposes, and providing transparency in data usage are essential privacy considerations. Also, AVs rely on GPS and other location-based technologies, raising concerns about location tracking and potentially misusing this information. Furthermore, AVs may capture and process passenger identities or biometric data for authentication or personalised services [116]. Protecting this sensitive information from unauthorised access or misuse is crucial. Hence, robust security systems may develop in the future to protect the private data of the driver, passenger, or owner from sharing with any unauthorised devices in the vehicular network.

4.6 Infrastructure Development

Strong communication and transportation networks are necessary for autonomous vehicles to perform efficiently and safely. The existing infrastructure may need upgrades to support autonomous capabilities, such as advanced road markings, signage, and communication networks [117]. Future research will optimise and adapt existing infrastructure to support AVs. It includes developing advanced communication networks (such as 5G and V2X) for seamless Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication, enhancing sensor infrastructure, and improving intelligent transportation systems for efficient traffic management [118]. Addressing these challenges requires collaboration between industry stakeholders, policymakers, researchers, and the public. Technological advancements, regulatory frameworks, safety measures, and public awareness are essential to overcome these challenges and pave the way for a future with safe and efficient autonomous vehicles.

5. OUTCOMES OF FUTURE RESEARCH

The future research direction of this study holds the promise of benefiting diverse stakeholders throughout extraordinary sectors. Firstly, policymakers and regulatory bodies stand to gather insights into developing effective, legitimate frameworks and legal responsibility allocation mechanisms to ensure the secure and accountable deployment of autonomous cars on public roads [119]. Additionally, industries engaged in AV technology development [120], including automobile manufacturers, software program developers, and sensor generation groups, can leverage studies' consequences to deal with technical barriers and enhance AV structures' reliability and overall performance. Moreover, improvements in the AV era can result in full-size societal benefits, along with stepped-forward road protection, reduced site visitor congestion, and elevated accessibility to transportation for individuals with mobility barriers [120]. Research addressing ethical and social problems surrounding AV adoption can inform public discourse and contribute to developing inclusive regulations that remember the needs and concerns of various groups [121]. Furthermore, cybersecurity corporations and privacy advocates can utilise research findings to broaden sturdy cybersecurity measures and privacy-enhancing technology to guard AV structures and passenger information from ability threats [122]. Lastly, infrastructure development stakeholders, including city planners, transportation businesses, and generation carriers, can benefit from research insights to lay out clever infrastructure answers that guide the seamless integration of AVs into present transportation networks [123].

6. CONCLUSIONS

Autonomous vehicles represent a significant advancement in the latest wave of technological innovations, serving as a significant indication of technological progress. Eliminating risky driving behaviours, such as driving when fatigued, is expected to result in fewer vehicle accidents and improve road safety. This study thoroughly investigates the pivotal enabling technologies necessary for the actualisation of autonomous vehicles, highlighting the interdependence between each technology and the advancement of AVs. In combination with sensors and AI, ADAS enables AVs to make intelligent judgments when confronted with pressing situations. Moreover, the IoT integrated with sensors, AI, and wireless networks, as well as V2X communication, will provide real-time information to other intelligent vehicles within the network. Finally, blockchain technology safeguards AVs from plausible security and privacy vulnerabilities. All the technologies are currently undergoing rapid evolution and advancements. To cope with those advancements, future researchers can focus on developing robust sensors, increasing the accuracy and efficiency of AI algorithms to ensure safety and security for unpredictable road and weather conditions. In addition, ethical considerations, reliability challenges, legal implications, and user adoption factors are vital concerns for upcoming research endeavours. These insights are expected to stimulate research and accelerate the development and advancement of intelligent autonomous vehicles with full autonomy in the near future.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

AUTHORS CONTRIBUTION

M. Naeem Hossain (Conceptualisation; Methodology; Data curation; Formal analysis; Visualisation; Writing - original draft)
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D. Ramasamy (Investigation; Writing - review and editing; Funding acquisition; Supervision)
K. Kadirgama (Data curation; Investigation)
M. M. Noor (Visualisation; Validation)

REFERENCES

[1] C. Tennant, J. Stilgoe, "The attachments of 'autonomous' vehicles," *Social Studies of Science*, vol. 51, no. 6, pp. 846–870, 2021.

[2] P. Tafidis, H. Farah, T. Brijs, A. Pirdavani, "Safety implications of higher levels of automated vehicles: A scoping review," *Transport Reviews*, vol. 42, no. 2, pp. 245–267, 2022.

[3] M. Al-Turki, N. T. Ratrout, S. M. Rahman, I. Reza, "Impacts of autonomous vehicles on traffic flow characteristics under mixed traffic environment: Future perspectives," *Sustainability*, vol. 13, no. 19, p. 11052, 2021.

[4] Ó. Silva, R. Cordera, E. González-González, S. Nogués, "Environmental impacts of autonomous vehicles: A review of the scientific literature," *Science of the Total Environment*, vol. 830, p. 154615, 2022.

[5] W. Pawłowski, K. Goniewicz, D. C. Schwebel, J. Shen, M. Goniewicz, "Road traffic injuries in Poland: Magnitude and risk factors," *European Journal of Trauma and Emergency Surgery*, vol. 45, no. 5, pp. 815–820, 2019.

[6] O. Tengilimoglu, O. Carsten, Z. Wadud, "Implications of automated vehicles for physical road environment: A comprehensive review," *Transportation Research Part E: Logistics and Transportation Review*, vol. 169, p. 102989, 2023.

[7] R. Rawl, "Transport safety," in *IAEA Bulletin*, vol. 40, no. 2, p. 18, 1998.

[8] A. S. Tigadi, N. Changappa, S. Singhal, S. Kulkarni, "Autonomous vehicles: Present technological traits and scope for future innovation," in *EAI/Springer Innovations in Communication and Computing*, pp. 115–143, 2021.

[9] D. Parekh, N. Poddar, A. Rajpurkar, M. Chahal, N. Kumar, G. P. Joshi, et al., "A review on autonomous vehicles: Progress, methods and challenges," *Electronics*, vol. 11, no. 14, p. 2162, 2022.

[10] S. Burton, I. Habli, T. Lawton, J. McDermid, P. Morgan, Z. Porter, "Mind the gaps: Assuring the safety of autonomous systems from an engineering, ethical, and legal perspective," *Artificial Intelligence*, vol. 279, p. 103201, 2020.

[11] Z. Sun, S. Balakrishnan, L. Su, A. Bhuyan, P. Wang, C. Qiao, "Who is in control? Practical physical layer attack and defense for mm wave-based sensing in autonomous vehicles," *IEEE Transactions on Information Forensics and Security*, vol. 16, pp. 3199–3214, 2021.

[12] N. E. Bezai, B. Medjdoub, A. Al-Habaibeh, M. L. Chalal, F. Fadli, "Future cities and autonomous vehicles: analysis of the barriers to full adoption," *Energy and Built Environment*, vol. 2, no. 1, pp. 65–81, 2021.

[13] M. Ryan, "The future of transportation: ethical, legal, social and economic impacts of self-driving vehicles in the year 2025," *Science and engineering ethics*, vol. 26, no. 3, pp. 1185–1208, 2020.

[14] R. Braun, "Autonomous vehicles: From science fiction to sustainable future," *Mobilities, Literature, Culture*, pp. 259–280, 2019.

[15] P. A. Hancock, "Some pitfalls in the promises of automated and autonomous vehicles," *Ergonomics*, vol. 62, no. 4, pp. 479–495, 2019.

[16] D. A. Janeera, S. S. R. Gnanamalar, K. C. Ramya, A. G. A. Kumar, "Internet of things and artificial intelligence-enabled secure autonomous vehicles for smart cities," in *Automotive Embedded Systems: Key Technologies, Innovations, and Applications*, pp. 201–218, 2021.

[17] P. Mallozzi, P. Pelliccione, A. Knauss, C. Berger, N. Mohammadiha, "Autonomous vehicles: State of the art, future trends, and challenges," in *Automotive Systems and Software Engineering*, pp. 347–367, 2019.

[18] V. K. Kukkala, J. Tunnell, S. Pasricha, T. Bradley, "Advanced driver-assistance systems: A path toward autonomous vehicles," *IEEE Consumer Electronics Magazine*, vol. 7, no. 5, pp. 18–25, 2018.

[19] J. Alfred Daniel, C. Chandru Vignesh, B. A. Muthu, R. Senthil Kumar, C. B. Sivaparthipan, C. E. M. Marin, "Fully convolutional neural networks for LIDAR–camera fusion for pedestrian detection in autonomous vehicle," *Multimedia Tools and Applications*, vol. 82, no. 16, pp. 1–24, 2023.

[20] T. Karkera, C. Singh, "Autonomous bot using machine learning and computer vision," *SN Computer Science*, vol. 2, no. 4, pp. 1–9, 2021.

[21] S. M. N. Sakib, "LiDAR Technology-an overview," *IUP Journal of Electrical and Electronics Engineering*, vol. 15, no. 1, pp. 36–57, 2022.

[22] A. P. Sligar, "Machine learning-based radar perception for autonomous vehicles using full physics simulation," *IEEE Access*, vol. 8, pp. 51470–51476, 2020.

[23] D. Faccio, A. Velten, G. Wetzstein, "Non-line-of-sight imaging," *Nature Reviews Physics*, vol. 2, no. 6, pp. 318–327, 2020.

[24] R. Stiawan, A. Kusumadjati, N. S. Aminah, M. Djamal, S. Viridi, "An ultrasonic sensor system for vehicle detection application," in *Journal of Physics: Conference Series*, p. 12017, 2019.

[25] Z. Du, Q. Miao, C. Zong, "Trajectory planning for automated parking systems using deep reinforcement learning," *International Journal of Automotive Technology*, vol. 21, pp. 881–887, 2020.

[26] A. Larey, E. Aknin, I. Klein, "Multiple inertial measurement units-An empirical study," *IEEE Access*, vol. 8, pp. 75656–75665, 2020.

[27] S. Campbell, N. O'Mahony, L. Krpalcova, D. Riordan, J. Walsh, A. Murphy, et al., "Sensor technology in autonomous vehicles : A review," in *29th Irish Signals and Systems Conference, ISSC2018*, pp. 1–4, 2018.

[28] R. Changalvala, H. Malik, "LiDAR data integrity verification for autonomous vehicle using 3D data hiding," *IEEE Symposium Series on Computational Intelligence (SSCI2019)*, vol. 7, pp. 1219–1225, 2019.

[29] H. A. Ignatious, H. El Sayed, M. Khan, "An overview of sensors in autonomous vehicles," *Procedia Computer Science*, vol. 198, no. 2021, pp. 736–741, 2021.

[30] A. Aliyu, J. G. Kolo, O. O. Mikail, J. Agajo, B. Umar, O. I. Aguagba, "An ultrasonic sensor distance induced automatic braking automobile collision avoidance system," in *IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON)*, pp. 570–576, 2017.

[31] D. Perea-Strom, A. Morell, J. Toledo, L. Acosta, "GNSS integration in the localization system of an autonomous vehicle based on particle weighting," *IEEE Sensors Journal*, vol. 20, no. 6, pp. 3314–3323, 2020.

[32] R. Bawack, K. Daniel, A. Carillo, "Artificial intelligence in practice: Implications for IS research," *Ai & Society*. 2019. [Online]. Available: https://www.researchgate.net/publication/333853703

[33] H. He, J. Gray, A. Cangelosi, Q. Meng, T. M. McGinnity, J. Mehnen, "The challenges and opportunities of human-centered AI for trustworthy robots and autonomous systems," *IEEE Transactions on Cognitive and Developmental Systems*, vol. 14, no. 4, pp. 1398–1412, 2022.

[34] A. Gupta, A. Anpalagan, L. Guan, A. S. Khwaja, "Deep learning for object detection and scene perception in self-driving cars: Survey, challenges, and open issues," *Array*, vol. 10, p. 100057, 2021.

[35] R. Bibi, Y. Saeed, A. Zeb, T. M. Ghazal, T. Rahman, R. A. Said, et al., "Edge AI-based automated detection and classification of road anomalies in VANET using deep learning," *Computational Intelligence and Neuroscience*, vol. 2021, pp. 1–16, 2021.

[36] N. Sanil, V. Rakesh, R. Mallapur, M. R. Ahmed, "Deep learning techniques for obstacle detection and avoidance in driverless cars," in *2020 International Conference on Artificial Intelligence and Signal Processing (AISP)*, IEEE, pp. 1–4, 2020.

[37] S. Grigorescu, B. Trasnea, T. Cocias, G. Macesanu, "A survey of deep learning techniques for autonomous driving," *Journal of Field Robotics*, vol. 37, no. 3, pp. 362–386, 2020.

[38] B. Jin, F. Khan, R. Alturki, M. A. Ikram, "Computational intelligence-enabled prediction and communication mechanism for IoT-based autonomous systems," *ISA transactions*, vol. 132, pp. 146–154, 2023.

[39] F. W. Alsaade, M. H. Al-Adhaileh, "Cyber attack detection for self-driving vehicle networks using deep autoencoder algorithms," *Sensors*, vol. 23, no. 8, p. 4086, 2023.

[40] S. Ray, "A quick review of machine learning algorithms," in *Proceedings of the International Conference on Machine Learning, Big Data, Cloud and Parallel Computing: Trends, Prespectives and Prospects (COMITCon 2019)*, pp. 35–39, 2019.

[41] A. Pramod, H. S. Naicker, A. K. Tyagi, "Machine learning and deep learning: Open issues and future research directions for the next 10 years," in *Computational Analysis and Deep Learning for Medical Care: Principles, Methods, and Applications*, pp. 463–490, 2021.

[42] X. Shi, Y. D. Wong, C. Chai, M. Z.-F. Li, "An automated machine learning (AutoML) method of risk prediction for decision-making of autonomous vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 11, pp. 7145–7154, 2020.

[43] M. A. Wani, F. A. Bhat, S. Afzal, A. I. Khan, "Supervised deep learning architectures," *Studies in Big Data*, vol. 57, pp. 53–75, 2020.

[44] M. R. Bachute, J. M. Subhedar, "Autonomous driving architectures: Insights of machine learning and deep learning algorithms," *Machine Learning with Applications*, vol. 6, p. 100164, 2021.

[45] S. Gollapudi, "Artificial intelligence and computer vision," in *Learn Computer Vision Using OpenCV: With Deep Learning CNNs and RNNs*, pp. 1–29, 2019.

[46] J. Janai, F. Güney, A. Behl, A. Geiger, "Computer vision for autonomous vehicles: Problems, datasets and state of the art," *Computer Vision for Autonomous Vehicles: Problems, Datasets and State of the Art*, vol. 12, no. 1–3, pp. 1–308, 2020.

[47] C. A. Reyes-García, A. A. Torres-García, "Fuzzy logic and fuzzy systems," in *Biosignal Processing and Classification Using Computational Learning and Intelligence: Principles, Algorithms, and Applications*, Elsevier, pp. 153–176, 2021.

[48] C. Dobbins, S. Fairclough, "Detecting and visualizing context and stress via a fuzzy rule-based system during commuter driving," in *2019 IEEE International Conference on Pervasive Computing and Communications Workshops*, pp. 499–504, 2019.

[49] M. Vashisht, B. Kumar, "Traffic sign recognition approach using artificial neural network and chi-squared feature selection," in *Lecture Notes in Networks and Systems*, vol. 445, pp. 519–527, 2023.

[50] A. Ray, M. H. Kolekar, "Image segmentation and classification using deep learning," in *Machine Learning Algorithms for Signal and Image Processing*, pp. 19–36, 2022.

[51] N. A. Hamad, K. M. A. Alheeti, S. S. Al-Rawi, "Intrusion detection system using artificial intelligence for internal messages of robotic cars," in *AIP Conference Proceedings*, p. 20005, 2022.

[52] E. Geetha Rani, T. Bellam, E. Mounika, P. Bhuvaneswari, C. Gopala Krishnan, D. Anusha, "A practical approach of recognizing and detecting traffic signs using deep neural network model," in *4th International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT2022)*, pp. 1–5, 2022.

[53] A. Nemade, S. Telang, V. Jumbad, A. Chel, G. Kaushik, M. Hussain, "Artificial Intelligence: A tool to resolve thermal behavior issues in disc braking systems," in *Artificial Intelligence and Industry 4.0*, vol. 1–2, pp. 117–141, 2022.

[54] A. Gorska, P. Guzal, I. Namiotko, A. Wedolowska, M. Wloszczynska, J. Ruminski, "Pedestrian detection in low-resolution thermal images," in *International Conference on Human System Interaction*, pp. 1–6, 2022.

[55] V. S. H. Gullapalli, "Machine learning for vehicle behavioural control," in *8th International Conference on Advanced Computing and Communication Systems (ICACCS2022)*, pp. 1453–1458, 2022.

[56] L. H. Meftah, R. Braham, "Deep residual network for autonomous vehicles obstacle avoidance," in *Lecture Notes in Networks and Systems*, pp. 647–656, 2022.

[57] N. A. Andriyanov, A. A. Lutfullina, "Eye recognition system to prevent accidents on the road," in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLIV-2/W1, pp. 1–5, 2021.

[58] I. Rizianiza, D. M. Shoodiqin, "Automatic braking system using fuzzy logic method," in *Journal of Physics: Conference Series*, p. 12005, 2021.

[59] M. A.-M. Khan, S.-H, Kee, N. Sikder, F. T. Zohoro, M. A. Al Mamun, M. T. Hassan, et al., "A Vision-based lane detection approach for autonomous vehicles using a convolutional neural network architecture," in *Joint 10th International Conference on Informatics, Electronics & Vision (ICIEV2021) and 5th International Conference on Imaging, Vision & Pattern Recognition (icIVPR2021)*, pp. 1–10, 2021.

[60] H. Chehri, A. Chehri, R. Saadane, "Traffic signs detection and recognition system in snowy environment using deep learning," in *Innovations in Smart Cities Applications: The Proceedings of the 5th International Conference on Smart City Applications*, vol. 4, pp. 503–513, 2021.

[61] G. Krishna Chaitanya, G. Maragatham, "Object and obstacle detection for self-driving cars using GoogLeNet and deep learning," in *Artificial Intelligence Techniques for Advanced Computing Applications: Proceedings of (ICACT2020)*, pp. 315–322, 2021.

[62] M. Sicha, "Traffic sign classification using deep learning," in *Proceedings II of the Conference Student EEICT*, pp. 79–82, 2021.

[63] M. Hasenjäger, H. Wersing, "Personalization in advanced driver assistance systems and autonomous vehicles: A review," in *IEEE 20th international conference on intelligent transportation systems (ITSC2017)*, pp. 1–7, 2017.

[64] B. Manichandra, Y. Shiao, "Advanced driver assistance systems," in *The Future of Road Transportation: Electrification and Automation*, pp. 214–241, 2023.

[65] M. Guerrieri, G. Parla, "Smart tramway systems for smart cities: A deep learning application in ADAS systems," *International Journal of Intelligent Transportation Systems Research*, vol. 20, no. 3, pp. 1–14, 2022.

[66] T. Alsuwian, R. B. Saeed, A. A. Amin, "Autonomous vehicle with emergency braking algorithm based on multi-sensor fusion and super twisting speed controller," *Applied Sciences (Switzerland)*, vol. 12, no. 17, p. 8458, 2022.

[67] M. Karthikeyan, S. Sathiamoorthy, "Control of an autonomous vehicle with obstacles identification and collision avoidance using multi view convolutional neural network," *Indian Journal of Computer Science and Engineering*, vol. 12, no. 1, pp. 178–192, 2021.

[68] B. Groelke, C. Earnhardt, J. Borek, C. Vermillion, "A predictive command governor-based adaptive cruise controller with collision avoidance for non-connected vehicle following," *IEEE Transactions on Intelligent Transportation Systems*, vol. 23, no. 8, pp. 12276–12286, 2021.

[69] W. Yin, "Machine learning for adaptive cruise control target selection," *Master in System Control and Robotics*, KTH Royal Institute of Technology, Sweden, 2019.

[70] S. N. Bhargav, V. A. Prasad, "Lane departure warning system using TDA3x-rvp board," in *11th International Conference on Computing, Communication and Networking Technologies (ICCCNT2020)*, pp. 1–6, 2020.

[71] R. Utriainen, M. Pollanen, H. Liimatainen, "The safety potential of lane keeping assistance and possible actions to improve the potential," *IEEE Transactions on Intelligent Vehicles*, vol. 5, no. 4, pp. 556–564, 2020.

[72] M. B. M. Mansour, A. Said, N. E. Ahmed, S. Sallam, "Autonomous parallel car parking," in *2020 Fourth World Conference on Smart Trends in Systems, Security and Sustainability (WorldS4)*, pp. 392–397, 2020.

[73] Y. Guo, H. Shi, "Automatic parking system based on improved neural network algorithm and intelligent image analysis," *Computational Intelligence and Neuroscience*, vol. 2021, pp. 1–12, 2021.

[74] F. Jameel, Z. Chang, J. Huang, T. Ristaniemi, "Internet of autonomous vehicles: Architecture, features, and socio-technological challenges," *IEEE Wireless Communications*, vol. 26, no. 4, pp. 21–29, 2019.

[75] A. Nanda, D. Puthal, J. J. P. C. Rodrigues, S. A. Kozlov, "Internet of autonomous vehicles communications security: overview, issues, and directions," *IEEE Wireless Communications*, vol. 26, no. 4, pp. 60–65, 2019.

[76] J. Fayyad, M. A. Jaradat, D. Gruyer, H. Najjaran, "Deep learning sensor fusion for autonomous vehicle perception and localization: A review," *Sensors*, vol. 20, no. 15, p. 4220, 2020.

[77] Y. Cao, N. Wang, C. Xiao, D. Yang, J. Fang, R. Yang, et al., "Invisible for both Camera and LiDAR: Security of multi-sensor fusion based perception in autonomous driving under physical-world attacks," in *Proceedings - IEEE Symposium on Security and Privacy*, pp. 176–194, 2021.

[78] X. Shen, R. Fantacci, S. Chen, "Internet of vehicles [scanning the issue]," *Proceedings of the IEEE*, vol. 108, no. 2, pp. 242–245, 2020.

[79] T.-H. Wang, S. Manivasagam, M. Liang, B. Yang, W. Zeng, R. Urtasun, "V2vnet: Vehicle-to-vehicle communication for joint perception and prediction," in *Computer Vision–ECCV 2020: 16th European Conference, Glasgow, UK, August 23–28, 2020*, pp. 605–621, 2020.

[80] D. Kanthavel, S. K. B. Sangeetha, K. P. Keerthana, "An empirical study of vehicle to infrastructure communications - An intense learning of smart infrastructure for safety and mobility," *International Journal of Intelligent Networks*, vol. 2, pp. 77–82, 2021.

[81] K. Suganthi, M. A. Kumar, N. Harish, S. HariKrishnan, G. Rajesh, S. S. Reka, "Advanced driver assistance system based on IoT V2V and V2I for vision enabled lane changing with futuristic drivability," *Sensors*, vol. 23, no. 7, p. 3423, 2023.

[82] M. N. Ahangar, Q. Z. Ahmed, F. A. Khan, M. Hafeez, "A survey of autonomous vehicles: Enabling communication technologies and challenges," *Sensors (Switzerland)*, vol. 21, no. 3, pp. 1–33, 2021.

[83] A. Manimuthu, V. Dharshini, I. Zografopoulos, M. K. Priyan, C. Konstantinou, "Contactless technologies for smart cities: Big data, IoT, and cloud infrastructures," *SN Computer Science*, vol. 2, no. 4, p. 334, 2021.

[84] S. Khare, M. Totaro, "Big data in IoT," in *10th International Conference on Computing, Communication and Networking Technologies (ICCCNT2019)*, pp. 1–7, 2019.

[85] H. Lu, Q. Liu, D. Tian, Y. Li, H. Kim, S. Serikawa, "The cognitive internet of vehicles for autonomous driving," *IEEE Network*, vol. 33, no. 3, pp. 65–73, 2019.

[86] S. Sharma, V. Chang, U. S. Tim, J. Wong, S. Gadia, "Cloud and IoT-based emerging services systems," *Cluster Computing*, vol. 22, pp. 71–91, 2019.

[87] M. Chen, Y. Tian, G. Fortino, J. Zhang, I. Humar, "Cognitive internet of vehicles," *Computer Communications*, vol. 120, pp. 58–70, 2018.

[88] E. Taylor, "Autonomous vehicle decision-making algorithms and data-driven mobilities in networked transport systems," *Contemporary Readings in Law and Social Justice*, vol. 13, no. 1, pp. 9–19, 2021.

[89] B. Singhal, G. Dhameja, P. S. Panda, B. Singhal, G. Dhameja, P. S. Panda, "Introduction to blockchain," in *Beginning Blockchain: A Beginner's Guide to Building Blockchain Solutions*, pp. 1–29, 2018.

[90] D. Yaga, P. Mell, N. Roby, K. Scarfone, "Blockchain technology overview," *arXiv preprint arXiv:1906.11078*, 2019.

[91] S. Ayvaz, S. C. Cetin, "Witness of things: Blockchain-based distributed decision record-keeping system for autonomous vehicles," *International Journal of Intelligent Unmanned Systems*, vol. 7, no. 2, pp. 72–87, 2019.

[92] A. Biswas, H. C. Wang, "Autonomous Vehicles enabled by the integration of IoT, edge intelligence, 5G, and blockchain," *Sensors*, vol. 23, no. 4, p. 1963, 2023.

[93] Y. Yuan, F.-Y. Wang, "Towards blockchain-based intelligent transportation systems," in *IEEE 19th international conference on intelligent transportation systems (ITSC2016)*, pp. 2663–2668, 2016.

[94] Z. Zhu, X. Wang, Y. Zhao, S. Qiu, Z. Liu, B. Chen, et al., "Crowdsensing intelligence by decentralized autonomous vehicles organizations and operations," *IEEE Transactions on Intelligent Vehicles*, vol. 7, no. 4, pp. 804–808, 2022.

[95] H. Altaş, G. Dalkiliç, U. C. Çabuk, "Data immutability and event management via blockchain in the internet of things," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 30, no. 2, pp. 450–468, 2022.

[96] N. Kamble, R. Gala, R. Vijayaraghavan, E. Shukla, D. Patel, "Using blockchain in autonomous vehicles," in *Artificial Intelligence and Blockchain for Future Cybersecurity Applications*, pp. 285–305, 2021.

[97] A. Hammoud, H. Sami, A. Mourad, H. Otrok, R. Mizouni, J. Bentahar, "AI, blockchain, and vehicular edge computing for smart and secure IoV: Challenges and directions," *IEEE Internet of Things Magazine*, vol. 3, no. 2, pp. 68–73, 2020.

[98] R. Kakkar, R. Gupta, S. Agrawal, S. Tanwar, R. Sharma, "Blockchain-based secure and trusted data sharing scheme for autonomous vehicle underlying 5G," *Journal of Information Security and Applications*, vol. 67, p. 103179, 2022.

[99] S. Bano, A. Sonnino, M. Al-Bassam, S. Azouvi, P. McCorry, S. Meiklejohn, et al., "Consensus in the age of blockchains," *arXiv preprint arXiv:1711.03936*, 2017.

[100] C. Zhang, C. Wu, X. Wang, "Overview of blockchain consensus mechanism," in *ACM International Conference Proceeding Series*, pp. 7–12, 2020.

[101] Z. Abubaker, M. U. Gurmani, T. Sultana, S. Rizwan, M. Azeem, M. Z. Iftikhar, et al., "Decentralized mechanism for hiring the smart autonomous vehicles using blockchain," in *Lecture Notes in Networks and Systems*, pp. 733–746, 2020.

[102] S. Wang, Y. Yuan, X. Wang, J. Li, R. Qin, F.-Y. Wang, "An overview of smart contract: architecture, applications, and future trends," in *IEEE Intelligent Vehicles Symposium (IV)*, pp. 108–113, 2018.

[103] P. Fraga-Lamas, T. M. Fernández-Caramés, "A review on blockchain technologies for an advanced and cyber-resilient automotive industry," *IEEE Access*, vol. 7, pp. 17578–17598, 2019.

[104] D. Petrovic, R. Mijailović, D. Pešić, "Traffic accidents with autonomous vehicles: Type of collisions, manoeuvres and errors of conventional vehicles' drivers," *Transportation Research Procedia*, vol. 45, pp. 161–168, 2020.

[105] A. Taeihagh, H. S. M. Lim, "Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks," *Transport Reviews*, vol. 39, no. 1, pp. 103–128, 2019.

[106] H. Khayyam, B. Javadi, M. Jalili, R. N. Jazar, "Artificial intelligence and internet of things for autonomous vehicles," in *Nonlinear Approaches in Engineering Applications: Automotive Applications of Engineering Problems*, pp. 39–68, 2020.

[107] K. Ahmad, M. Maabreh, M. Ghaly, K. Khan, J. Qadir, A. Al-Fuqaha, "Developing future human-centered smart cities: Critical analysis of smart city security, data management, and ethical challenges," *Computer Science Review*, vol. 43, p. 100452, 2022.

[108] M. Milford, S. Anthony, W. Scheirer, "Self-driving vehicles: Key technical challenges and progress off the road," *IEEE Potentials*, vol. 39, no. 1, pp. 37–45, 2019.

[109] N. J. Goodall, "Ethical decision making during automated vehicle crashes," *Transportation Research Record*, vol. 2424, no. 1, pp. 58–65, 2014.

[110] H. Wang, A. Khajepour, D. Cao, T. Liu, "Ethical decision making in autonomous vehicles: Challenges and research progress," *IEEE Intelligent Transportation Systems Magazine*, vol. 14, no. 1, pp. 6–17, 2022.

[111] D. Bissell, T. Birtchnell, A. Elliott, E. L. Hsu, "Autonomous automobilities: The social impacts of driverless vehicles," *Current Sociology*, vol. 68, no. 1, pp. 116–134, 2020.

[112] S. Arfini, D. Spinelli, D. Chiffi, "Ethics of self-driving cars: A naturalistic approach," *Minds and Machines*, vol. 32, no. 4, pp. 717–734, 2022.

[113] H. S. M. Lim, A. Taeihagh, "Autonomous vehicles for smart and sustainable cities: An in-depth exploration of privacy and cybersecurity implications," *Energies*, vol. 11, no. 5, p. 1062, 2018.

[114] V. K. Kukkala, S. V. Thiruloga, S. Pasricha, "Roadmap for cybersecurity in autonomous vehicles," *IEEE Consumer Electronics Magazine*, vol. 11, no. 6, pp. 13–23, 2022.

[115] T. Mulder, N. E. Vellinga, "Exploring data protection challenges of automated driving," *Computer Law & Security Review*, vol. 40, p. 105530, 2021.

[116] T. H. Nguyen, T. G. Vu, H. L. Tran, K. S. Wong, "Emerging privacy and trust issues for autonomous vehicle systems," in *International Conference on Information Networking*, pp. 52–57, 2022.

[117] T. U. Saeed, "Road infrastructure readiness for autonomous vehicles," *PhD Thesis*, Purdue University, United States, 2019.

[118] M. M. Rana, K. Hossain, "Connected and autonomous vehicles and infrastructures: A literature review," *International Journal of Pavement Research and Technology*, vol. 16, no. 2, pp. 264–284, 2023.

[119] B. Eastman, S. Collins, R. Jones, J. J. Martin, M. S. Blumenthal, K. D. Stanley, "A comparative look at various countries' legal regimes governing automated vehicles," *Journal of Law and Mobility*, vol. 2023, no. 1, p. 2, 2023.

[120] K. Ljubi, A. Groznik, "Role played by social factors and privacy concerns in autonomous vehicle adoption," *Transport Policy*, vol. 132, pp. 1–15, 2023.

[121] M. Sadaf, Z. Iqbal, A. R. Javed, I. Saba, M. Krichen, S. Majeed, et al., "Connected and automated vehicles: Infrastructure, applications, security, critical challenges, and future aspects," *Technologies*, vol. 11, no. 5, p. 117, 2023.

[122] N. Liu, A. Nikitas, S. Parkinson, "Exploring expert perceptions about the cyber security and privacy of connected and autonomous vehicles: A thematic analysis approach," *Transportation research part F: Traffic Psychology and Behaviour*, vol. 75, pp. 66–86, 2020.

[123] A. Duvall, S. Young, J. Fish, A. Henao, J. Sperling, B. Powell, et al., "Roadmap to automated mobility systems: Informing the planning of a sustainable, resilient transportation ecosystem for dallas/fort worth international airport," National Renewable Energy Lab.(NREL), Golden, CO (United States), 2022. [Online]. Available: www.nrel.gov/publications.

NOMENCLATURE

Abbreviations

RADAR	Radio Detection and Ranging	DT	Decision Tree
LiDAR	Light Detection and Ranging	ML	Machine Learning
AV	Autonomous Vehicle	DL	Deep Learning
AI	Artificial Intelligence	CAN	Controller Area Network
IoT	Internet of Things	CV	Computer Vision
SAE	Society of Automotive Engineers	DQL	Deep Q-Learning
ADAS	Advanced Driver Assistance Systems	V2X	Vehicle-to-Everything
IMU	Inertial Measurement Unit	V2V	Vehicle-to-Vehicle
GPS	Global Positioning System	V2I	Vehicle-to-Infrastructure
ANN	Artificial Neural Network	V2D	Vehicle-to-Device
CNN	Convolutional Neural Network	V2N	Vehicle-to-Network
LSTM	Long Short-Term Memory	V2P	Vehicle-to-Pedestrian
KNN	K-Nearest Neighbor	LTE	Long Term Evolution