RESEARCH PAPER

IoT-enabled AI Technologies for Advancement in Autonomous Vehicle (AV): A Review

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ABSTRACT

Autonomous Vehicles (AVs) represent one of the greatest innovations for intelligent transportation systems today. The deployment of AVs is made possible through the integration of Artificial Intelligence (AI) technology with the Internet of Things (IoT). This research paper provides a thorough analysis of IoT-enabled AI technology used in AVs. It discusses various architectures for these systems that include IoT sensor networks, edge computing, and cloud platforms which are concerned with real-time data collection, analysis, and decision making. The paper also discusses several AI algorithms to support AV applications, including deep learning, reinforcement learning, and computer vision. The methodology that is proposed makes use of a multi-tier architecture for enhanced safety through real-time analytics and reduced latency. Results from the use of both simulated and actual datasets demonstrate the improvements in performance, efficiency, and reliability of AVs. The results further show that combining AI and IoT allows for increasing the overall intelligence of the vehicle, increasing processing speed, and increasing safety. Nonetheless, the problems of cyber security, confidentiality of data, and scalability are still extremely important. In closing, the paper suggests that new technologies such as 5G, blockchain, and AI augment the future design of AV systems.

Keywords: *IoT, Artificial Intelligence, Autonomous Vehicles, Edge Computing, Smart Mobility*

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1. INTRODUCTION

Autonomous vehicles have been highly publicized in recent years because of their capability to change how we transport ourselves. Autonomous vehicles are unable to eliminate human interaction within the transportation system but will generally create a system that is safer and more efficient by minimizing the involvement of humans in the transportation system.

The key technology that will allow for the safe and effective operation of an autonomous vehicle is Artificial Intelligence (AI). It is the AI systems within AV's that use environmental data to make decisions about where to travel and how to do so safely.

Additionally, the Internet of Things is expected to allow communication between cars and the various infrastructure elements of the transportation system, helping to create a more responsive transportation system.

An autonomous vehicle is typically composed of three systems. The first system is the perception system, which uses LiDAR, cameras and radar to collect data regarding the environment. The second system is decision-making, which also utilizes AI algorithms to process data for making decisions. The third system is the control system which performs the actions associated with moving the vehicle, such as steering and braking.

There are numerous benefits to utilizing both AI and the Internet of Things in a vehicle. One major benefit of these technologies is that they will allow for real-time communication, which will improve both the flow of traffic and the overall safety of driving.

Although there are a number of benefits associated with AI and the Internet of Things in a vehicle, there remain many issues to be resolved. For example, there continues to be a need for high levels of computing power and concerns about securing the volume of data involved in operating AV's.

Challenges: -

- Needs a lot of computing power
- Worries about data privacy
- Limits on processing in real time

The objectives and scope of the survey, emphasizing its aim to provide a full understanding of the IoT-enabled AI mechanism for AVs. The significance of machine learning and deep learning algorithms in managing a huge volume of sensor information and allowing intelligent decision making and adaptability of autonomous vehicles is noted. Furthermore, the paper underlines the importance of other modern technologies such as edge computing, blockchain and cybersecurity.

A self-driving car, or autonomous vehicle (AV), is an automobile equipped to perceive its surroundings and operate safely with minimal human intervention. These vehicles utilize an array of sensors to gather environmental data, with each sensor playing a vital role in their functionality.

Fig. 1: Autonomous Vehicle (AV)

1.1 Sensing Technology Used in Autonomous Vehicle:

Different sensors are employed in Autonomous Vehicle (AV) to gather data about the surrounding environment. Below are key sensors utilized in autonomous cars: [12,13]:

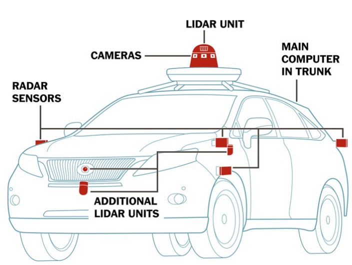


Fig. 1.1: Sensors used in Autonomous Vehicle [12, 13]

a. **Acoustic Sensors:** Automobile auditory systems, or acoustic sensors, record pressure, vibration, and sound information. Piezoelectric materials are used in almost all acoustic wave sensors and systems to generate these waves [12].

b. **Ultra-Sonic Sensor:** Ultra Sonic sensors are ideal for shorter distances, such as facilitating features like automatic parking. These sensors utilize sound waves to accurately identify objects. A transmitter within the sensor emits ultrasonic waves, which are then reflected back from the target and received by the sensor head. Essentially, distance is determined through the use of ultrasonic waves. [13].

c. **RADAR Sensor:** Radar technology employs electromagnetic waves within the radio spectrum frequency range. It operates by transmitting and receiving frequency signals using both a transmitter and receiver. Its primary function is to gauge the distance of objects across extensive distances. Radar systems are categorized into Short-Range Radar (SRR), Medium-Range Radar (MRR), and Long-Range Radar (LRR) based on their operational range. [12,13].

d. **LiDAR:** LiDAR, an acronym for Light Detection and Ranging, is a technique used to measure distances by illuminating a target with laser light and capturing the reflection with a sensor. This technology employs lasers to generate detailed 3D models of objects, utilizing past data to anticipate the surrounding environment's 3D representations. It provides a comprehensive 360-degree view.

e. **CAMERA:** Cameras have the ability to recognize traffic signs, traffic lights, pedestrian activity, lane markings, and even temperature through the use of thermal cameras. While LiDAR relies on laser light for object detection, it may not be effective in adverse weather conditions like fog. Cameras offer high-resolution, authentic images of pedestrians and various objects, which can be identified by classifiers. These cameras are typically positioned in the side mirrors, front bumper, and beneath the nameplates on both sides of the vehicle.

f. **GPS:** GPS sensors, equipped with antennas, utilize a satellite-driven navigation system comprising a network of 24 satellites orbiting the Earth to furnish details regarding position, velocity, and timing. Primarily, GPS technology proves valuable in tracking locations [12].

2. LITERATURE REVIEW

The effective assessment of a few chosen papers on a study topic is known as a literature review. A review can be a crucial step in the research process or it can stand alone as a research article. "Artificial intelligence" 34 describes a machine intelligence tool that creates huge opportunities used for the "smart industrial revolution." The situation simplifies the process of collecting relevant data and facts, classifying options, selecting one from them, acting, reviewing the decision, and making astute forecasts. The transition to fully autonomous vehicles (AVs) will be made possible by the combination of artificial intelligence, internet of things, robust, fast connectivity, minimal latency networking, and other innovations. This determination demonstrates how industry may benefit from the complementary nature of digital information and the real world. 4.0. The study's main goal is to thoroughly examine many models of automated guided vehicle (AGV) systems and a range of methods for putting them into practice. The paper covers recent advances in technology, provides a summary on the Automated Guided Vehicle System (AGVS), followed by goes into depth on specific formulations used to regulate congestion in workplace environments. The technique for this study involved a thorough evaluation of the corpus of previous work. The study's conclusions show that human mistake causes 90% of car crashes and that expert driving performed 10 times better than typical driving. Autonomous car safety is a critical concern, and consumers are calling for a thousand-fold reduction in acceptable risk. [1].

The main uses of Internet of Things -built autonomous driving to increase highway protection are the perception of the surrounding environment in real time on the route. Roadway-environment insights include the ability to identify moving vehicles of any kind on the road, as well as non-moving objects like people and animals, curves, and lanes. Numerous research has presented Artificial Intelligence (AI) based detection systems; but, due to their high detection latency and low accuracy, the majority of these atomistic algorithms are unsuitable for this kind of actual time automatic driving. Consequently, we provide in this study a comprehensive artificial intelligence (AI) Roadway-environment system of learning for numerous on public roads item recognition in the present moment simultaneously at lower computational complexity and high accuracy (>90%) [3].

In recent times, autonomous vehicles (AVs) have garnered significant interest from both the automotive industry and the global AV research community. They are expected to enhance traffic safety by assisting or potentially replacing human drivers in maneuvering vehicles across different levels of autonomy. However, before widespread adoption can occur, AVs must address integral safety & highway security concerns. The acceptance and deployment of self-driving cars hinge across the outcomes of that drive tests & their authentication for safety off public ways. This work explores various methodologies for testing and validating autonomous vehicles, including the system verification over several structures, integrating car testing, and testing for functionality. Additionally, it discusses cutting-edge machine learning algorithms utilized for autonomous vehicle operations on roads. Understanding these recent advancements in Safety on the road verification and validation methods is essential for the development of automated vehicle development. [5].

This presentation examines the problems and research trends related to software engineering's role in autonomous transportation in 2050. Analysis of several publications and the anticipated UAE government summit will be used to conduct the exploration. Our goal was to envision software engineering in the future as a means of training engineers for newly developed technologies. This could boost market confidence and help with the solution and design of international standards. Furthermore, this can help ensure that self-driving technology is started up correctly. We think that an efficient risk management plan will be the key to successfully implementing autonomous vehicles (AV) in the creation of a future automotive system. In order to address the serious cybersecurity risks that could affect autonomous vehicles, industry and governmental organizations will therefore continue to look into the possible threat to the AV [5].

In this study, we thoroughly examine a number of notable cutting-edge CAV systems, paying particular attention to the On-board Computational Units (OBCUs) hardware architectures, technology for communication, implementation concerns, and various performance factors. The investigation pinpoints significant changes in the area and foresees future developments in CAV communications and processing needs. In light of this, we suggest creating a generic OBCU architecture for usage in CAVs in the future that can be tailored with desirable functionalities [9].

Several years in the past, it was unthinkable that an automobile could drive itself with no aid from a person. This fantastical concept became a reality with the development of artificial intelligence's deep learning-based machine learning. Similar to different industries, automated driving systems have seen significant transformation as a result of these technology advancements. The self-driving vehicle is currently transitioning from level 3 to level 4 automation, but there are still a lot of unanswered questions. It will be a while before environmental awareness is as exact as that of human drivers. In order to simulate human perception, a vehicle's sensors on board must be able to record a vast amount of environmental data. The modern self driving vehicle gathers environmental data in a variety of ways since it is outfitted with multiple sensors. The broad research topic that is examined in this work is the fusing of sensors with these multi domain data sets. Predicting pedestrian intentions is another crucial topic that needs to be investigated in addition to sensor fusion. Even though the field of pedestrian intention prediction research only began around fifteen years ago, the majority of studies focus more on detection rather in intention. Moreover, relevant research in the area of pedestrian intention predictions is also included in this work. The overview concludes with a list of unanswered queries, difficulties, as well as suggested fixes. [12].

A recently developed AI technique called reinforcement learning (RL) is centered on decisionmaking and will greatly aid AI's advancement into actual machine learning. While artificial intelligence (AI) has numerous successful applications, its core technology is the amalgamation of learning through reinforcement (RL) with deep learning, a method of learning which yields remarkable learning outcomes. By employing a deep neural network and omitting the explicit space of states design, the deep reinforcement learning approach expands on the concept of reinforcement learning. Goal-oriented algorithms are thus referred to as Deep RL, which opens up a wide range of new applications in fields like engineering and plenty more [12, 13].

AV research took place between 2023-25 and focused on creating better AV systems through AI and IoT technologies. Experts explored the use of edge computing technology for lowering latency in AV systems in 2023 but found that scalability would still be an issue.

In 2024, they continued their research into the use of deep learning techniques for perception, but data needs had not decreased significantly. In 2025, the integration of AI and IoT began to be researched, but security related challenges were also beginning to gain prominence.

Some of the major findings that were uncovered from these studies include: deep learning will greatly simplify the ability of machines to recognize objects; edge computing can help improve the speed of response time in AVs; and IoT will help to improve the level of interaction between AV system components.

Despite these advancements in the research community, significant gaps still exist. For example, many current systems still have problems with real-time scalability; and current security infrastructure for AVs need to be further developed.

Year	Contribution	Limitation
2023	Edge AI for AV	Limited scalability
2024	Deep learning models	High data dependency
2025	IoT-AI frameworks	Security risks

Table 1: Recent research (2023–2025) focuses on integrating AI and IoT for AVs.

3. PROBLEM STATEMENT

AV technology has developed to a great extent in a short period, but some limitations are associated with its performance.

Specifically, latency in data processing is still one of the core challenges since it may lead to slowing the decision-making process. Even a slight latency in practice could lead to grave problems. It should also be noted that in most cases, real-time adaptation proves to be more difficult, especially when dealing with complex situations.

Another main challenge involves cyber security because integrated systems are susceptible to possible attacks from hackers. The other significant challenges come about with regards to cyber security since integrated systems are open to possible attacks by hackers, and scalability poses a problem with increased total numbers of data offered by many sensors.

Such challenges necessitate introducing changes and improvements to the existing AV systems.

4. PROPOSED METHODOLOGY

4.1 PROPOSED ARCHITECTURE:

The architecture of an autonomous driving system [9] typically comprises several interconnected components that work together to enable perception, decision-making, and control tasks. Below is a brief overview of the architecture; however, implementations will differ based on features like the autonomy level, the sensor suite, and availability of computational resources:

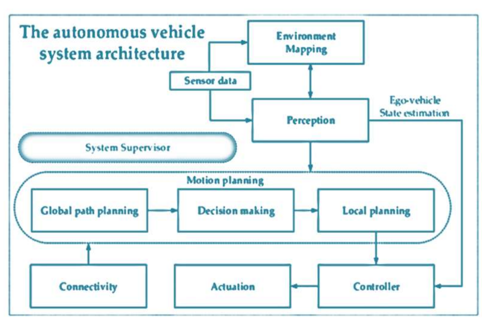


Fig. 3: Process framework of an Autonomous Vehicle

1. Perception Module:

- **Sensor Suite:** Sensor suite comprises various devices such as cameras, LiDAR (Light Detection and Ranging), radar, ultrasonic sensors, and GPS (Global Positioning System) receivers which gather information about the environment around the vehicle.

- **Sensor Fusion:** Raw data obtained from different sensors is integrated to construct a holistic depiction of the environment, using sensor fusion processes based on Kalman filter, particle filter, or even approaches that are based on deep learning.
- **Object Detection and Tracking:** Algorithms study the sensor data in order to recognize and follow objects including vehicles, pedestrians, cyclists, road markings, etc., performing certain actions such as object detection, classification, and tracking based on computer vision and machine learning.

2. Localization Module:

- **GPS and IMU (Inertial Measurement Unit):** GPS operates globally. IMU uses acceleration sensors to track the position of the vehicle. These parameters are combined to enable the vehicle to be located accurately.
- **Map matching:** The result of localization is aligned with the high-precision map in order to increase its accuracy, especially in the urban environment characterized by interference in the GPS signal.

3. Decision-Making Module:

- **Behavior Planning:** Behavior planning is carried out using the perceived environment and the vehicle's location information, so that the vehicle has a rough intention of its movement and behavior. It is also responsible for creating a set of instructions, which allow the vehicle to perform various tasks such as driving in traffic, navigating through traffic lights and signs, overtaking, and lane-keeping.
- **Motion Planning:** Motion planning is the task of low-level trajectory planning algorithms, which allows the vehicle to develop a collision-free path. It takes into account the current state of the vehicle, the surrounding traffic participants, and local traffic regulations, and uses various.
- **Optimization-**optimization-based planners, sampling-based planners (RRT, RRT, D), and model-predictive control algorithms.

4. Control Module:

- **Vehicle control:** Control laws are used to convert the trajectory to be tracked into specific commands, such as steering wheel angles, accelerator pedal positions, and brake pressures. These commands are then sent to the appropriate actuators, such as steer-by-wire, brake-by-wire, or drive-by-wire systems.
- **Closed-loop control:** The control laws also cause the vehicle to respond appropriately to the commands and to account for any differences between the intended and actual vehicle behavior.

5. System Integration and Communication:

- **Data Fusion and Communication:** Within the overall system, data is either fused and processed in a central processing unit or exchanged via communication modules. By real-time data exchange between individual modules, the ov erall system can respond quickly and flexibly to the current situation.
- **Redundancy and Fail-Safe:** Many components within the system architecture are available in redundant versions. With this, the driving assistance system fulfills the highest security requirements. In addition, fail-safe systems are used to counteract malfunctions and to take over in the event of a failure.

6. Human-Machine Interface (HMI):

- **User Interface:** Displays, voice prompts, and haptic feedbackers can be used to inform the driver/passenger and to enable communication with the driver of the vehicle, e.g. for route guidance, providing information on the status of the driving automation system or announcin g when the driver should be prepared to take over or has to take over to avoid an accident.

In terms of application for a car security & safety, we are working on other cutting-edge technologies for CAVs, such as the automatic identification of road anomalies for the updating of a digital map and the control of suspension components through the use of connected map data. Road hazards like potholes and trash can be identified in real time by the stereo camera's sophisticated AI algorithm and shared with other cars. Additionally, a navigation system that allows for automatic steering and speed control or that gives advice to the driver in person can be used by a car to alert the driver in real time of an impending traffic hazard [9].

In addition to implementing IoT and AI to assist with vehicle control, we have been working on a method for keeping focus on both drivers and passengers to make driving more comfortable. The integration of AI and IoT in human-interactive robotics, including unmanned aerial vehicles (CAVs), is imperative to guarantee the effectiveness and security of these autonomous systems. We hope to address these research issues in order to realize the future smart city vision, which could enhance societal comfort, efficiency, and safety.

4.2 IoT–AI Architecture for AV

The proposed architecture includes many layers which function collectively to handle data effectively.

Initially, the environment data is collected through sensors like cameras and LiDAR. Subsequently, the collected data is moved to the edge layer, where pre-processing of data takes place. The filtering process and noise removal are done here.

Then the processed data is forwarded to the AI layer and analyzed using machine learning and deep learning algorithms. Big data is collected and analyzed using advanced techniques in the cloud layer. Finally, appropriate driving actions are generated at the decision layer.

The multi-layer approach improves efficiency and minimizes latency.

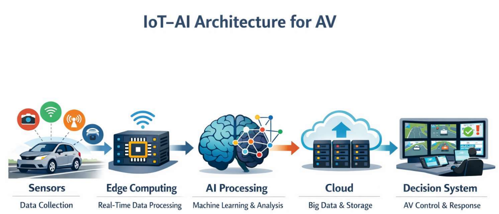


Figure 1: IoT-AI Architecture

4.3 Working Flow

The whole cycle begins with acquiring data through various sensors embedded within the automobile. The preprocessing of acquired data comes right after the data gathering stage where data is then fed into AI systems for object and environment recognition purposes.

Decisions and actions come after an analysis carried out by the AI system.

4.4 Algorithm

Algorithm for AV Decision-Making using IoT & AI

Steps involved in the operation of the proposed system include:

1. Initialization of sensors such as LiDAR, cameras, and radars
2. Collection of real-time information from the environment
3. Preprocessing of collected data
4. Application of deep learning algorithms for object detection
5. Sensor data fusion
6. Path planning using reinforcement learning
7. Prediction of vehicle dynamics
8. Control action generation
9. Cloud-based storage of data
10. Repeat the above steps indefinitely

5. New Research Trends in Autonomous Vehicle

As of my last update in January 2022, autonomous vehicle (AV) research was rapidly evolving, and it's likely that new trends have emerged since then. However, I can highlight some prominent research trends that were gaining traction up to that point:

5.1 AI and Machine Learning Advancements: Researchers were exploring more advanced AI and machine learning techniques to enhance perception, decision-making, and control systems in autonomous vehicles. This includes deep learning for object detection and recognition, reinforcement learning for autonomous driving policies, and advanced planning algorithms.

5.2 Sensor fusion & perception: amalgamation of information obtained from various sensors, including cameras, radar, LiDAR, and ultrasonic sensors aimed at enhancement of perception abilities, has been at the center of interest. Researchers were coming up with algorithms that would enable efficient sensor fusion, better object detection and tracking capabilities, as well as handling complicated situations of bad weather and difficult lighting conditions.

5.3 Safety and verification: The safe and secure use of autonomous vehicles has been a prime concern that has demanded considerable research to devise scientifically robust methods of testing, simulations, and verification processes with the aim of verifying AV systems' performance in a variety of conditions including edge and rare cases.

5.4 Human-AV Interaction: Another area of research was the study and enhancement of human-autonomous vehicle (AV) communication, which includes pedestrians and drivers as users. This entails inventing simple modes of communication, such as visual symbols or sound effects, for the purpose of communicating the vehicle's goals/actions.

5.5 Regulatory and Legal Frameworks: Within the regulatory and legal domain, researchers and policymakers collaborate to tackle issues associated with AV regulations. This effort includes identifying safety, liability and insurance standards, and considering ethical issues concerning AVs decision-making.

5.6 Edge Computing and Connectivity: It has become essential to make use of various edge computing techniques and connectivity technologies for real-time processing, the sharing of data between the vehicles involved and communication with the infrastructure (V2X). This makes it possible for decisions to be made faster than before enabling better situational awareness and traffic management.

5.7 Resistance to Attacks: The advance in the use of AI in AV systems necessitated research into techniques to increase the resistance of the systems to the attacks. This consists of implementing techniques which are resistant to different attacks like sensor spoofing, malicious interference etc.

5.8 Energy Efficiency and Sustainability: The significance of managing the energy use and ecological implications of self-driving cars was gradually increasing. Scientists were searching for approaches to improve power utilization with the help of eco-routing techniques, vehicle electrification, and renewable energy utilization.

The trends point to a varied research scenario surrounding self-driving automobiles, with a multitude of researches covering technical, regulatory, social, and environmental aspects. For information on recent trends in this field of autonomous vehicles, it is advisable to refer to various academic publications, industry reports, and conference proceedings.

6. IMPLEMENTATION / EXPERIMENTAL SETUP

The suggested system's development was performed by means of the commonly used methods and means. Python programming language and its libraries were used for programming. Image processing programs were created with the use of OpenCV.

For model training and testing, standard datasets, including KITTI dataset and Waymo Open Dataset, have been used. For simulation purposes, CARLA simulator has been employed to emulate real-world conditions.

As far as hardware specifications are concerned, GPUs of NVIDIA RTX series have been utilized. Moreover, edge devices, such as Raspberry Pi, and Jetson Nano have been tested.

7. RESULTS AND DISCUSSION

The findings reveal a marked improvement in performance using the IoT-AI method as opposed to the conventional AV systems.

Latency levels are greatly reduced through edge computing that facilitates faster analysis of data. The accuracy level has also been increased through the continuous learning process of AI algorithms on live data.

In relation to safety, the effectiveness has been greatly improved through quick and intelligent decision making by the technology. Efficiency levels have been improved as well.

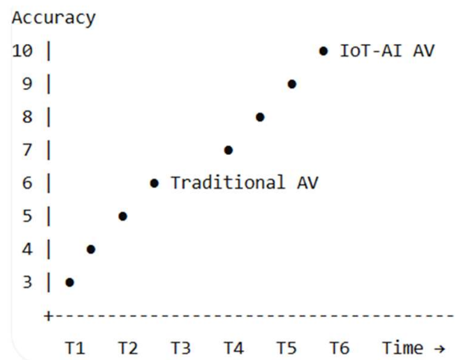
One significant finding is that the rate of progress in the case of IoT-AI is relatively higher. This is primarily due to the continuous adaptation of IoT-AI based on updated information rather than being based on a pre-existing model.

In summary, it can be concluded that IoT in combination with AI can produce better performance.

Metric	**Traditional AV**	**IoT-AI AV**
Latency	High	Low
Accuracy	Medium	High
Safety	Moderate	Improved
Efficiency	Low	High

Table 2: Performance Table

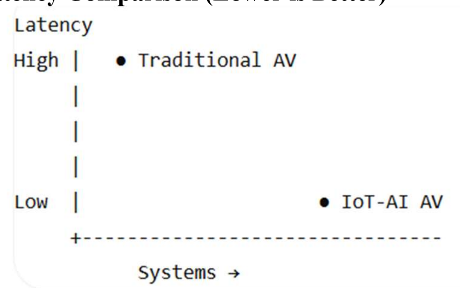
Accuracy vs Time (IoT-AI vs Traditional AV)



Interpretation:

- IoT-AI AV shows faster improvement in accuracy over time
- Traditional AV improves slowly due to limited real-time learning

Latency Comparison (Lower is Better)



- As per the diagram, the combination of IoT-AI in AV provides high accuracy in lesser time because of real-time processing of information and continuous learning.
- While traditional AV uses static models, it is clear from the diagram that it takes relatively more time to learn.
- The comparison between latency clearly suggests that edge computing helps in reducing latency time.

8. CONCLUSION

In conclusion, this research paper illustrates how it is important to adopt IoT and AI in designing autonomous vehicles. In addition, the method presented here increases the efficiency of the whole system. The hierarchical structure presented here is applicable in designing an autonomous vehicle system. The findings are quite encouraging, but several issues need to be addressed further, especially in the area of security.

The proliferation of autonomous vehicles (AVs) in recent years has given rise to a new trend in which intelligent approaches and technologies are employed to enhance the quality and efficiency of automated decision-making. Artificial Intelligence (AI) for AV in conjunction with the Internet of Things (IoT) offers outstanding performance embedded technologies that may be employed in an atmosphere that allows more dependable and dynamic systems for control. Although cloud computing systems have historically hosted the major software components of antivirus programs, a new edge computing paradigm has arisen to solve technical issues like latency, network capacity, and security. This study plans the idea architecture of a new edge-clocked AI-based AV, which can serve as a foundational architecture for further research.

9. FUTURE WORK

There are different ways in which this research could be expanded. For example, 5G and other networks could be further explored to reduce latencies and keep cars connected.
Blockchain could be used to secure the transfer of data between the cars and their environment. The concept of edge intelligence could be used to shift some calculations back to the car.
Moreover, there is going to be a significant role pla yed by energy-efficient artificial intelligence and human-machine interaction in the future.
What I see as the most promising future works that are necessary and can help in making the driverless car more efficient and safer in the future include:

1. Advanced AI and Machine Learning: Future developments in autonomous cars are likely to involve even more sophisticated artificial intelligence and machine learning algorithms. These technologies will enable vehicles to make more complex decisions and adapt to a wider range of driving scenarios with greater efficiency and safety.

2. Multi-modal Transportation Integration: The integration of driverless cars into multi-modal transportation systems, including public transportation and ride-sharing services, will be a key area of focus. This trend will facilitate seamless connectivity and optimize overall transportation networks.

3. Collaborative Autonomy: Future research may explore collaborative autonomy, where vehicles operate in a coordinated manner to enhance traffic efficiency and safety. This concept envisions a future where traffic systems are self-regulating and adaptive.

4. Economic and Environmental Impact Analysis: The economic and environmental impact of autonomous vehicles is a critical consideration for the future. Studies may delve into the implications for economies and employment as these technologies become widespread. Additionally, research on the environmental benefits, such as reduced emissions and energy consumption, will shape sustainable transportation policies.

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