CURRENT TOPICS IN AI(DLMAISCTAI01): Autonomous Vehicles

Latest Trends & Efforts In The Development Of Autonomous Vehicles

Research Essay

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List Of Abbreviations

AI: Artificial Intelligence
ML: Machine Learning
GPS: Global Positioning System
LiDAR: Light Detection and Ranging
TDoA: Time difference of Arrival
IPA: Intelligent Process Automation
SLAM: Simultaneous Localization and Mapping
IMU: Inertial Measurement Units
DSRC: Dedicated Short Wave Communication.
C-V2X: Cellular Vehicle-To-Everything
CNN: Convolutional Neural Network
RNN: Recurrent Neural Network
LSTM: Long Short-Term Memory
SVMs: Support Vector Machines
GMM: Gaussian Mixture Model
MDPs: Markov Decision Process
MCTS: Monte Carlo Tree Search
IOT: Internet of Things

Introduction

Autonomous vehicles or self-driving vehicles are one of the major developments in the advancement of artificial intelligence in transportation. Self-driving vehicles can sense their environment and are able to do the navigation with little or no input from humans. The technologies used in self-driving vehicles have evolved a lot over the past few decades. It can observe its surroundings and make appropriate decisions based on input from devices connected to it. We can call them sensory devices, which play the key role in control and coordination of autonomous vehicles. Autonomous vehicles use various sensing devices such as cameras, GPS, LiDAR, etc. to collect various information about the surroundings. This data then feeds to various advanced artificial intelligence and machine learning algorithms. These algorithms will process the data and generate output which will help to take appropriate decisions for their movements.

The development of autonomous vehicles has the potential to change locomotion in several ways. It can revolutionize transportation by improving safety, reducing traffic congestion, and most importantly, making transportation more accessible for those who can't drive. Recent trends and efforts in the development of the autonomous vehicle industry are so diverse that they will be discussed in detail in this article.

Latest trends and efforts in autonomous vehicles industry

The development of information technology and the ability of computers to handle more and more batch and live stream data have aided the technological growth in many areas which in turn reflects in the growth of autonomous vehicles as well. In addition, the growth of satellite communications in GPS tracking and mobile networks in object detection through various TDoA (Time Difference of Arrival) concepts involving state-of-the-art methods in multilateration are helping to contribute to this field (E. DiGiampaolo, 2022).

Today, the technology used for autonomous or self-driving cars has evolved significantly during this time. Many adjacent technological developments as well as socio-economic needs have been contributing to it. Many technology companies have already started developing and testing self-driving cars. The fields of application are wide and varied, from personal vehicles to industrial uses such as IPA (Intelligent Process Automation) (P. S. Kholiya, 2021) enabled systems. There are multiple factors driving the development of self-driving cars. Some of these are advanced technologies such as sensors, machine learning (ML) and artificial intelligence (AI). Whereas the need for safer and more efficient modes of transportation, including reduced traffic congestion, fuel efficiency, and reduced accident rates, is also a major driving factor. Autonomous vehicles consist of 4 interconnected units like Sensing, Perception, Decision and Action as shown in the diagram below.

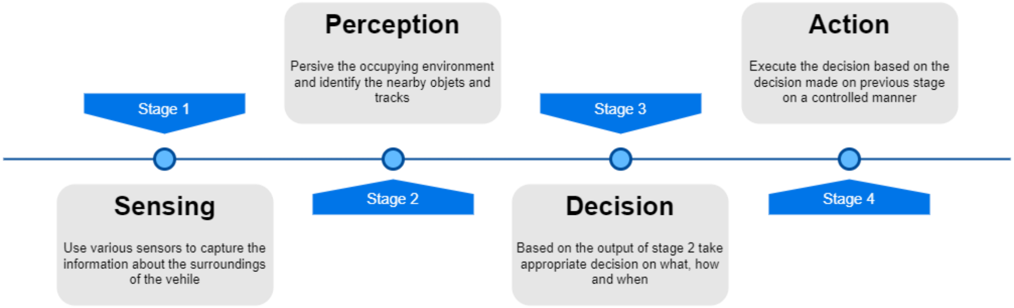

Figure 1: Four major contributing units of self-driving vehicles

The faster growth and development of autonomous vehicles are fueled by different areas such as technological growth, collaborative testing and development, safety and security regulatory changes, ethical and social implications and the promising growth of future technologies as listed below.

- Advancements in sensor technology
- Machine learning and artificial intelligence
- Collaborative development
- Testing and deployment
- Safety and regulatory challenges
- Ethical and societal implications
- Potential future developments

1. Advancements in sensor technology

Like sensory organs of any living organism, the sensors are the sensory or perception end points of any autonomous vehicles. Self-driving cars must use a variety of components to monitor position, speed, direction, and traffic information for seamless route planning and navigation. The current trends in self-driving car technology are to use and integrate more and more sensory devices to percept its surroundings. For example: RADAR, LiDAR, etc (De Jong Yeong, 18 March 2021).

There are various kinds of sensory devices to gather inputs from its surroundings which can be either stationary or moving objects, localization of the vehicles or the gyroscopic measurements as shown in below diagram.

1.1. Camera Vision

Cameras help to capture images of the surrounding environment. These are the best sensor solutions to get an accurate visual representation of the surroundings of the self-driving vehicle. Multiple wide-angle and narrow-angle cameras on all four sides of the vehicle will capture a 360-degree view of the surrounding environment. Cameras capture the images of pedestrians, signs, and other objects. However, it is not possible to visually identify obstacle distances using cameras; for this, we rely on LiDAR and RADAR systems.

1.2. LiDAR

LiDAR – Light Detection and Ranging (Y. Wang, 2022), is a sensor technology which can create a map of the environments it belongs to. It is very important to track objects a little far from the vehicle to take the necessary action in a timely manner for an occurrence of an unpredictable situation while moving forward or backward as far as an autonomous vehicle is concerned. The latest LiDAR device can detect the movement as well as stationary objects up to 400 meters. The maps thus created are important for the decision-making process of autonomous vehicles while they are moving. Usually, the LiDAR systems use infrared light to detect objects. Sample LiDAR image shown below.

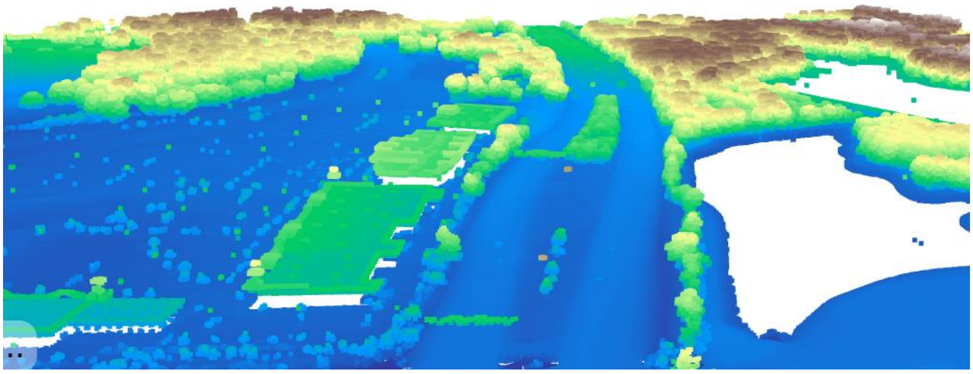

Figure 2: Sample LiDAR image

1.3. SLAM

Simultaneous localization and mapping (SLAM) (Bailey, 2006) algorithms help autonomous vehicles to create a map of their surroundings at the same time the vehicle can locate themselves on the map. It allows self-driving vehicles to perceive an unknown terrain and navigate effortlessly. SLAM mostly depends on the LiDAR system to capture the information about surrounding objects to create the localization map. SLAM uses front-end sensor-dependent data processing and back-end sensor-independent data processing. The former deals with motion planning and obstacle position estimations, while the latter deals with graph optimization. The data processed by the back-end system will be fed as an input to the front-end as in a feedback loop that will help to draw a precise positioning map of its surrounding environment. The basic architecture of the SLAM is given below.

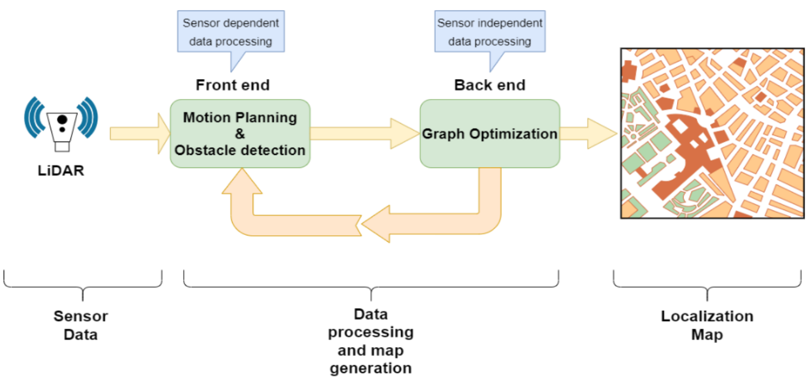

Figure 3: SLAM architecture

1.4. RADAR

The basic principle of operation of RADAR and LiDAR is the same. The only difference is that radar uses millimeter waves, while LiDAR uses light waves. As the RADAR uses millimeter waves, it provides millimeter precision, which in turn facilitates high-resolution obstacle detection and high-precision position and locomotive determination. Compared to LiDAR, RADAR devices can detect dynamic objects, such as other vehicles in the track, over a large area.

1.5. Ultrasonic sensors

Ultrasonic sensors are used to detect the presence of nearby objects such as pedestrians, animals, etc. which are near the vehicle and help to reduce the speed of the vehicles and avoid accidental collisions. These sensors are very useful in parking spaces.

1.6. GPS

Real-time navigation is a major part of self-driving cars. In order to provide a highly accurate road map for an autonomous vehicle, it is necessary to know the exact geographic location of the vehicle at that point in time in time. GPS devices can provide accurate location information in the form of numerical coordinates (latitude and longitude) information, which can be combined with real-time map data such as Google Maps to determine the exact geographic location of the self-driving car.

1.7. Inertial Measurement Units (IMUs)

Just like the external factors, it is very important to monitor the internal parameters as well for a self-driving vehicle. The IMU's will monitor the acceleration, the angular rate and the orientation of the vehicle by using accelerometers and gyroscope. They can be thought of as the inner ear of a self-driving car. They help to maintain the stability of the vehicle. Unlike other sensors, the IMU sensors can detect the vehicle's movements (Maneewarn, 2008) .

1.8. Communication technologies

Self-driving cars communicate with each other using various communication technologies. For example, DSRC and C-V2X (Sara LAHDYA, 2022).DSRC or Dedicated Short Range Communication technology is used for autonomous vehicles to communicate with each other. Whereas C-V2X or Cellular vehicle-to-everything is a generic term for car's communication system. Data collected through various sensors will be processed and analyzed by various systems, helping to provide a seamless path to fully autonomous driving. Multilateration technology used in cellular network communications locates objects by using a continuous map of three mobile tower signals.

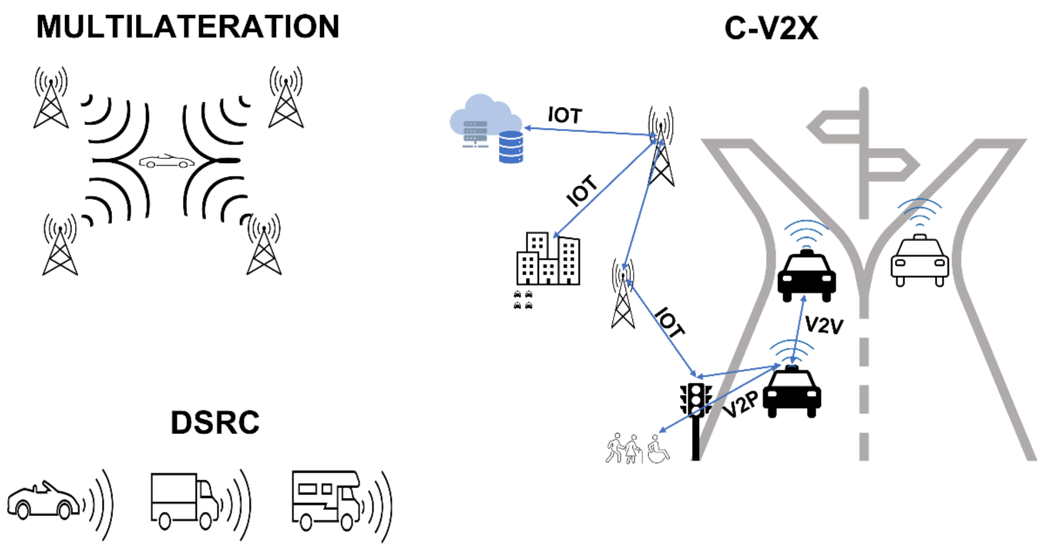

Figure 4: Different modes of inter vehicular communication systems.

2. Machine learning and artificial intelligence

The data produced by the sensors in the autonomous vehicle will be used by the Machine learning and artificial intelligence system for the control and coordination of the vehicle. The use of machine learning algorithms and artificial intelligence powered decision-making systems are the inevitable part of autonomous vehicles. Their usage increases day by day because algorithms were highly important for the development of self-driving locomotion systems. The ML algorithms use the data produced by the sensors and the system become matured over the period by the exposure of more and more datasets when it ramps up on an unknown terrain with an unforeseeable circumstance in real time. The produced output of machine learning systems can be leveraged to take appropriate decisions for autonomous vehicles. Here, the ML systems help to process the sensor data and help to perceive the terrain properties of the vehicle. Whereas the artificial intelligence system helps to take appropriate decisions and guaranty safety and efficiency.

There are various ML and AI algorithms used in the development of self-driving cars (S. Perla, 2022). Although machine learning and artificial intelligence algorithms are related to each other, there are also differences. Machine Learning algorithms are a subset of artificial intelligence algorithms. In self-driving vehicles, machine learning algorithms are used to train models with the data captured from the sensors to do predictions or taking decisions. They are designed based on the idea that machines can learn from data and improve the performance over the period by the exposure of more and more data. Supervised, Unsupervised, Semi-supervised and reinforcement algorithms are various machine learning algorithms used in self-driving car development. The various ML algorithms and their area of applications in the development of autonomous vehicles are given in the diagram below.

- Convolutional Neural Networks (CNNs): Used for image processing tasks such as object recognition and semantic segmentation.

- Recurrent Neural Networks (RNNs): Used for time series data and sequential data processing, such as understanding the context of a scene over time.
- Long Short-Term Memory (LSTM): A type of RNN that is useful for processing sequences of data with long-term dependencies.
- Support Vector Machines (SVMs): Used for supervised learning tasks such as classification and regression.
- Kalman Filters: A type of algorithm used for estimating the state of a system from noisy measurements, commonly used for sensor fusion.
- Particle Filters: Algorithm used for nonlinear and non-Gaussian state estimation, commonly used for object tracking and localization.
- Reinforcement Learning: Used for decision making, planning, and control in self-driving vehicles.
- Gaussian Mixture Model (GMM): Used for clustering and classification, commonly used for object tracking and motion prediction.

The artificial intelligence algorithms are a wider category which includes the ML algorithms as well. AI algorithms are designed to mimic human intelligence. There are algorithms for natural language processing, image recognition, decision making, and more. The AI algorithms used in self-driving cars are rule-based systems, expert systems, and other forms of narrow AI systems that are not based on learning from data. The various AI algorithms and their area of applications in the development of autonomous vehicles are given in the diagram below.

- Decision Trees: Used to make decisions based on a set of rules, commonly used for object detection and classification.
- Random Forests: An ensemble of decision trees, commonly used for object detection and classification.
- Neural Networks: Used to model complex relationships and make predictions, commonly used for image processing, sensor fusion, and control.
- Fuzzy Logic: Used to make decisions based on imprecise or uncertain information, commonly used for controlling vehicle dynamics.
- Bayesian Networks: Probabilistic graphical models used for reasoning under uncertainty, commonly used for decision making and perception.
- Markov Decision Processes (MDPs): A mathematical framework for modeling decision-making problems with uncertainty, commonly used for path planning and control.
- Q-Learning: A type of reinforcement learning algorithm used for decision making and control in self-driving vehicles.
- Monte Carlo Tree Search (MCTS): Algorithm used for decision-making in uncertain, stochastic environments, commonly used for path planning and control.

Together, these algorithms provide the vehicle with a comprehensive understanding of its surroundings, enabling it to make judgments based on this knowledge.

3. Collaborative development

The development of the autonomous vehicle is not done by a single company, but it is a collaborative development approach, which takes a long time to reach up to today’s stage. There were contributions from many technology companies, research institutes, government authorities and universities. The collaborative contribution of these institutions has accelerated the development of autonomous vehicles. There are various advantages for collaborative development. The strength and expertise of different institutions can advance the development of new ideas and thoughts, which accelerates the development strategy at the same time the risk and cost of development also shared between them.

There are various advantages for the collaborative development approaches of self-driving vehicles.

- Combined research and development: Various companies must work together to develop the components of self-driving vehicles. It may include development and testing of various components together as a team.
- Shared test data: Various component tests generate massive amounts of data that will be shared between technology partners to advance in testing and development.
- Succeed the common standards and regulations: It is always better to follow the standards to optimize growth and faster development. Succeeding with the rules and regulations will help to maintain consistency throughout the process, which in turn will help in getting results faster.
- Testing and Validation: Every stage of autonomous vehicle development must be tested and validated, and all stakeholders must actively participate in testing and enforce validation of results to ensure safety.
- Support from Government authorities: It is always mandatory to work with the government authorities and organizations to ensure the safe and secure development of self-driving cars and make sure the deployment among the society is safe, efficient and beneficial to the society.

The collaborative development approach brings together the different capabilities of various technical as well as non-technical organizations and research institutions to accelerate the development and development of autonomous vehicles.

4. Testing and deployment

Multiple companies are starting to test their self-driving car prototypes in real time, deploying them on roads, in trucks, delivery vans, and in warehouses and industrial operations. The testing and deployment are a multifaceted process that relies on various steps and methodologies. This can be divided into different stages.

4.1. Stage 1: Research and Development

This involves the process of gathering technical requirements for developing an autonomous vehicle and developing various components such as sensors, processing units and their corresponding software.

4.2. Stage 2: Simulation

The developed sensors, software and hardware must be tested in simulated environments in different conditions of terrain, weather and circumstances to ensure the performance is adequate and make sure they are safe and secure.

4.3. Stage 3: Closed course testing

During this phase, the developed self-driving prototypes will be tested on private roads in different environments, and test conditions such as weather and terrain are tested in a controlled manner. Tests will generate real-world scenarios, such as different weather and lighting conditions.

4.4. Stage 4: Open testing on public roads

This can be considered as the open road-testing phase. In this phase, the autonomous vehicle is deployed on the real road between other vehicles and pedestrians. This will help analyze the vehicle's efficiency under real-world conditions and allow the test to identify any problems that may arise in such conditions.

4.5. Stage 5: Deployment

This is the final testing phase of self-driving cars. Here, autonomous vehicles are deployed in real-world environments and commercial vehicles are deployed for consumer use.

Throughout the testing and development phase, it is mandatory to ensure the safety and reliability of self-driving vehicles. It is important to collect all logging data for regular security and audit checks. Also, securing regulatory complaints and obtaining certification from government authorities is very important for every stage of development.

5. Safety and regulatory challenges

Around the world, many countries are developing and testing autonomous vehicles. Self-driving cars can be considered the golden feather of future transportation technology, despite It's in its infancy right now. Governments around the world are developing new laws and regulations to overcome obstacles and concerns related to self-driving cars. Safety, accountability, privacy, cybersecurity, regulations, and social acceptance are major challenges in the development and deployment of autonomous vehicles.

5.1. Safety

This is not only about the safety of passengers, but also the safety of fellow vehicles, pedestrians, and other road users such as animals, etc. must be ensured. To meet this challenge, all the devices used in the development of self-driving cars, such as sensors, software, hardware, etc., are used to develop self-driving cars. Thoroughly tested and validated. The logs must be collected and subjected to periodic auditing and assessment. Also, make sure these are certified by some government agency at every stage of development.

5.2. Accountability

Who did what? This is a major problem that arises in accidents involving autonomous vehicles. It could be due to a software or hardware failure or due to a driver error or victim error not taking timely action.

5.3. Privacy

It is important to safeguard the privacy of passengers and other road users. It has to be monitored, what the cameras and sensors capture, and what software does with it to ensure privacy. This is another challenge when considering the deployment of autonomous vehicles in the real world.

5.4. Cyber-security

Autonomous vehicles use various IoT devices to transfer data between endpoints for processing and analysis to ensure a seamless travel experience. It is possible for hackers to crack and destroy data. It is one of the major challenges for vehicle developers to safeguard the vehicle's software and hardware from cyber-attacks using advanced tools and technologies (Y. S. Pawar, 2022).

5.5. Regulations

Governments have proposed various rules and regulatory constraints to ensure the safe and successful deployment of autonomous vehicles on the road. The regulation includes security measures such as cybersecurity and data privacy measures. It is important to ensure that vehicle developers follow the rules and regulations during the development process.

5.6. Acceptance of new technology by the society

AI-powered, self-driving cars are new to consumers, and it will take time for them to get used to it. Consumer concerns must be brought to the fore and clarified with evidence so they can keep up with new technological advances. Societal acceptance is one of the main challenges for new developments in the field of autonomous vehicles.

Overall, this is something that companies developing self-driving cars, government authorities and society work together to solve and make sure self-driving cars are safe and secure for everyone.

6. Ethical and societal implications

The adoption of self-driving cars may raise some ethical and social implications in society. Its main impacts are in job sector, motorized accessibility for the elderly and disabled, and the potential for discrimination in society that leads to social segregation. The direct impact on human drivers working in logistics and transportation in the labor sector can lead to unemployment and economic imbalances. It may exacerbate the inequality and discrimination in society. However, self-driving cars have the ability increase the accessibility of people who can't drive due to various problems like elderly people or handicapped. Self-driving cars rely on various complex algorithms to make decisions. There is a chance of biasing these algorithms due to various reasons like gender, race, etc. Furthermore, humans have higher reflexive responses than machines in quick decision-making situations such as accidents and emergencies. It is a big challenge to make self-driving cars to acquire such human intelligence (Holstein, 2018).

7. Potential future developments

The industry is doing more and more research and development to improve the performance and efficiency of self-driving vehicles. Research is ongoing to explore new and complex ways of deploying autonomous vehicles. For example, fields such as urban planning, traffic management, and transportation infrastructure design and development share few common application areas. In addition, they can also be deployed in wars, natural disaster areas, places where human invasion is almost impossible, such as narrow deep-hole mining areas, deep-sea underwater exploration, and extraterrestrial object research, etc.

The Advanced sensor and perception system integration provides a more accurate view of the vehicle's navigation path during transit. Advances in this field will help vehicles better understand and respond to their surroundings. Self-driving cars use highly sophisticated algorithms to make decisions. Improved decision-making systems will enhance the ability of self-driving cars to make more accurate decisions faster and more accurately. Currently, in some cases, human intervention is unavoidable. Advanced automation technology integration will alleviate the need for human intervention in some cases. With advanced automation, this can improve over time, and fully autonomous vehicles may soon be a reality.

Growth of cellular network technology helps self-driving cars to be connected faster in the network and that will indirectly help them to connected to more and more IOT devices. This will help to share information among other vehicles and coordinate their movements. Advances in cellular technology will help self-driving cars connect faster in the network, which will indirectly help them connect to the growing number of IoT devices. Autonomous vehicles have the potential to combine with public transportation such as buses and trains to improve traffic efficiency. Faster network connections help self-driving cars share information among other vehicles and coordinate their movements. Compared with terrain self-driving vehicles, self-driving flying cars can be used for emergency evacuation and rapid movement of goods and people. This contributes to the development of urban air mobility (Kersten Heineke, 2021).

Conclusion

In conclusion, the field of development of self-driving cars is very promising. It is rapidly evolving and many companies, research institutes and governments are putting enormous efforts in the growth of the autonomous vehicle industry. Numerous advancements are happening in the field of autonomous vehicles which include increasing use of sensors and advanced technologies like Machine Learning and Artificial intelligence. At the same time, infrastructure development and cellular technology advancements also exasperate the autonomous vehicle's optimistic growth. Governments and industry groups are also working to develop regulatory measures and safety standards. Despite some challenges and hurdles, which need to be overcome, the future of the self-driving vehicle is promising. It is anticipated that autonomous vehicles will benefit society in many ways, including safety, efficiency, and convenience.

Bibliography

Bailey, H. D.-W. (2006). Simultaneous localization and mapping: part I. *IEEE Robotics & Automation Magazine*.

De Jong Yeong, G. V.-H. (18 March 2021). *Sensor and Sensor Fusion Technology in Autonomous Vehicles:.* MDPI.

E. DiGiampaolo, F. M. (2022). *A Localization System for Autonomous Vehicles Based on TriLateration Tags.* 16th European Conference on Antennas and Propagation (EuCAP), Madrid, Spain: IEEE. Retrieved from IEEE Xplore: https://ieeexplore.ieee.org/document/9768963

Holstein, T. &. (2018). Ethical and Social Aspects of Self-Driving Cars.

Kersten Heineke, R. H. (2021, December 22). *What's next for autonomous vehicles?* Retrieved from McKinsey & Company: https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/whats-next-for-autonomous-vehicles

Maneewarn, R. J. (2008). Neural networks terrain classification using Inertial Measurement Unit for an autonomous vehicle. *ieeexplore*.

P. S. Kholiya, A. K. (2021). Intelligent Process Automation: The Future of Digital Transformation. *10th International Conference on System Modeling & Advancement in Research Trends (SMART).* IEEE Xplore .

S. Perla, N. N. (2022). Implementation of Autonomous Cars using Machine Learning. *International Conference on Edge Computing and Applications(ICECAA).* Tamilnadu: IEEE Xplore.

Sara LAHDYA, T. M. (2022). DATA SECURITY CHALLENGES IN SELF-DRIVING CAR. *DATA SECURITY CHALLENGES IN SELF-DRIVING CAR*.

V. Maglogiannis, D. N.-B. (2022). Experimental V2X Evaluation for C-V2X and ITS-G5 Technologies in a Real-Life Highway Environment. *IEEE Transactions on Network and Service Management*.

Y. S. Pawar, P. H. (2022). Cyber Attack Detection On Self-Driving Cars Using Machine Learning Techniques. *2022 IEEE 3rd Global Conference for Advancement in Technology (GCAT).* Bangalore: IEEE.

Y. Wang, W. S. (2022). Simultaneous Localization of Rail Vehicles and Mapping of Environment With Multiple LiDARs. *IEEE Robotics and Automation*.