Fusion of Multidisciplinary Research, An International Journal (FMR) , Vol.**1**, Iss.**2**, 2020

FMR

ARTICLE

Autonomous Vehicles and Robust Decision-Making in Dynamic Environments

Henry H. James, Razu Pawel, Gawin Saduf*

School of Engineering and Mathematical Sciences, La Trobe University, Bundoora, Victoria 3086, Australia

*Corresponding author: gawinsadu@latrobe.edu.au

(Received: 19 March 2020; Revised: 25 May 2020; Accepted: 18 July 2020; Published: 09 August 2020)

Abstract

Autonomous vehicles (AVs) are at the forefront of transforming transportation, requiring robust decision-making capabilities to navigate dynamic environments effectively. These vehicles rely on advanced sensors, machine learning algorithms, and real-time data processing to make split-second decisions that ensure safety and efficiency. Key challenges include accurately perceiving the environment, predicting the behavior of other road users, and responding to unpredictable conditions such as changing weather, road obstacles, and traffic patterns. Robust decision-making in AVs integrates various technologies, including computer vision, sensor fusion, and deep learning, to create comprehensive situational awareness. Decision-making frameworks, such as reinforcement learning and probabilistic modeling, enable AVs to evaluate multiple scenarios and select optimal actions under uncertainty. Additionally, the development of vehicle-to-everything (V2X) communication enhances situational awareness by allowing AVs to exchange information with infrastructure and other vehicles. Ensuring the reliability and safety of AVs in dynamic environments requires rigorous testing, validation, and continuous improvement of decision-making algorithms. Ethical considerations, regulatory frameworks, and public acceptance also play crucial roles in the widespread adoption of autonomous vehicles. This abstract highlights the technological and methodological advancements in robust decision-making for AVs, emphasizing their potential to revolutionize transportation by enhancing safety, reducing congestion, and improving mobility in dynamic and complex environments.

Keywords: Autonomous Vehicles; Decision-Making; Dynamic Environments; Machine Learning; Sensor Fusion; V2X Communication

Abbreviations: AV: Autonomous vehicle, AI: Artificial intelligence, GPS: Global Positioning System

1. Introduction

Autonomous vehicles (AVs) represent a significant advancement in transportation technology, with the potential to transform how people and goods move from one place to another. Unlike traditional vehicles, AVs are equipped with advanced sensors, artificial intelligence (AI) algorithms, and decision-making systems that enable them to navigate roads and interact with the environment without human intervention. However, deploying AVs in dynamic environments, such as busy city streets or unpredictable weather conditions, presents unique challenges that must be addressed to ensure the safety and reliability of these vehicles. Robust decision-making is essential to navigate these complex environments effectively and make split-second decisions that prioritize safety and efficiency (Fig. 1) [1, 2].

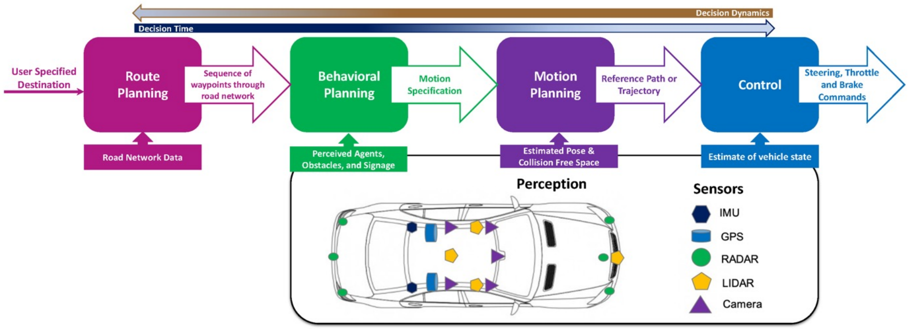

Figure 1. Software Architecture of Autonomous Vehicle.

Autonomous vehicles (AVs) are poised to revolutionize the transportation landscape, offering a glimpse into a future where mobility is safer, more efficient, and accessible to all. With advancements in sensor technology, artificial intelligence, and computing power, AVs have the potential to navigate roads and interact with their surroundings without human intervention. However, deploying AVs in dynamic environments introduces a myriad of challenges that must be addressed to ensure their safe and reliable operation [3]. Dynamic environments, characterized by unpredictable weather conditions, changing traffic patterns, and unexpected obstacles, pose significant hurdles for AV technology. In such settings, robust decision-making becomes paramount, as AVs must make split-second decisions to navigate complex scenarios while prioritizing safety and efficiency. This necessitates sophisticated algorithms capable of adapting to rapidly changing conditions and making informed decisions in real-time [4].

The intersection of AV technology and robust decision-making in dynamic environments represents a critical frontier in transportation research. Understanding the challenges inherent in dynamic environments and developing effective strategies to overcome them are essential steps towards realizing the full potential of AV technology. This requires interdisciplinary collaboration between experts in fields such as computer science, engineering, psychology, and public policy to address the multifaceted challenges posed by AV deployment [5]. In this article, we delve into the complex landscape of autonomous vehicles and robust decision-making in dynamic environments. We examine the key challenges faced by AVs in dynamic settings, explore current approaches to addressing these challenges, and discuss future directions for research and innovation. By shedding light on the intricacies of AV technology and decision-making in dynamic environments, we aim to provide insights into the ongoing efforts to revolutionize transportation and shape the future of mobility [6].

2. Evolution of Autonomous Vehicles

The development of AV technology has evolved rapidly over the past few decades, from early experiments and prototypes to the deployment of semi-autonomous and fully autonomous vehicles on public roads. Key milestones, breakthroughs, and current state of deployment and adoption of AV technology are discussed, highlighting the progress made in sensor technology, AI algorithms, and vehicle automation (Fig. 2).

The evolution of autonomous vehicles (AVs) represents a significant milestone in transportation technology, marking a paradigm shift towards safer, more efficient, and convenient mobility solutions. From early experiments to today's sophisticated prototypes, AV technology has undergone rapid development, driven by advancements in sensing, artificial intelligence (AI), and robotics. As AVs become increasingly capable of navigating roads and interacting with their surroundings with-

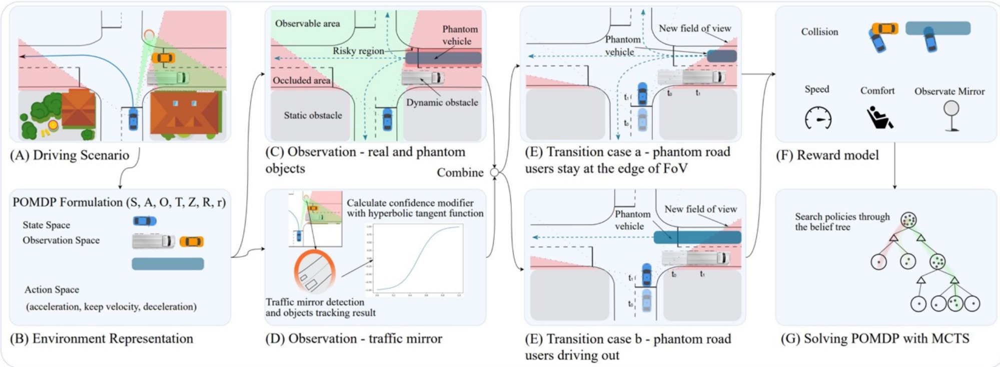

Figure 2. A framework of traffic mirror-aware POMDP behavior planner.

out human intervention, the need for robust decision-making in dynamic environments becomes more pressing [6, 7].

The evolution of AV technology can be traced back to the pioneering work of researchers and engineers who laid the groundwork for autonomous navigation. Early experiments in robotics and AI paved the way for the development of self-driving vehicles capable of perceiving their environment and making decisions based on real-time data. Key milestones, such as the DARPA Grand Challenges and the introduction of semi-autonomous features in commercial vehicles, have played a crucial role in advancing AV technology and accelerating its adoption [8].

However, deploying AVs in dynamic environments presents unique challenges that must be addressed to ensure their safe and reliable operation. Dynamic environments, characterized by unpredictable weather conditions, changing traffic patterns, and unexpected obstacles, require AVs to make split-second decisions while prioritizing safety and efficiency. Robust decision-making algorithms capable of adapting to rapidly changing conditions are essential to navigate these complex scenarios effectively. We explore the evolution of autonomous vehicles and the role of robust decision-making in dynamic environments. We examine the key milestones and breakthroughs that have shaped AV technology, discuss the challenges posed by dynamic environments, and explore current approaches to addressing these challenges. By shedding light on the evolution of AV technology and its intersection with robust decision-making, we aim to provide insights into the ongoing efforts to revolutionize transportation and shape the future of mobility [8, 9, 10].

2.1 Challenges in Dynamic Environments

Dynamic environments present a myriad of challenges for AVs, including unpredictable traffic patterns, changing road conditions, and unexpected obstacles. This section explores the various challenges encountered in dynamic environments and the implications for AV technology. Factors such as weather conditions, pedestrian and cyclist behavior, and road construction can significantly impact AV performance and require robust decision-making capabilities to navigate safely and efficiently (Fig. 3).

Deploying autonomous vehicles (AVs) in dynamic environments presents a multitude of challenges that must be overcome to ensure safe and reliable operation. Dynamic environments are characterized by constantly changing conditions, such as varying weather patterns, unpredictable road conditions, and the presence of pedestrians, cyclists, and other vehicles. These factors introduce complexities that can pose significant hurdles for AV technology and require robust decision-making capabilities to navigate effectively.

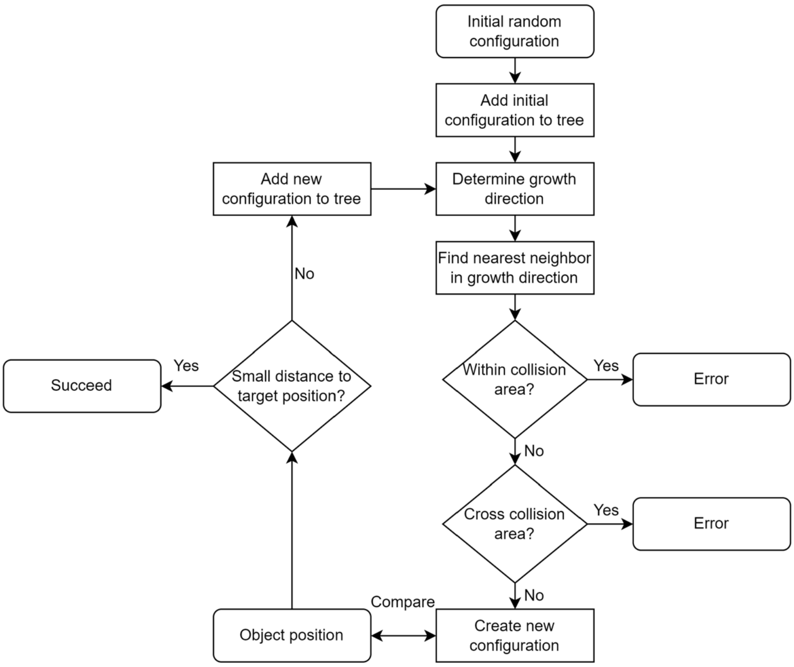

Figure 3. Flowchart of the RRT algorithm

One of the primary challenges in dynamic environments is the unpredictability of external factors. AVs must be able to adapt to rapidly changing conditions, such as sudden changes in weather, road closures, or unexpected obstacles. This requires real-time processing of sensor data and the ability to make split-second decisions to ensure the safety of passengers and other road users [6].

Another challenge is the variability of road conditions and infrastructure. Dynamic environments may include a wide range of road types, from urban streets to rural highways, each with its own set of challenges and hazards. AVs must be capable of navigating these diverse environments while adhering to traffic laws and regulations, as well as local customs and norms [9, 10, 11]. Furthermore, the presence of other road users, such as pedestrians, cyclists, and manual drivers, adds an additional layer of complexity. AVs must be able to detect and respond to the behavior of these road users in real-time, anticipating their movements and adjusting their own behavior accordingly to avoid collisions and ensure safe interactions [12, 13].

Addressing these challenges requires the development of robust decision-making algorithms that can adapt to changing conditions and prioritize safety in dynamic environments. By leveraging advances in sensing, perception, and AI, AVs can navigate complex scenarios effectively and pave the way for safer and more efficient transportation systems.

3. Sensing and Perception

Sensing and perception are fundamental components of AV technology, enabling vehicles to perceive and interpret their surroundings. AVs rely on a variety of sensors, including LiDAR, radar, cameras, and GPS, to detect and track objects, identify road signs and markings, and navigate the environment. This section discusses the role of sensing and perception in AV technology and the challenges associated with sensor limitations, environmental variability, and perception errors.

Sensing and perception are fundamental components of autonomous vehicles (AVs), enabling them to perceive and interpret their surroundings in dynamic environments. AVs rely on a variety of sensors, including LiDAR, radar, cameras, and GPS, to detect and track objects, identify road signs and markings, and navigate the environment. These sensors provide the necessary input for AV decision-making algorithms to make informed decisions in real-time.

LiDAR (Light Detection and Ranging) sensors emit laser pulses and measure the time it takes for the pulses to bounce back from surrounding objects, creating a three-dimensional map of the environment. LiDAR sensors are particularly effective for detecting objects at long ranges and in low-light conditions, making them essential for AVs operating in dynamic environments. Radar sensors use radio waves to detect the distance, speed, and direction of objects in the vehicle's vicinity. Radar sensors are especially useful for detecting moving objects, such as vehicles and pedestrians, and can penetrate through fog, rain, and other adverse weather conditions [11, 12].

Cameras capture visual information from the surrounding environment, providing high-resolution images that allow AVs to recognize objects, interpret road signs, and detect lane markings. Cameras are essential for tasks such as object detection, traffic sign recognition, and pedestrian detection, but they may be susceptible to poor lighting conditions and occlusions. GPS (Global Positioning System) provides precise location information, allowing AVs to determine their position relative to the surrounding environment. GPS is used for navigation and localization, enabling AVs to follow predetermined routes and maintain accurate positioning in dynamic environments [13, 14].

However, sensing and perception in dynamic environments pose several challenges for AV technology. Sensor limitations, environmental variability, and perception errors can impact the reliability and accuracy of sensor data, leading to potential safety hazards. Addressing these challenges requires the development of robust sensing and perception systems that can adapt to changing conditions and ensure the safety and reliability of AVs in dynamic environments [15].

3.1 Localization and Mapping

Accurate localization and mapping are essential for AVs to navigate effectively in dynamic environments. This section explores techniques for vehicle localization, high-definition mapping algorithms, and the integration of localization and mapping with decision-making processes. Challenges such as GPS inaccuracies, map inconsistencies, and dynamic changes in the environment are discussed, along with potential solutions to address these challenges.

3.2 Path Planning and Trajectory Optimization

Path planning and trajectory optimization are critical components of AV decision-making, determining the optimal route for vehicles to reach their destination while avoiding obstacles and adhering to traffic rules. This section explores various path planning algorithms and trajectory optimization techniques used in AV technology, including probabilistic roadmaps, potential field methods, and model predictive control. Challenges such as real-time computation, dynamic traffic conditions, and uncertain environmental factors are discussed, along with strategies to improve path planning and trajectory optimization in dynamic environments.

4. Decision-Making Algorithms

Decision-making algorithms play a central role in AV technology, enabling vehicles to make real-time decisions based on sensor data, localization information, and mapping data. This section explores different decision-making frameworks, including rule-based systems, machine learning approaches, and hybrid models. Challenges such as uncertainty, ambiguity, and conflicting objectives are discussed, along with strategies to improve decision-making algorithms for robust performance in dynamic environments [15, 16].

In the realm of autonomous vehicles (AVs), decision-making algorithms play a pivotal role in navigating dynamic environments safely and efficiently. These algorithms are responsible for processing sensor data, interpreting the surrounding environment, and making real-time decisions to control the vehicle's actions. In dynamic environments where conditions can change rapidly, robust decision-making algorithms are essential to ensure the safety of passengers and other road users while optimizing the vehicle's performance.

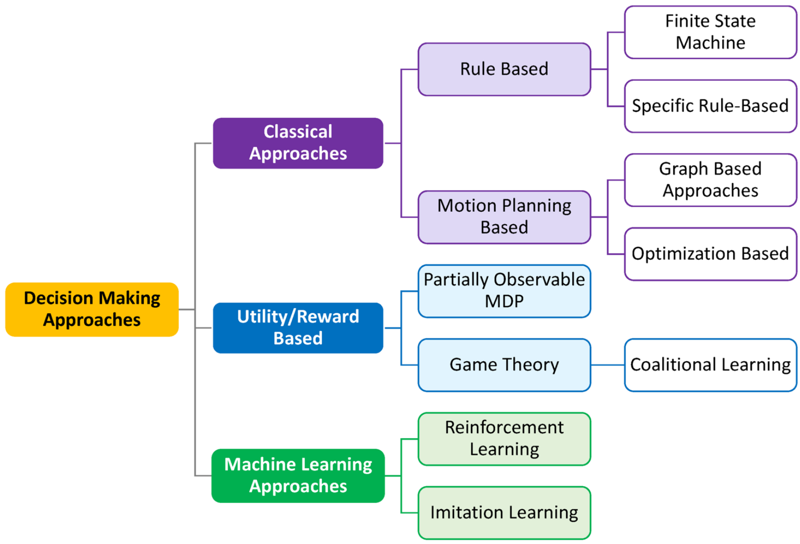

Figure 4. Categorization of Decision-Making Approaches for Autonomous Vehicles

There are several types of decision-making algorithms used in AVs, each with its own strengths and limitations. Rule-based systems rely on predefined sets of rules and heuristics to guide the vehicle's behavior in different situations. While rule-based systems are relatively simple and easy to understand, they may struggle to adapt to complex and unpredictable scenarios (Fig. 4).

Machine learning approaches, such as neural networks and deep learning, have gained popularity in recent years for their ability to learn from data and improve decision-making performance over time. These algorithms can analyze large volumes of sensor data and learn complex patterns and relationships, enabling AVs to make more informed decisions in dynamic environments. However, machine learning algorithms require extensive training data and may be susceptible to biases and errors.

Hybrid models combine the strengths of rule-based systems and machine learning approaches to achieve robust decision-making in dynamic environments. By integrating domain knowledge with data-driven insights, hybrid models can leverage the advantages of both approaches while mitigating their respective weaknesses. These models can adapt to changing conditions, learn from experience, and make informed decisions in real-time.

Despite the advancements in decision-making algorithms, challenges remain in ensuring their reliability and safety in dynamic environments. Uncertainty, ambiguity, and conflicting objectives are inherent in real-world scenarios, requiring sophisticated algorithms capable of handling complex decision-making tasks. Addressing these challenges requires continued research and innovation to develop more robust and adaptive decision-making algorithms that can navigate the complexities of dynamic environments effectively. By leveraging advances in AI, machine learning, and optimization techniques, AVs can achieve safer and more efficient operation in dynamic environments, paving the way for the widespread adoption of autonomous mobility solutions.

4.1 Safety and Risk Management

Ensuring the safety of AVs and their occupants is paramount, particularly in dynamic environments where unexpected hazards and risks may arise. This section discusses strategies for safety and risk management in AV technology, including fail-safe mechanisms, emergency response protocols, and risk assessment techniques. Challenges such as legal and ethical considerations, liability issues, and public perception are discussed, along with potential solutions to mitigate safety risks and enhance public trust in AV technology. Ensuring the safety of passengers, pedestrians, and other road users is paramount in the development and deployment of autonomous vehicles (AVs) in dynamic environments. AV technology introduces new safety considerations and challenges that must be addressed to mitigate risks and ensure the reliability of autonomous mobility solutions [16].

Safety and risk management strategies in AV technology encompass various aspects, including fail-safe mechanisms, emergency response protocols, and risk assessment techniques. These strategies aim to identify potential hazards, prevent accidents, and minimize the consequences of unforeseen events in dynamic environments. One key aspect of safety and risk management is the implementation of fail-safe mechanisms that allow AVs to react appropriately in the event of system failures or unexpected events. Fail-safe mechanisms include redundant sensors, backup systems, and emergency braking capabilities, which can help mitigate the impact of technical failures and ensure the safety of passengers and other road users [17].

Emergency response protocols are another critical component of safety and risk management in AV technology. These protocols outline procedures for handling emergency situations, such as accidents, malfunctions, or adverse weather conditions. AVs must be equipped with systems that enable them to communicate with emergency services, alert passengers to potential hazards, and take appropriate action to mitigate risks. Risk assessment techniques are essential for identifying and mitigating potential hazards and risks associated with AV operations in dynamic environments. These techniques involve analyzing data from sensor inputs, traffic patterns, and environmental conditions to identify potential safety hazards and assess their likelihood and severity. By understanding and quantifying risks, AV developers can implement targeted safety measures and design robust decision-making algorithms that prioritize safety in dynamic environments [18].

Overall, safety and risk management is a critical aspect of AV technology that requires a comprehensive approach to ensure the safety and reliability of autonomous mobility solutions in dynamic environments. By implementing fail-safe mechanisms, emergency response protocols, and risk assessment techniques, AV developers can mitigate risks and build trust in the safety of autonomous vehicles, paving the way for widespread adoption and integration into the transportation system.

5. Human-AV Interaction

Human-AV interaction is an important aspect of AV technology, influencing user acceptance, trust, and adoption. This section explores design principles for human-AV interfaces, communication systems, and interaction protocols. Factors such as user trust, transparency, and accountability are discussed, along with strategies to improve human-AV interaction and enhance user experience in dynamic environments (Fig. 5).

As autonomous vehicles (AVs) become increasingly prevalent in dynamic environments, the interac-

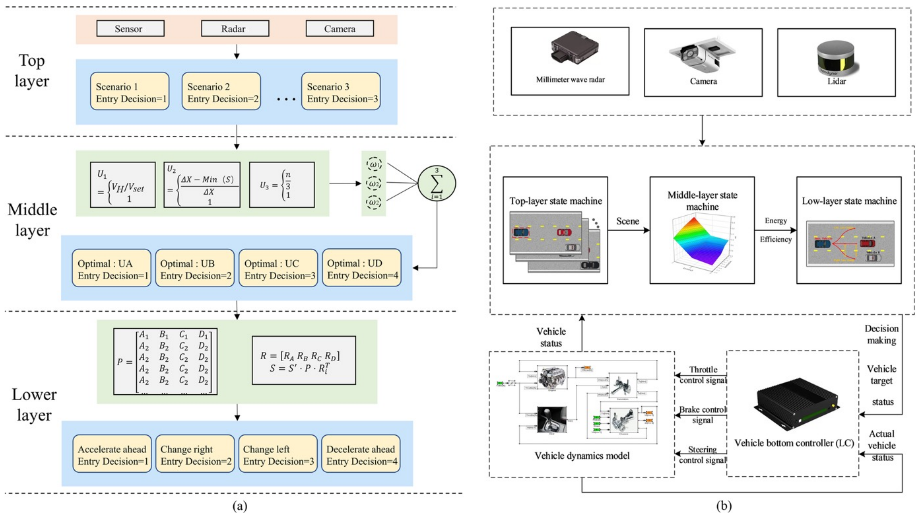

Figure 5. Schematic diagram of the simulation establishment

tion between humans and AVs becomes a critical aspect of their successful deployment. Human-AV interaction encompasses the design of user interfaces, communication systems, and interaction protocols that facilitate seamless collaboration between humans and AVs in various scenarios.

One key consideration in human-AV interaction is designing intuitive and user-friendly interfaces that allow passengers to interact with AVs effectively. User interfaces should provide clear feedback on the vehicle's status, route, and upcoming actions, enabling passengers to understand and trust the AV's decision-making process. Visual displays, voice commands, and tactile feedback can enhance the user experience and build confidence in AV technology [18]. Communication systems play a crucial role in facilitating communication between AVs and other road users, such as pedestrians, cyclists, and manual drivers. AVs must be able to communicate their intentions, such as stopping, yielding, or changing lanes, to ensure safe interactions with other road users. Communication protocols, such as standardized signaling methods and auditory cues, can help establish clear communication channels and reduce the likelihood of misunderstandings or accidents [19].

Trust, transparency, and accountability are essential considerations in human-AV interaction, as they influence user acceptance and adoption of AV technology. AVs must demonstrate reliability, predictability, and adherence to ethical principles to earn the trust of passengers and other road users. Transparency about AV capabilities, limitations, and decision-making processes is crucial for building trust and ensuring informed decision-making by passengers and stakeholders. Ethical considerations, such as the allocation of responsibility in the event of accidents or emergencies, also play a role in human-AV interaction. AVs must be programmed to prioritize the safety of passengers and other road users while adhering to legal and ethical principles. Clear guidelines and protocols for handling ethical dilemmas and unforeseen events can help ensure that AVs make responsible decisions in dynamic environments [20].

5.1 Real-World Applications and Case Studies

Real-world applications of AV technology in dynamic environments are explored, including urban and suburban settings, highway driving, and off-road navigation. Case studies highlight successful deployment of AV technology and lessons learned from real-world scenarios. Examples of AVs navigating through congested traffic, adverse weather conditions, and complex road infrastructure are presented, showcasing the capabilities and challenges of AV technology in dynamic environments.

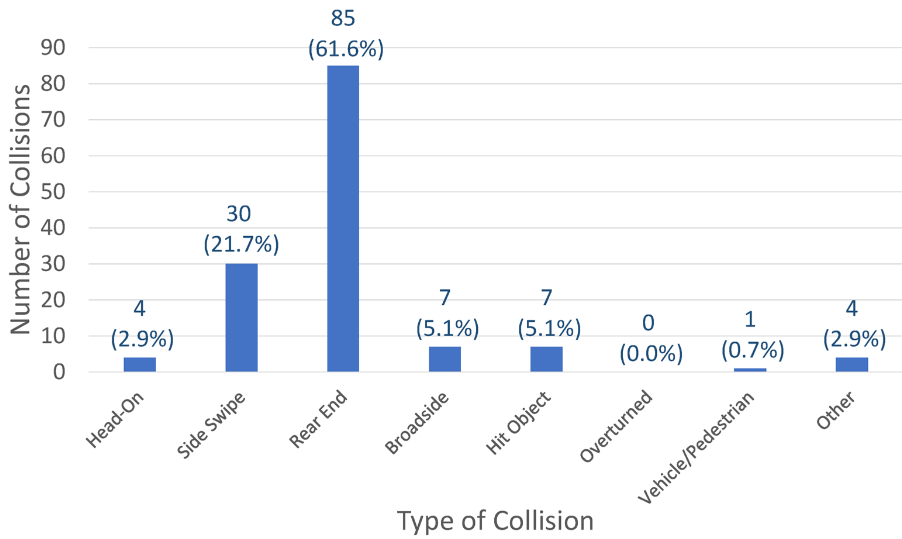

Figure 6. Schematic diagram of the simulation establishment

The deployment of autonomous vehicles (AVs) in real-world settings has provided valuable insights into their capabilities, limitations, and challenges in dynamic environments. From urban streets to suburban neighborhoods and highway driving, AVs have been tested and deployed in a variety of scenarios, showcasing their potential to revolutionize transportation and mobility (Fig. 6).

In urban environments, AVs have been used for ride-hailing services, public transportation, and last-mile delivery, offering convenient and efficient mobility options for residents and visitors. Case studies in cities such as San Francisco, Singapore, and Tokyo have demonstrated the feasibility of AV technology in navigating dense urban traffic, interacting with pedestrians and cyclists, and adapting to complex road infrastructure. Suburban and rural environments present different challenges for AV deployment, including longer travel distances, less predictable traffic patterns, and narrower roads. Case studies in suburban areas have focused on AVs' ability to navigate residential neighborhoods, handle varying road conditions, and interact with other road users. Similarly, AVs have been tested on rural highways and country roads, demonstrating their capabilities for long-distance travel and highway driving.

Highway driving represents a significant application of AV technology, with potential benefits in terms of safety, efficiency, and congestion reduction. Case studies of AVs on highways have focused on their ability to maintain safe following distances, merge into traffic, and navigate complex highway interchanges. These studies have highlighted the potential for AVs to improve traffic flow, reduce accidents, and enhance the overall driving experience on highways. Off-road navigation presents another frontier for AV technology, with applications in agriculture, mining, and exploration. Case studies of AVs in off-road environments have explored their ability to navigate rugged terrain, avoid obstacles, and perform tasks such as crop monitoring and exploration. These studies have demonstrated the potential for AV technology to revolutionize industries that rely on off-road vehicles for transportation and operations [21].

Overall, real-world applications and case studies of AV technology provide valuable insights into its capabilities, limitations, and challenges in dynamic environments. By testing AVs in diverse scenarios and environments, researchers and developers can identify areas for improvement, refine decision-making algorithms, and accelerate the transition to autonomous mobility solutions [22].

6. Future Directions and Research Challenges

Emerging technologies, trends, and research priorities shaping the future of AV technology are discussed. Collaborative efforts and interdisciplinary approaches are highlighted as key strategies to address complex challenges and unlock the full potential of autonomous mobility. Future directions for AV technology, including advancements in sensing and perception, decision-making algorithms, and human-AV interaction, are explored, along with research challenges and opportunities for innovation.

As autonomous vehicles (AVs) continue to evolve, there are several key areas for future research and development to address in order to enhance their capabilities and enable robust decision-making in dynamic environments. One of the key challenges is improving the reliability and accuracy of sensing and perception systems, which are essential for AVs to perceive and interpret their surroundings accurately in real-time. This includes developing advanced sensor fusion techniques, enhancing sensor resolution and range, and mitigating the effects of sensor noise and uncertainty.

Another area of research is advancing decision-making algorithms to handle complex and unpredictable scenarios more effectively. This involves developing algorithms that can adapt to changing conditions, anticipate potential hazards, and prioritize safety while optimizing for efficiency. Machine learning techniques, reinforcement learning, and probabilistic modeling are promising approaches for improving decision-making in dynamic environments.

Additionally, addressing the social and ethical implications of AV technology is an important research challenge. This includes understanding public perception and acceptance of AVs, addressing concerns about privacy and security, and developing ethical frameworks for AV decision-making. Collaborative efforts between researchers, policymakers, and industry stakeholders are needed to address these challenges and ensure the safe and responsible deployment of AV technology in dynamic environments.

7. Conclusion

Autonomous vehicles have the potential to revolutionize transportation by offering safer, more efficient, and convenient mobility solutions. However, deploying AVs in dynamic environments presents unique challenges that require robust decision-making capabilities to ensure safety and reliability. By leveraging advances in sensing, perception, localization, and decision-making algorithms, AVs can navigate dynamic environments effectively and accelerate the transition to autonomous mobility. Continued research, innovation, and collaboration are essential to overcome remaining challenges and unlock the full potential of AV technology in dynamic environments. Autonomous vehicles have the potential to revolutionize transportation by offering safer, more efficient, and convenient mobility solutions. However, deploying AVs in dynamic environments presents unique challenges that require robust decision-making capabilities to ensure safety and reliability. By leveraging advances in sensing, perception, localization, and decision-making algorithms, AVs can navigate dynamic environments effectively and accelerate the transition to autonomous mobility. Continued research, innovation, and collaboration are essential to overcome remaining challenges and unlock the full potential of AV technology in dynamic environments.

References

[1] Mark Campbell, Magnus Egerstedt, Jonathan P How, and Richard M Murray. “Autonomous driving in urban environments: approaches, lessons and challenges”. In: *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 368.1928 (2010), pp. 4649–4672.

[2] Amir Mirheli, Leila Hajibabai, and Ali Hajbabaie. “Development of a signal-head-free intersection control logic in a fully connected and autonomous vehicle environment”. In: *Transportation Research Part C: Emerging Technologies* 92 (2018), pp. 412–425.

[3] Alireza Talebpour and Hani S Mahmassani. “Influence of connected and autonomous vehicles on traffic flow stability and throughput”. In: *Transportation research part C: emerging technologies* 71 (2016), pp. 143–163.

[4] Wilko Schwarting, Alyssa Pierson, Javier Alonso-Mora, Sertac Karaman, and Daniela Rus. “Social behavior for autonomous vehicles”. In: *Proceedings of the National Academy of Sciences* 116.50 (2019), pp. 24972–24978.

[5] Yonggang Liu, Xiao Wang, Liang Li, Shuo Cheng, and Zheng Chen. “A novel lane change decision-making model of autonomous vehicle based on support vector machine”. In: *IEEE access* 7 (2019), pp. 26543–26550.

[6] Zhihua Qu. *Cooperative control of dynamical systems: applications to autonomous vehicles.* Springer Science & Business Media, 2009.

[7] Emilio Frazzoli, Munther A Dahleh, and Eric Feron. “Robust hybrid control for autonomous vehicle motion planning”. In: *Proceedings of the 39th IEEE Conference on Decision and Control (Cat. No. 00CH37187).* Vol. 1. IEEE. 2000, pp. 821–826.

[8] Sebastian Brechtel, Tobias Gindele, and Rüdiger Dillmann. “Probabilistic decision-making under uncertainty for autonomous driving using continuous POMDPs”. In: *17th international IEEE conference on intelligent transportation systems (ITSC).* IEEE. 2014, pp. 392–399.

[9] Wilko Schwarting, Javier Alonso-Mora, and Daniela Rus. “Planning and decision-making for autonomous vehicles”. In: *Annual Review of Control, Robotics, and Autonomous Systems* 1 (2018), pp. 187–210.

[10] Alexander G Cunningham, Enric Galceran, Ryan M Eustice, and Edwin Olson. “MPDM: Multipolicy decision-making in dynamic, uncertain environments for autonomous driving”. In: *2015 IEEE International Conference on Robotics and Automation (ICRA).* IEEE. 2015, pp. 1670–1677.

[11] Amir Rasouli and John K Tsotsos. “Autonomous vehicles that interact with pedestrians: A survey of theory and practice”. In: *IEEE transactions on intelligent transportation systems* 21.3 (2019), pp. 900–918.

[12] Jesse Levinson and Sebastian Thrun. “Robust vehicle localization in urban environments using probabilistic maps”. In: *2010 IEEE international conference on robotics and automation.* IEEE. 2010, pp. 4372–4378.

[13] Philip Koopman and Michael Wagner. “Autonomous vehicle safety: An interdisciplinary challenge”. In: *IEEE Intelligent Transportation Systems Magazine* 9.1 (2017), pp. 90–96.

[14] David Isele, Reza Rahimi, Akansel Cosgun, Kaushik Subramanian, and Kikuo Fujimura. “Navigating occluded intersections with autonomous vehicles using deep reinforcement learning”. In: *2018 IEEE international conference on robotics and automation (ICRA).* IEEE. 2018, pp. 2034–2039.

[15] John Fox, Richard P Cooper, and David W Glasspool. “A canonical theory of dynamic decision-making”. In: *Frontiers in psychology* 4 (2013), p. 150.

[16] Mykel J Kochenderfer. *Decision making under uncertainty: theory and application.* MIT press, 2015.

[17] Mark Pfeiffer, Michael Schaeuble, Juan Nieto, Roland Siegwart, and Cesar Cadena. “From perception to decision: A data-driven approach to end-to-end motion planning for autonomous ground robots”. In: *2017 ieee international conference on robotics and automation (icra)*. IEEE. 2017, pp. 1527–1533.

[18] Shai Shalev-Shwartz, Shaked Shammah, and Amnon Shashua. “Safe, multi-agent, reinforcement learning for autonomous driving”. In: *arXiv preprint arXiv:1610.03295* (2016).

[19] Laurene Claussmann, Marc Revilloud, Dominique Gruyer, and Sébastien Glaser. “A review of motion planning for highway autonomous driving”. In: *IEEE Transactions on Intelligent Transportation Systems* 21.5 (2019), pp. 1826–1848.

[20] Xuemin Hu, Long Chen, Bo Tang, Dongpu Cao, and Haibo He. “Dynamic path planning for autonomous driving on various roads with avoidance of static and moving obstacles”. In: *Mechanical systems and signal processing* 100 (2018), pp. 482–500.

[21] Haoyu Bai, Shaojun Cai, Nan Ye, David Hsu, and Wee Sun Lee. “Intention-aware online POMDP planning for autonomous driving in a crowd”. In: *2015 ieee international conference on robotics and automation (icra)*. IEEE. 2015, pp. 454–460.

[22] Christos Katrakazas, Mohammed Quddus, Wen-Hua Chen, and Lipika Deka. “Real-time motion planning methods for autonomous on-road driving: State-of-the-art and future research directions”. In: *Transportation Research Part C: Emerging Technologies* 60 (2015), pp. 416–442.