Artificial Intelligence in Autonomous Vehicles.

Informative Paper.

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1. Introduction

In recent years, the Artificial Intelligence (AI) industry has developed rapidly, and is now implemented almost everywhere, from education to the exact sciences and engineering. Artificial Intelligence has become a part of modern society, with applications across almost all sectors, significantly simplifying various aspects of daily life. AI is also extensively used in the field of Autonomous Vehicles (AVs), promising to make driving both much safer and more comfortable, and as a result, reducing the number of accidents and traffic congestion. It is evident that more and more companies are giving preference to and invest in the development of Autonomous Vehicles. Consequently, a new field of Artificial Intelligence in AVs is emerging that requires detailed study to understand complex systems and hardwares involved. Artificial Intelligence technologies, such as machine learning and computer vision, which rely on a large number of different transducers, cameras and sensors, provide autonomous vehicles with nearly complete decision-making freedom, requiring virtually no external human intervention. The field of Artificial Intelligence in Autonomous Vehicles is relatively new; therefore, it is essential to understand precisely how Artificial Intelligence works, what technologies are employed to ensure safe decision-making, and what obstacles stand in the way of using AVs.

2. Overview of Autonomous Vehicles

Autonomous vehicles, or self-driving cars, are vehicles that can move and operate without human intervention. They are equipped with artificial intelligence, sensors, cameras, radars and lidars to sense the environment, make decisions and control movement [1, 2]. The idea of self-driving cars appeared back in the 1920s, but serious progress began in the 1980s with research, for example, by Navlab at Carnegie Mellon University [3]. In the 2000s, Google (now Waymo) and Tesla pioneered the idea of modern autonomous driving systems [4].

Currently, self-driving cars are displayed in ranks from 0 to 5, depending on the degree of autonomy [5]. Most new models fall on the 2 or 3 level, where partial control by the human is necessary. Fully autonomous cars (level 5) are still in development stages. Companies like Waymo, Tesla and Cruise are testing autonomous vehicles in controlled environments, but concerns over safety and regulation remain central challenges. Despite this, autonomous vehicles have enormous potential, since they would reduce the number of accidents.

3. Mechanisms of Artificial Intelligence in Autonomous Vehicles

3.1. Machine Learning

Machine learning (ML) is a fundamental technology for decision-making algorithms, and to understand precisely how AVs operate, the concept of ML should be understood. It is important to note that artificial intelligence is entirely based on machine learning systems, and consequently, Machine Learning is one of the main technologies used in AVs, and all key algorithms are built upon it. ML allows systems to record collected data in databases, enabling them to learn from experience and improve performance without explicit programming. By using algorithms such as supervised, unsupervised, and reinforcement learning, ML enables AVs to perform tasks like object detection, path planning, and decision-making [6]. For instance, convolutional neural networks (CNNs) are optimally used in image recognition, and recurrent neural networks (RNNs) are utilized to process sequential data, such as predicting vehicle paths [6]. ML models are trained on vast datasets collected from sensors, allowing AVs to learn how to handle diverse driving conditions. However, data quality, computational resource needs, and model explainability are still challenges. Despite these difficulties, ML continues to evolve in AVs, with safety and efficiency on the rise. Future research will focus on developing robust, explainable, and energy-efficient ML models to enable trustworthy deployment in real-world settings [6].

3.2. Explainable Artificial Intelligence (XAI) in Autonomous Vehicles

To understand how AI works, and AVs in general, the concept of Explainable Artificial Intelligence (XAI) is used [7]. The XAI algorithm works on a series of interconnected steps that help the vehicle, thanks to various sensors, determine its location in space, the distance to diverse hindrances, and based on this data, make decisions and perform the necessary actions. The algorithm is divided into five main stages: ‘’perception, localization, planning, control and system management’’ [7]. AVs are equipped with sensors, including LiDAR (Light Detection and Ranging) and IR (Infrared) [2]. These sensors collect data about the vehicle's surroundings, such as obstacles, pedestrians, and other vehicles. In the perception step, raw images are recorded into the system, and the AI compares this data with huge databases, thus classifying objects and generating heatmaps. For instance, if the sensor has identified an object as a human, XAI can explain by what signs and which visual features it has made such a conclusion. In the localization step, AI combines data from multiple sensors (LiDAR, radar, different cameras) to create a comprehensive representation of the environment. Furthermore, it uses Global Positioning System (GPS) to estimate the vehicle’s location and orientation [8]. Techniques like convolutional neural networks (CNNs) are commonly used for this purpose [9]. At the planning stage, the XAI generates a sequence of actions. Omeiza et al. [7] emphasize that systems such as ‘’*XAI-PLAN’’ and ‘’Refinement-based Planning (RBP)’’* are used to explain the decision-making of XAI. As an illustration, if an AV decides to change lanes, the XAI system can clarify the factors that influenced this decision. At the control stage, the system translates sophisticated graphs and other data to low-level machine commands (e.g. steering angle, brake decisions). The XAI fully controls the actions taken, guarantees their safety, and, if necessary, can explain on the basis of which factors it has taken a particular maneuver. For example, if AV slows down, the system can explain that this was due to detecting some obstacle or detecting a pedestrian crossing the road [8]. Finally, the system management step involves the collection of all information about the vehicle's actions and generates post-fact explanations of all the maneuvers performed, including which technologies and sensors were used for certain manipulations. Moreover, the system includes Human-Machine Interaction (HMI) [7] by providing explanations to the driver through various interfaces, such as in-vehicle displays. Figure 1 illustrates the key components involved in the operation of an autonomous vehicle (AV).

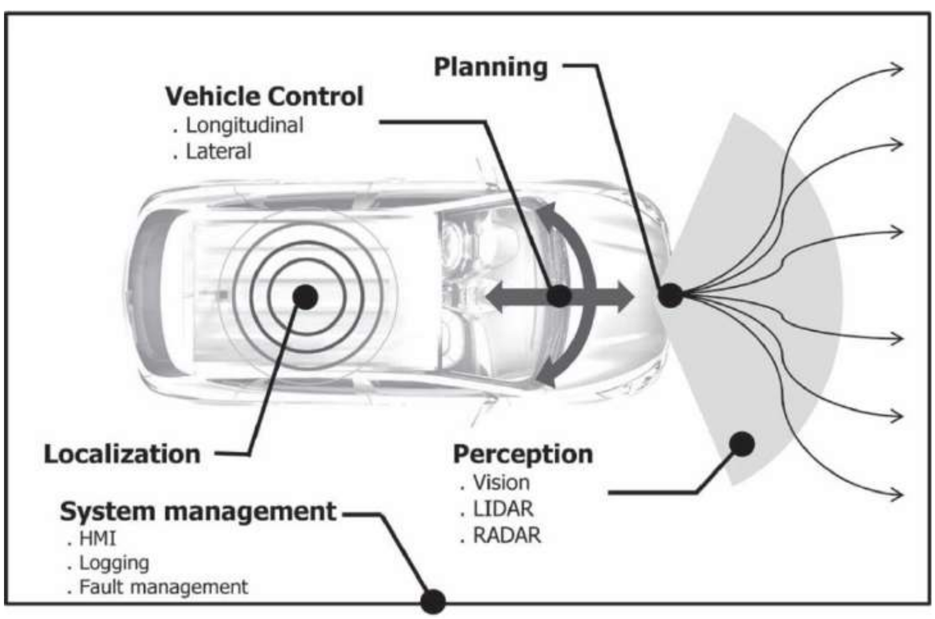

Figure 1.

3.3. Sensor Fusion

Sensor fusion is a central technology in autonomous vehicles (AVs), enabling the integration of data from miscellaneous detectors such as cameras, LiDAR, radar, and ultrasonic sensors to build a robust and reliable model of the surroundings. By taking advantages of each sensor — high-resolution cameras for images, LiDAR for depth sensing, and radar for reliable operation under adverse weather — sensor fusion enhances perception performance to make navigation more safe and decent [10]. Techniques like Kalman filters, particle filters, and deep learning-based fusion are used to improve object detection, localization, and trajectory estimation [11]. Advances in the future focus on enhancing fusion algorithms to operate real-time and scalability, paving the way for entirely autonomous systems. As sensor fusion technology improves, it will be key to making AVs more autonomous, helping them drive safely and efficiently in complex environments.

4. Benefits of Artificial Intelligence in Autonomous Vehicles

Many people have the feeling that if there is no human intervention, then something can definitely go wrong, and therefore many do not trust the work of AI in AVs. In fact, as studies show [12], in addition to the fact that autonomy makes driving both much easier and more enjoyable, it is also much safer. Referring to the Tesla report (Figure 2), which presents the number of miles driven before an accident occurred in 2023 and 2024, it is evident that cars using Autopilot, on average, traveled 5–6 times farther without accidents compared to those without it.

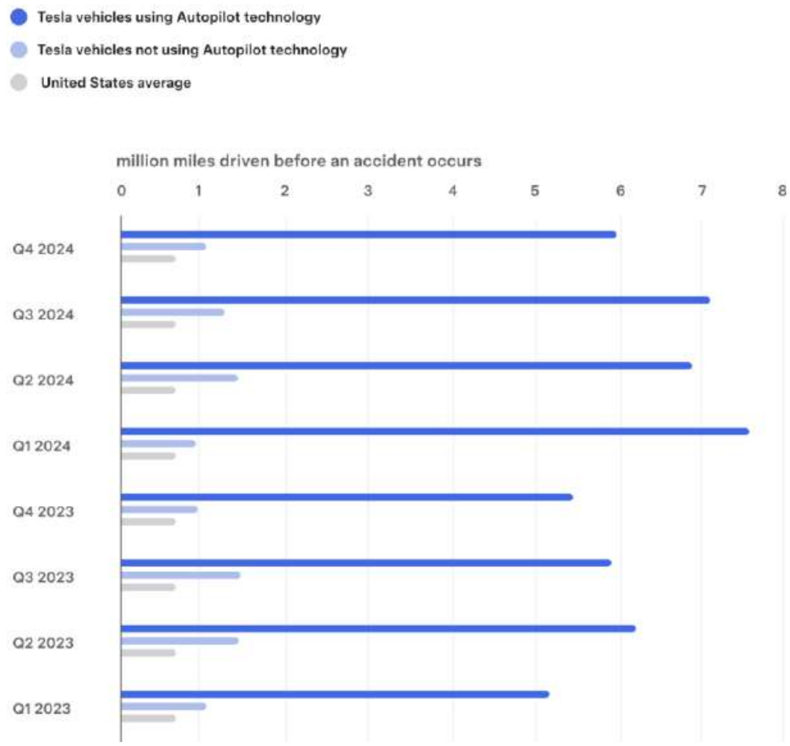

Figure 2.

5. Challenges and Limitations of AI in Autonomous Vehicles

Despite the proven safety of using autonomous vehicles in general, and artificial intelligence for their operation in particular, the integration of autonomous cars using AI faces a large number of obstacles [13].

5.1. Technical Difficulties

One of the main problems is to ensure the reliability and safety in various conditions. Although modern sensors and AI algorithms are able to work effectively under ideal conditions, they can face difficulties in adverse situations [14]:

- Harsh weather conditions: rain, snow, fog, or bright sun can degrade the quality of data received from cameras and lidars, making it difficult to recognize objects.
- Difficult traffic situations: the unpredictable behavior of pedestrians, animals, or other drivers can put AI in a dead end, especially if such situations were not provided for in the training data.

5.2. Ethical Dilemmas (Areas of Controversy)

Autonomous vehicles raise a number of ethical issues that are still the subject of debate. Fleetwood [15] notes that one of the main issues remains the situation in which the vehicle must choose between two unfavorable outcomes. For instance, if an accident is imminent, should the AI sacrifice the pedestrian's life to save the passengers, or vice versa? Hudson et al. [16] also note the following issues:

- Responsibility for decisions — Who should be responsible for the decisions made by AI? Car manufacturer, algorithm developer, or vehicle owner?
- The value of human life — How should AI assess the value of life in critical situations? For example, should it take into account age, social status, or the number of people involved in an accident?

Additionally, AVs generate and process vast amounts of data, raising concerns about privacy and cybersecurity. Ensuring the security of AI systems is critical to prevent hacking and unauthorized access to sensitive information [13].

These questions do not clear distinct answers, making them one of the most controversial areas in the development of autonomous cars.

6. Conclusion

To conclude, the future of autonomous vehicles looks promising. With the development of technology, and the improvement of AI algorithms, we can expect AVs to become more comfortable, safe and affordable. Technologies like 5G connectivity or quantum computing will enable faster data processing, hence improved decision-making [9]. Already today, companies like Tesla or Waymo are actively testing and implementing autonomous technologies. Autonomous cars are expected to become a part of transportation infrastructure, since they can change not only the way we travel, but also the entire transportation ecosystem. Artificial intelligence is at the heart of autonomous vehicles, ensuring their ability to perceive the environment, make decisions, and move safely without human intervention. Despite existing challenges such as technical difficulties, ethical issues, and regulatory issues, autonomous cars have enormous potential to improve the safety and efficiency of transportation. But in order for this to happen, we as a society should not reject scientific breakthroughs, as many people do not understand how modern technologies, including Artificial Intelligence, work, and they do not trust them because of this ignorance, although many studies indicate the opposite. While the quality of data is important, the "presentation style and language and the interfaces by which the data is provided" are also important for explanations in autonomous driving [14]. With continued technological development and solutions to current challenges, AVs may soon become a reality, transforming our lives for the better.

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