Overview of Autonomous Vehicle and Its Challenges

Chinmay Amrutkar, Anushka Satav, Puskaraj D. Sonawwanay, and Ashish H. Pawar

Abstract The autonomous vehicles (AVs) are an intelligent mode of transport which can perceive their surroundings and perform autonomous actions without human control. The advanced driver assistance systems (ADAS) technology is considered as the future of transportation systems. The main aim of autonomous driving is to implement a safe transport system for people of all ages, minimize accidents and congestion on roads and make use of resources more efficiently. As the performance of AV will not be affected by emotions, distraction, fatigue compared to humans, it makes them more reliable and safer. Along with the advantages, there are various challenges faced by the AVs which need to be resolved before they can be fully commercialized. This paper presents a comprehensive overview of autonomous vehicles including its development, review challenges faced and future presence.

Keywords Autonomous vehicles · Intelligent vehicles · Object detection · Sensor technology · Advanced driver assistance systems · Challenges

1 Introduction

In today's society, the autonomous vehicles (AVs) are becoming more distinguished in the field of research as well as for commercial use. AV is able to navigate and operate independently without human intervention, by its ability to analyze the environment and control independently. They aim to provide safer mobility especially for the elderly, reduce the number of accidents and avoid traffic [1]. About 1.3 million casualties per year are caused due to road crashes, as per the World Health Organization's report on road traffic injuries (Feb-2020) [2]. Most of the casualties are caused due to distractions, over-speeding, drinking, etc. The society needs a more structural and safer system of transportation which can be achieved by AVs on a larger scale [3]. Various companies and researchers working on AVs realize the several challenges

C. Amrutkar · A. Satav · P. D. Sonawwanay (✉) · A. H. Pawar
School of Mechanical Engineering, Dr. Vishwanath Karad MIT World Peace University, Pune, India
e-mail: puskarajdsonawwanay@gmail.com

P. M. Pawar et al. (eds.), *Techno-Societal 2022*,
https://doi.org/10.1007/978-3-031-34648-4_25

which need to be solved for building reliable AVs. Accuracy in obstacle detection and decision control are few of the challenges faced [1]. The environment perceptions as well as large-scale network guided technologies are important for vehicle safety [4]. Based on the literature survey it is seen that various reviews have been conducted related to AV development, social impact, sensors used, etc. [3, 5–7]. Our work presents a comprehensive overview of autonomous vehicles and focuses on the working, challenges faced and the future scope.

2 Development of Autonomous Vehicles

2.1 Levels of Automation

Society of Automotive Engineers (SAE) defined the classification of intelligent vehicles in 2014, which is accepted worldwide and shown in Fig. 1 [8]. The six levels of automation are based on the allotment of driving tasks between vehicle and the driver [9]. Level 0 involves no automation and the vehicle is monitored by the driver, whereas level 5 vehicles achieve complete autonomous driving. Here, vehicles can responsibly run on any roads [1]. Similarly, the National Highway Traffic Safety Administration (NHTSA) has also categorized autonomous vehicle technologies in 6 levels (0–5) [10].

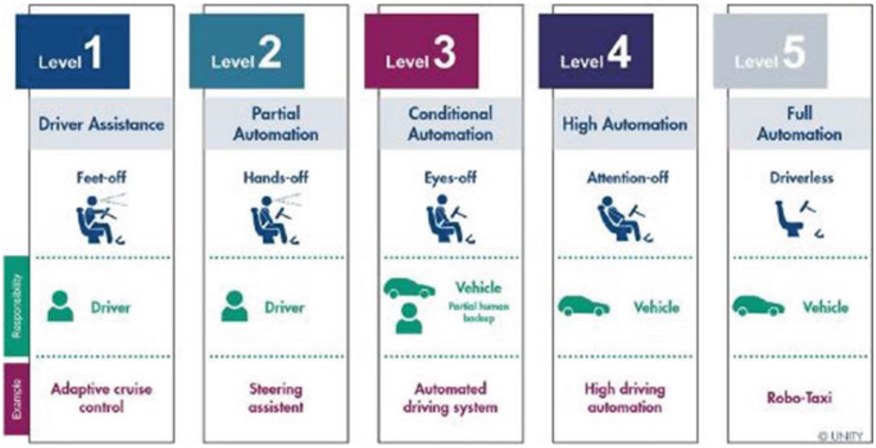

Fig. 1 Levels of vehicle automation according to SAE [8]

2.2 Sensor Technologies for Environment Perception

The sensing system of AV is responsible for surrounding data collection in real-time which helps them function autonomously. They provide information to the vehicle for object detection, lane occupancy, traffic flow, pedestrian detection, path planning and collision avoidance. The various sensors along with their drawbacks are as follows:

1. Ultrasonic sensor—Reliable to various light conditions but cannot be used at high speed with maximum range of 2 m [11].
2. Image Sensors—Generate images which are processed for object detection. Cameras are used in Tesla cars for complete self-driving features [12].
3. RADAR sensor—Emits radio waves which echo after hitting obstacles and the object position and speed is calculated but causes false alarms due to metal objects.
4. LIDAR sensors—Light Detection and Ranging (LIDAR create a real time virtual 3D environment but are affected by weather and are expensive [13, 14].
5. GNSS—Helps to determine the speed and location of a vehicle. It describes the layout of satellites and provides information like navigation, and traffic.
6. GPS—In this system, GPS provides longitude, latitude, and altitude and is a crucial part of path planning in autonomous vehicles [15].

Sensor data is organized efficiently by selecting suitable sensors and can be classified based on specifications, mode, and data type [16]. In a study, using LiDAR and thermal infrared cameras, an object detection algorithm was built which worked efficiently in day as well as night period [17].

2.3 Algorithms for Object Detection and Path Planning

Machine learning, Deep Learning, and Reinforcement learning algorithms are used for pedestrian detection [18], path planning [19], like:

1. CNN: CNN can be applied to AVs for pedestrian detection and path planning as this algorithm works best for image processing.
2. RCNN: It provides greater accuracy than CNN. It is used for traffic signs and pedestrian detection [20].
3. SLAM: Simultaneous localization and mapping (SLAM) estimates the body's relative position in a surrounding [21]. RADAR-SLAM provides velocity and LiDAR-SLAM is used for pedestrian detection, motion control and path planning [22].
4. YOLO: It is used for real-time object detection as it is fast and user-friendly.

Using DL and RL methods by learning their advantages and challenges can be used, which can remove the use of lengthy ML methods [19].

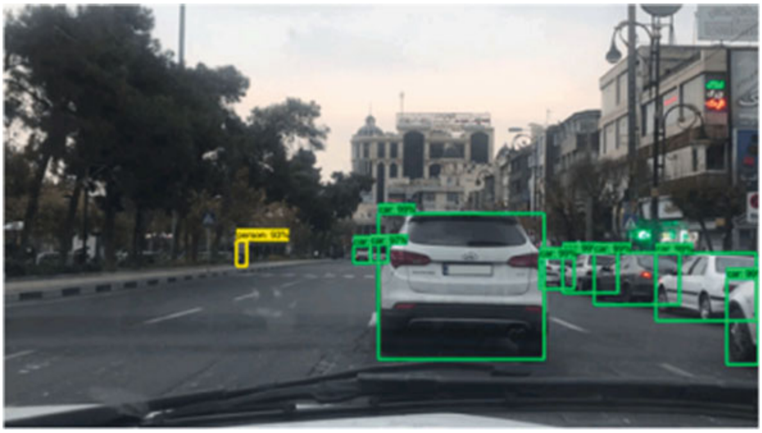

Fig. 2 Object detection using R-CNN [27]

Object detection: Object detection locates the roads, traffic signs, pedestrians, etc. It is becoming more accurate and reliable with time [19]. Pedestrian detection in real-time can be implemented in AVs using CNN [23]. Figure 2 shows object detection using R-CNN. In the design of ADAS, various algorithms are used to get surround and forward-view data fusion images to make AVs safer [24]. Semi-supervised 3D target detection can also be used with a fast 3D object detector; this needs only a small amount of labeled data [25]. A brief review of the 3D object detection techniques, for various scenarios faced during autonomous driving, is required for safety of the passengers [26].

Trajectory generation and Motion planning algorithms: The first step in navigation knows the location of a vehicle with respect to its surroundings. The next step is to follow the simplest path towards the required goal, followed by motion planning. It calculates steering angle, acceleration, and braking control, while path prediction consists of short-term path calculations of AV and future states. Various models and control methods can be used to choose a suitable path to reach a desired location [28]. SLAM method is used for navigation and localization of the AVs. Visual SLAM is being preferred over LiDAR sensors as they are cheaper and easy to install [22]. To change lanes on a highway, an approach including CNN and RNN can be effectively used [29].

2.4 Control System of AV

The decision made by the AVs is controlled by a Control Unit which is of two types: Direct control system, uses PC and needs controllers for different actuators and sensors, and Electric control unit (ECU), along with PC controls the AV. There are some maneuvering systems that can be used without ECU (as they are expensive) [30]. The accuracy of navigation of AVs, calculating steering angles and vehicle speed, can be improved using CNN and results show that cars can drive automatically follow the lane stably with accuracy of 98.23% [31]. To improve steering and acceleration mechanisms, approaches using various types of control systems can be used [19].

Advanced Driver Assistance Systems (ADAS) in AVs: ADAS are active and passive systems designed to eliminate human error and assist while driving to improve driver's performance. It uses various sensors to perceive the surrounding and it helps AV to take action when necessary [32]. It should be prepared to control the AV in worst case scenarios with utmost safety. ADAS is a bright application of AI and the availability of huge datasets is improving its performance. The Crash Avoidance and Overtaking Advice (CAOA) subsystems take decisions for AV's overtaking on road [33]. Safeties on roads, reducing pollution, and efficient travel are benefits of new AI algorithms with ADAS. Figure 3 shows integration of sensors with ADAS systems in AVs.

Impact of AVs on Society: AVs are considered as the future of the transport system as they can make mobility more accessible for people unable to drive, like senior citizens, people with disabilities and children. Safer road travel will help reduce accidents. Impact of AVs can be predicted with the help of various simulation software [35]. To study the impact of AV on safety, environment and safety, various traffic simulation models can be used [10, 35, 36]. One study of traffic simulation of city Duisburg in 2020, 2030, and 2050 shows that, under the same traffic flow, increasing AVs can improve traffic flow and shorten the average travel time [37]. Network traffic matrix prediction can predict future network traffic behavior to improve

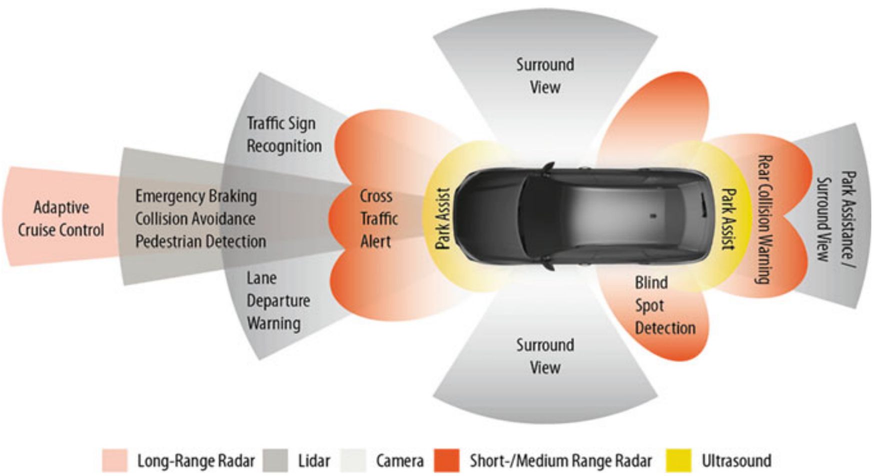

Fig. 3 ADAS integrated with sensors in modern AVs [34]

network management and planning [38]. A review of Agriculture autonomous vehicles (AAVs) was done by Hokkaido University from 1990 to 2018, where various aspects of AAVs development, future scope are discussed in detail [39].

3 Challenges of Autonomous Vehicles

AVs provide many advantages over conventional transport systems but implementation in today's world poses several challenges and issues that need to be solved. This can be done by analyzing those challenges and through extensive research and development, providing solutions for the same. Various challenges faced by the AVs are discussed.

1. Several challenges and their solutions in [33], have been described as follows:
   (a) Driving AVs in dim light, glare and weather like rain, snow, fog, etc.
   (b) To prevent vehicle collisions hidden in blind areas, when making lane changes for turning on bends, overtaking, etc.
   (c) In AVs, tackling roads with mud, oil, sand, grease, ice, dust, food waste, glass, and accidents, can cause a car to lose control and roll over.
2. Congested metropolitan streets with heavy traffic and arriving pedestrians.
3. To change the law and traffic regulations to address AV ownership and operation.
4. Human decision-making is influenced by a variety of circumstances. A person might ethically think about crashing the car to save a pedestrian. For AVs, this sort of moral thinking and appropriate decision-making is essential.
5. Prior to each ride, an AV's sensors and systems must be checked and verified. And a cut-off mechanism must always be provided for safety purposes.
6. Traffic forecasting for autonomous vehicles is a difficult problem due to complex spatial modeling of the road network and non-linear temporal dynamics [40].
7. Development of a human–machine interface (HMI) system that assists passengers while complete automated driving uses the information continuously provided to enhance the mode awareness (i.e., their mental model about the current status and liability of the automated driving system) [41].
8. For AVs to function successfully, extremely high-quality, specialized maps may be needed. Planning is challenging since the best route between collection and drop-off places in AVs is dynamic.
9. A number of monetary problems, including expensive initial, service, maintenance, and spare cost, hinder the adoption of AV [2].
10. Cyber security is the main barrier in commercializing AVs in India. By turning off the safety features, it is possible to alter the software and computer system of the car, just as it is possible to purposefully cause an accident [2].

4 Conclusions

The paper gives an overview of the current scenario of working, development, challenges faced and the scope of AVs in the future. The key aspects related to the development of AVs such as AV's working, implementation, algorithms, intelligence, safety, impact on society, and study of various researches being conducted are discussed in this work. It shows the ability of AVs to make mobility in the future more efficient, safer, cleaner and more comprehensive. Based on this research we can highlight these challenges which require more efficient solutions:

1. Making ethical decisions for any kind of circumstances faced while driving.
2. Accurate detection of obstacles, pedestrians, mapping surroundings when vehicle is driving at high speeds.
3. Cyber-attacks on the AV can cause casualties, injuries, damage to property, etc.
4. Use of various sensors, their availability and costs can make AVs very expensive.

Many challenges faced in implementation of AVs make commercializing fully autonomous intelligent vehicles non-feasible and portrays the need for extensive research on AVs.

References

1. Martínez-Díaz, M., & Soriguera, F. (2018). Autonomous vehicles: Theoretical and practical challenges. In *Transportation research procedia* (pp. 275–282). Elsevier B.V.
2. Kumar, G., James, A. T., Choudhary, K., Sahai, R., & Song, W. K. (2022). Investigation and analysis of implementation challenges for autonomous vehicles in developing countries using hybrid structural modeling. *Technological Forecasting and Social Change, 185*, 122080.
3. Singh, S., & Saini, B. S. (2021). Autonomous cars: Recent developments, challenges, and possible solutions. In *IOP conference series: Materials science and engineering*. IOP Publishing Ltd.
4. Bimbraw, K. (2015). Autonomous cars: Past, present and future: A review of the developments in the last century, the present scenario and the expected future of autonomous vehicle technology. In *Proceedings of ICINCO 2015—12th international conference on informatics in control, automation and robotics* (pp. 191–198). SciTePress.
5. Raza, M. (2018). Autonomous vehicles: levels, technologies, impacts and concerns. *International Journal of Applied Engineering Research, 13*(16), 12710–12714.
6. Rajasekhar, M. V., & Jaswal, A. K. (2015). Autonomous vehicles: the future of automobiles. *IEEE International Transportation Electrification Conference (ITEC)*, pp. 1–6.
7. Van Brummelen, J., O'Brien, M., Gruyer, D., & Najjaran, H. (2018). Autonomous vehicle perception: The technology of today and tomorrow. *Transportation Research Part C: Emerging Technologies, 89*, 384–406.
8. Avoci, U. M., Marco, C., Antonio, P., & Consolatina, L. (2021). Enhanced sensor coverage for autonomous vehicles with a preliminary integration of fault detection scheme. In *Measurement: Sensors*. Elsevier Ltd.
9. Parekh, D., Poddar, N., Rajpurkar, A., Chahal, M., Kumar, N., Joshi, G. P., Cho, W. (2022). A review on autonomous vehicles: Progress, methods and challenges. *Electronics (Basel), 11*, 2162.

10. Tyagi, A. K., & Aswathy, S. U. (2021). Autonomous intelligent vehicles (AIV): Research statements, open issues, challenges and road for future. *International Journal of Intelligent Networks., 2*, 83–102.
11. Budisusila, E. N., Arifin, B., Prasetyowati, S. A. D., Suprapto, B. Y., & Nawawi, Z. (2020). Artificial neural network algorithm for autonomous vehicle ultrasonic multi-sensor system. In *EECCIS 2020–2020 10th electrical power, electronics, communications, controls, and informatics seminar* (pp. 128–131). Institute of Electrical and Electronics Engineers Inc.
12. Autopilot | Tesla. Retrieved October 11, 2022, from https://www.tesla.com/autopilot
13. Zamanakos, G., Tsochatzidis, L., Amanatiadis, A., & Pratikakis, I. (2021). A comprehensive survey of LIDAR-based 3D object detection methods with deep learning for autonomous driving. *Computers and Graphics (Pergamon), 99*, 153–181.
14. Ahangar, M. N., Ahmed, Q. Z., Khan, F. A., & Hafeez, M. (2021). A survey of autonomous vehicles: Enabling communication technologies and challenges. *Sensors, 21*, 706
15. Rahiman, W., & Zainal, Z. (2013). An overview of development GPS navigation for autonomous car. In *IEEE 8th conference on industrial electronics and applications (ICIEA)* (pp. 1112–1118).
16. Ignatious, H. A., El-Sayed, H., & Khan, M. (2021). An overview of sensors in autonomous vehicles. In *Procedia computer science* (pp. 736–741). Elsevier B.V.
17. Choi, J. D., & Kim, M. Y. (2022). A sensor fusion system with thermal infrared camera and LiDAR for autonomous vehicles and deep learning-based object detection. *ICT Express, 9*, 222–227.
18. Sha, M., & Boukerche, A. (2021). A novel visibility semantic feature-aided pedestrian detection scheme for autonomous vehicles. *Computer Communications, 179*, 50–61.
19. Elallid, B., Benamar, N., Hafid, A. S., Rachidi, T., & Mrani, N. (2022). A comprehensive survey on the application of deep and reinforcement learning approaches in autonomous driving. *Journal of King Saud University—Computer and Information Sciences. 34*, 7366–7390.
20. Carranza-García, M., Lara-Benítez, P., Garcia Gutierrez, J., & Riquelme, J. C. (2021). Enhancing object detection for autonomous driving by optimizing anchor generation and addressing class imbalance. *Neurocomputing, 449*, 229–244.
21. Bresson, G., Alsayed, Z., Yu, L., & Glaser, S. (2017). Simultaneous localization and mapping: A survey of current trends in autonomous driving. *IEEE Transactions on Intelligent Vehicles, 2*, 194–220.
22. Cheng, J., Zhang, L., Chen, Q., Hu, X., & Cai, J. (2022). A review of visual SLAM methods for autonomous driving vehicles. *Engineering Applications of Artificial Intelligence, 114*, 104992.
23. Pranav, K. B., & Manikandan, J. (2020). Design and evaluation of a real-time pedestrian detection system for autonomous vehicles. In *2020 zooming innovation in consumer technologies conference, ZINC 2020* (pp. 155–159).
24. Yang, J., Liu, S., Su, H., & Tian, Y. (2021). Driving assistance system based on data fusion of multisource sensors for autonomous unmanned ground vehicles. *Computer Networks, 192*, 108053.
25. Zhang, J., Liu, H., & Lu, J. (2022). A semi-supervised 3D object detection method for autonomous driving. *Displays, 71*, 102117.
26. Ghasemieh, A. & Kashef, R. (2022). 3D object detection for autonomous driving: methods, models, sensors, data, and challenges. *Transportation Engineering, 8*, 100115. https://doi.org/10.1016/j.treng.2022.100115
27. Khosravian, A., Amirkhani, A., Kashiani, H., & Masih-Tehrani, M. (2021). Generalizing state-of-the-art object detectors for autonomous vehicles in unseen environments. *Expert Systems with Applications, 183*, 115417.
28. Bacha, S., Saadi, R., Ayad, M.Y., Aboubou, A., & Bahri, M. (2017). A review on vehicle modeling and control technics used for autonomous vehicle path following. In *2017 International Conference on Green Energy Conversion Systems (GECS)* pp. 1–6.
29. Xing, Y., Lv, C., Wang, H., Cao, D., & Velenis, E. (2020). An ensemble deep learning approach for driver lane change intention inference. *Transportation Research Part C: Emerging Technologies, 115*, 102615.

30. Choi, J. H., Lee, H. J., Oh, S., & Nam, K. (2022). Development of vehicle maneuvering system for autonomous driving. *Mechatronics, 85*, 102798.
31. Duong, M.-T., Do, T.-D., Le, M.-H. (2018). *Navigating self-driving vehicles using convolutional neural network*. IEEE.
32. What is ADAS (Advanced Driver Assistance Systems)? | Dewesoft. Retrieved October 11, 2022, from https://dewesoft.com/daq/what-is-adas
33. Perumal, P. S., Sujasree, M., Chavhan, S., Gupta, D., Mukthineni, V., Shimgekar, S. R., Khanna, A., & Fortino, G. (2021). An insight into crash avoidance and overtaking advice systems for autonomous vehicles: A review, challenges and solutions. *Engineering Applications of Artificial Intelligence, 104*, 104406.
34. Types of ADAS Sensors in Use Today | Dewesoft. Retrieved October 10, 2022, from https://dewesoft.com/daq/types-of-adas-sensors
35. Orfanou, F. P., Vlahogianni, E. I., Yannis, G., & Mitsakis, E. (2022). Humanizing autonomous vehicle driving: Understanding, modeling and impact assessment. *Transportation Research Part F: Traffic Psychology and Behaviour, 87*, 477–504.
36. Miglani, A., & Kumar, N. (2019). Deep learning models for traffic flow prediction in autonomous vehicles: A review, solutions, and challenges. *Vehicular Communications, 20*, 100184
37. Ma, X., Hu, X., Weber, T., & Schramm, D. (2021). Effects of automated vehicles on traffic flow with different levels of automation. *IEEE Access, 9*, 3630–3637.
38. Aloraifan, D., Ahmad, I., & Alrashed, E. (2021). Deep learning-based network traffic matrix prediction. *International Journal of Intelligent Networks, 2*, 46–56.
39. Roshanianfard, A., Noguchi, N., Okamoto, H., & Ishii, K. (2020). A review of autonomous agricultural vehicles (The experience of Hokkaido University). *Journal of Terramechanics, 91*, 155–183
40. Miglani, A., & Kumar, N. (2019). Deep learning models for traffic flow prediction in autonomous vehicles: A review, solutions, and challenges. *Vehicular Communications, 20*, 100184.
41. Bellet, T., Cunneen, M., Mullins, M., Murphy, F., Pütz, F., Spickermann, F., Braendle, C., & Baumann, M. F. (2019). From semi to fully autonomous vehicles: New emerging risks and ethico-legal challenges for human-machine interactions. *Transportation Research Part F: Traffic Psychology and Behaviour, 63*, 153–164.