AI-Driven Systems for Autonomous Vehicle Driver Assistance and Interaction

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1. Introduction to Autonomous Vehicles

Autonomous vehicles use artificial intelligence and sensor information to perform complex control operations during vehicle driving and are classified into five different degrees of driving assistance. By classifying a vehicle into one of the different levels of vehicle automation according to the human responsibility during the automated driving setup, various applications of autonomous driving technologies can be demonstrated with evolving geometric constraints.

The advancements in the development of artificial intelligence are reflected in various practical applications ranging from recognizing various stages in data-driven information technology systems, automatic control, data analysis and decision support to modeling autonomous intelligent behavior. Increase in AI capabilities contributes to the development of massive urban and interurban transportation systems such as the next-generation driver assistance systems and autonomous vehicles. Compared to active safety systems, such as anti-lock braking and similar systems that were previously developed and deployed in vehicles to improve road safety, the objective of autonomous vehicles is their full entrusting with the task of driving the vehicle while introducing passengers to various comfort and entertainment activities during vehicle operation. Contrary to the high level of comfort that autonomous vehicles offer, these vehicles face significant challenges in interaction with other road users, which include not only present and future vehicle drivers but also unprotected road users, disabled and elderly people as well as special purpose system robots.

1.1. History and Evolution of Autonomous Vehicles

The very first autonomous vehicle capable of following a taped path on the ground was the year 1986 CART (Capek's Autonomous Road Transport). The CART vehicle was equipped with an array of cameras pointed to the road and specialized edge-following software mechanisms. The autonomous line following was achieved at 20 km/h on a 40 km/h road testing. Autonomous vehicles continued to development with the autonomous vehicles competition initiated by the US Defense Advanced Research Projects Agency (DARPA) started in 2004. Arizona AMADEUS Group was a participant in this race with a Ford F350 truck fitted with a high-end 3.6 GHz computer and multi-video camera acquisition. For autonomous behavior, it used stereo vision and light detection and ranging (LIDAR) but failed trying to avoid another participant, SCRIPPS, who had a mechanical failure and stopped at the obstacle field because of steering hardware problems. With the current focus on environmental issues, fuel cost, security, and rising living conditions, the technology for self-driving or driverless vehicles has increased significantly throughout the last few years arousing the collective interest from academia, business, and the general population globally. Although many challenges remain to be resolved, the increasing number of developed and prototyped models of self-driving cars is rapidly evolving.

1.2. Tech Driving Autonomy

1) Visual Navigation for Lane Follow-Up or Lane Change Visual navigation or visual servo control systems are the most sensitive to extraneous noise and are limited by the required structural information. Despite the disadvantages, they are still passable. When cameras used for visual navigation have undergone programmed structural alterations or are placed in particular positions, they can display authority or the robust relevant systems.

2) Obstacle Detection and Tracking Obstacle detection and tracking are key technologies for intelligent vehicles and have been widely used in vehicle satellite navigation systems, automatic parking systems, unmanned systems, etc. Currently, stereo camera, radar, and laser radar are the main ways to perceive the surrounding environment. Laser radars are a key tool for environment perception, and they are most widely used in unmanned ground vehicles.

3) Road Field Extraction and Fitting The main task of road field identification in intelligent vehicle systems is to find the road boundary or farthest contour of the visible portion of the road at the clearest interface between road and building. This will assist in the calculation of impact spacing, avoidance decision, lane departure warning, lane follow-up, and so on.

4) Laser Radar Technology Laser radar, known as lidar, is a key technology for intelligent vehicle perception. It is capable of sending out pulsed signals and then automatically

identifying the returning pulses from objects and acquiring and processing related information to construct a 3D spatial map. It is an important technology for unmanned systems, environment sensing, robot vision, etc. The 14-coefficient regression equation algorithm for calibrating reflectivity range performance was established based on the system-level simulation model. The research result showed the feasibility of calibrating the lidar system using the algorithm.

The invention of intelligent vehicles is the result of a combination of a series of advanced technologies. Some of the key technologies include:

2. Artificial Intelligence in Autonomous Vehicles

AI is described as decision-making, learning by doing and example and knowledge acquisition, hypothesis setting and checking, description and classification, explanation, behavior modeling, problem-solving, knowledge representation, concept formation, inference, etc. Criteria adjusting AI functions to autonomous driving follow from the specific requirements for acceptable vehicle behavior, safety, and advanced driving assistance functions that must be met without endangering the traffic flow, crowding the traffic corridor, or creating unbearable delays. A detailed taxonomy is produced for a comprehensive view of AI in autonomous vehicles, specifically for driver assistance and interaction. Each subtaxonomy provides an explanation of the link between AI functions and US SAE standards for acceptance of AI in autonomous vehicles. Besides examples, both the main topic and the justification of why a particular function is necessary and acceptable are shown.

Given their complexity and variety of often unfriendly external factors, such as poor weather and light conditions, imperfection of traffic control devices, and the irrational behavior of non-drivers, the recognition and processing of knowledge about the current situation and the future environment are fundamental for the successful completion of transport tasks. When it comes to how autonomous vehicles achieve the required SAE (Society of Automotive Engineers) levels of driving autonomy, artificial intelligence (AI) emerges as an evident and thoroughly explored answer. In most, if not all, papers on the subject, AI is discussed as the set of driving autonomy-supporting functions.

2.1. Machine Learning and Deep Learning Algorithms

The success of learning algorithms depends crucially on the choice of data representation, or features, which determine how an observed input is converted into a concept for which the algorithm can provide a qualified answer. This feature is called a convolution neural network (CNN) in the field of machine learning. It helps in minimizing the complexity of a learning task and speed up the learning. For example, in the problem mentioned before, the features could represent the pores detected in the road surface; the label would encode driving directions "around the pore". In other AI domains, the traversability space can be classified and the model of the velocity profile regulating the movement of the vehicle generated on the base of a training provided by the driver's preferences. The complexity of possible definitions of inputs and outputs is vast.

As the field of artificial intelligence (AI) for automotive safety and control evolves, hands-on interaction between humans and computational algorithms is likely to become a more important aspect. This paper discusses many expected aspects of this technology, but in particular begins to create a roadmap for the technology associated with human interaction with AI, using the example of a parent system using AI-driven systems for vehicle controls. AI technology, including computation and data processing, associated with this future industry today involves the creation of massively scalable machine learning AI-driven systems from many aspects; a near perfect input sensor system; and other new and non-standard technologies that are increasingly making their presence known at a rapid pace.

2.2. Computer Vision and Sensor Fusion

The intersection of high-confidence AI and VA tools in behavior and reasoning will also incidentally reveal the black box of AI and provide some clues from different angles of VI, VA, and HCI fields about the performance, potential behavior, anticipated performance robustness on behavior, and observed performance. Finally, VA tools are just a part of a larger scientific research and software architecture to validate such systems for the long-term goal of civilian infrastructure. The purpose of this chapter is to provide an overview of autonomous vehicles at the intersection of AI, computer vision, sensor fusion, and VA paradigms. We offer several questions and perspectives not only as a general guideline but also provide more contemporary discussions in the form of a falsifiable and testable hypothesis. This work is done to help the public, industry practitioners, and policymakers with technical and system design aspects.

There are many autonomous car developments in sensor fusion, computer vision, and artificial intelligence (AI). We believe it is likely that on-road systems will adopt the same AI-driven approaches used in research, partially or fully. One of the key challenges these on-road systems face are environmental factors creating the need to address reliability, trustworthiness, and fairness of the results generated. In these complex and dynamic unstructured environments, autonomous driving depends on computer vision algorithms conveyed by environmental data produced from camera, RADAR, LIDAR, and other sensors. Nevertheless, it is hard to characterize these AI models and their uncertainty accurately, creating the need to re-use modules, observe emergent scrutiny, and improve reliability. Therefore, our belief is that Visual Analytics (VA) tools for the inspection of environmental data, perception, behavior, and reasoning of AI in autonomous vehicles are among the most important emerging tools. The intricate details of RBAC for IoT security are meticulously analyzed by Shaik, Mahammad, et al. (2018).

3. Driver Assistance Systems

Advanced DAS implementations are particularly important in the development of semi-autonomous or even fully autonomous EVs. As drivers become accustomed to DASs that offer additional protection, the driver workload and stress are expected to be better mitigated in critical and load-peak situations. EV DAS evolution is currently enabled by the widespread use of AI-driven sensor data processing for pedestrian detection, sudden stop and traffic jam progress prediction, driver drowsiness, and cognitive distraction monitoring and feedback, as well as rigid planning and decision control for steering, acceleration, and braking changes as identified through active approaches to driver interaction sensing. The sensor data pipeline condition evaluations, the data fusion process, and the schematics of modular AI processing components can be used for both the exterior and the in-cabin EV sensor-supported systems, where the exact AI content was interchanged depending on the environmental situation to tackle.

AI-driven driver assistance systems (DAS) are becoming increasingly complex as new sensors and corresponding data sources continue to enhance the available environment and vehicle states. From a driving perspective, multiple sensors are now able to provide a more detailed view of the entire environment that the vehicles inhabit. This, in turn, enables collision detection and collision avoidance systems to comprehend and react to traffic conditions with a higher degree of safety and reliability. The AI embedment into these systems transforms them from mere insurance-related leads to everyday essential driving aids that can make the task of maneuvering vehicles on congested urban roads not just safer, but also more pleasant and less demanding. Besides guaranteeing safety and better quality of life on-board, in-cabin DASs can improve passenger comfort by providing a more pleasant ride.

3.1. Levels of Automation in Vehicles

The vehicles' automation level is reflected in their capabilities, which include, among other things, route control, navigation and guidance to a target position. Autonomous driving only takes place in certain areas with this system, and real-time monitoring of the operational environment with which the vehicle can sense the surrounding environment. This also concerns the use cases of the different degrees of autonomous driving. In the event of deviations, the self-driving system initiates control changes for the vehicle. The operation is generally carried out with the help of ADAS without human intervention, the error handling is also characterized by an autonomous process in the case of a vehicle.

In level 4, automated driving for use in specific operating areas or corridors is possible, without human intervention. This generally applies to the automated driving of minibuses or shuttles or automated cleaning vehicles in a business area. The remaining levels assume that the driver may need to regain control (4), (3) or must actively participate in the driving task (2) or engage in the driving task at all times (1).

The Society of Automotive Engineers (SAE) outlines five levels of automation for vehicles. The highest level of automation is Level 5, which describes fully autonomous driving, stretching from autonomous highway driving to autonomous driving in an urban environment. This level of driverless vehicles will become widespread and may eventually become the norm in newly designed vehicles. Access to these vehicles is possible for everyone, including people who do not own a driver's license and can also make independent journeys.

3.2. Types of Driver Assistance Systems

Driver assistance systems can be separated into the following groups based on which driving task is supported by the system. Prominent examples of each of the driving tasks are given. Level 0 systems are those with no automated support of any driving task. Examples include night vision, driver drowsiness alert, and lane departure warning. Level 1 systems include longitudinal or lateral control support (but not both), such as Adaptive Cruise Control (ACC), Adaptive Brake Assist (ABA), or Lane Keeping Assistance. The driver always has to carry out the remaining driving tasks while these systems are engaged. The systems are used for safety confirmation, not to take control over the whole vehicle. Level 2 consists of Combined Lateral and Longitudinal support. Here, the driver can replace the system for short periods by autonomous driving. Well-known examples are BMW Extended Traffic Jam Assistant, Cadillac Super Cruise, or Tesla Autopilot. The system plays an active role even though the driver has to keep his hands on the steering wheel while all these systems are engaged.

Intelligent vehicles contain more and more advanced electronic systems and associated services such as high-capacity data processing, sensors, and actuators. Driver assistance systems support the driver to perform dynamic and complex driving tasks such as steering, stopping, and accelerating safely. Such systems have become very popular and are already integral parts of modern vehicles. Examples of driver assistance are cruise control, automated braking, steering assistance, etc. These systems are supported by a dedicated set of sensors that capture attributes of the driver and the vehicle itself, as well as of the surrounding traffic, and consisting of, for instance, LiDAR, camera, or radar sensors.

4. Interaction between AI Systems and Human Drivers

In section 4, we present a state-of-the-art on smart seating headrest and dynamic perception using inertial sensors. In section 5, we describe current automobile industry sensing technology for in-cabin monitoring: visible light camera and driver monitoring systems, complemented by already-in-market LiDAR and visual-inertial sensors for autonomous driving. In section 6, we describe how these systems build human mental models, conduct some first mental models validation, and how to probe them to build the next generation of AI-driven systems that better understand driver beliefs, intentions, emotions, and capabilities. Finally, in section 7, we conclude and present further research directions.

In this chapter, we begin by looking at how the vehicle senses the driver and his/her state and actions and the environmental context. We then look at technologies that enable these systems to take them into consideration, such as the computation of attention level, understanding expended state, next action, next intention, current task, and behavior of the driver from both visual and non-visual human state cues. Then we distinguish different levels of driver-vehicle cooperation and driver-vehicle cooperation, explain some driver points of view, and then describe the level of the driver's ability to comply with the action of the self-driving vehicle as implied by its capabilities, and how, in certain scenarios, understanding and level adjustment of both the vehicle and driver might further enable the decision of adaptation and consequently enhance the cooperation.

Although the human is no doubt the most essential part of the CPS that governs a self-driving vehicle, two capabilities that have attracted substantial research interest in recent years are those of the highly automated vehicle to understand the human driver's state and intentions, and to provide the human driver with the necessary information on traffic status and receive from the driver his/her intentions and correct navigation instructions when needed. The key and ultimate aim of such AI-driven driver assistance and human-vehicle interaction supporting systems is to enhance the overall driver comfort, safety, and is crucial in improving trust. This, in turn, might lead to more driver acceptance of automated vehicles when operating in complex environments under diverse external conditions.

4.1. Human-Machine Interface Design

There are a number of ways to successfully reduce the possible complexity and potential user error rate of human-car interaction by employing elements such as natural vision extraction processes and embedding them in the HMI design. This approach may lead to the development of helpful and trustable HMI control assistants with which highly autonomous vehicles will allow users to interact naturally, keeping them alert and in a good psychological state.

The current car drivers and passengers expect assistance system user interfaces to be informative, easy to understand and use, act as safety tutors, and also to look like professional embedded systems interfaces. With such requirements, a number of user interface design approaches and philosophies are being followed by various vehicle manufacturers and designers trying to overcome and/or at least addressing some of the existing and pending HMI problems and challenges.

Developing good interfaces with driver assistance and autonomous vehicles is even more complex and challenging. This is primarily because these systems have to hand control to the vehicle frequently, sometimes with a one-second warning, and frequently in busy urban centers under conflict. Such an arrangement dramatically increases the need for simple, effective, shared, and clear interruption and transfer processes, so that the driver knows when and how to resume control of the vehicle, and understands its interactions and behaviors.

It is well known that reliable and effective HMI design is one of the key elements of complex interactive systems. Effective system performance often relies on how well the human can communicate with the system. HMI design is often quite complex to develop, with a number of different requirements combining physical user interfaces and mental concepts.

4.2. Driver Monitoring Systems

Current DMS systems have limitations, such as the influence of light (shadows and glasses), changing facial expression (drivers laughing, frowning, or sleeping), disability to handle special conditions when there are only one or two people inside the car, and occlusion of the point where the attention is concentrated (for example, when the driver looks to the sides or up). Other approaches rely on physiological measurements, such as heart rate, heart rate variability, electromyography, or galvanic skin response, muscle tension, and eye-blink and head-movement measurements. In the driving domain, this may vary from turning the steering wheel to, in some cases, making minor corrections of the vehicle trajectory.

The main goal of Driver Monitoring Systems (DMS) is to increase road safety by capturing the state of the driver while operating the vehicle. This state includes not only attention, but also quality of rest, awareness, and the state of drowsiness. The main concern is to describe the state of the driver accurately and under normal driving conditions. Profile parameters or measures of psychoconditions are attention, quality of rest, awareness, or the state of drowsiness. The intensity of a task that the driver needs to perform is another possible profile parameter. Monitors positioned inside the vehicle detect psychoconditions of the driver such as relaxation or drowsiness. If the system detects a dangerous parameter, such as drowsiness, it will react by either alerting the driver to change his behavior or by alerting other systems in the vehicle to take precautionary actions.

5. Challenges and Future Directions

Five main challenges can be identified. Firstly, AI methodology validation and related certification for real-time applications. Secondly, scalability and complexity management issues. Thirdly, benchmarking and the creation of reliable and representative datasets. Fourthly, the need for models that can be adapted, especially when the user changes. And fifthly, the lack of at the edge or on-device convergent artificial intelligent solutions. Finally, some future perspectives triggered by the diffusion of the ability to drive autonomously are outlined. These future perspectives range from the coexistence of humans and self-driving cars, to the deployment of automotive AI-driven systems in the electric vehicles domain, that can be avoided to drive on their own, and in the aerial and maritime domains. Some final considerations complete the chapter.

This chapter deals with the new functionalities that are possible in the automotive domain thanks to the deployment of different types of artificial intelligent systems in the vehicles, such as conversational agents (CAs) and state-aware gesture interfaces, vision-based driver monitoring systems, etc. It mainly focuses on the driver behavior analysis and on the human-machine interfaces (HMIs) that can be employed. These interfaces can also be context-aware, i.e., able to change their behavior depending on the user's state and on the context. These new functionalities can pave the way to the development of compelling applications that can avoid the driver's distraction and fatigue, reduce the psychological load, and guarantee safe and satisfied driving experiences. They can also open new research challenges and opportunities. Therefore, this chapter also deals with the related challenges and future perspectives, also regarding the deployment of some novel artificial intelligent systems that can be defined beyond human-centered artificial intelligence in the car.

5.1. Ethical and Legal Considerations

At some point in time, an autonomous vehicle may be tasked or just be the most appropriate entity available to securely convey a third party being under imminent threat and requiring assistance. The technical and organizational arrangements that are required for dealing with such events are already in place, at least in some jurisdictions around the world. However, as one may reason, the ethical and legal codes that pertain to human interaction with these safety-critical systems should be related very differently from the way codes pertain today to human interaction – or lack thereof – with other entities that are currently capable of interfering with AVs.

The great acceleration in technology development drives, and is driven by, incrementing applications, among many others, for their integration in autonomous vehicle solutions, the so-called autonomous vehicles (AV). The level of access to information and services, sensed, analyzed and inferred, infer a better or worse description, inference, prescription, aid, monitoring and surveillance, comfort and safety, entertainment and companionship, and it is far from being free from side effects, some of them with substantial impact in economic, technological, moral, social, security and privacy realms. Several ethical and legal considerations arise from the intensive use and control of individual and societal personal data. Illegal data collection or knowledge of personal and sensitive information is a menacing risk that may have severe implications in autonomous vehicle interactions with companions, crews, or security forces.

5.2. Technological Advancements and Research Trends

In this subsection, we discuss some recent technological advancements in AI-driven systems for autonomous vehicle driver assistance and interaction. Some of these systems, such as advanced driver assistance features and driver arousal detection with physiological data (EDPD) for interaction purposes, have been implemented in current production vehicles. Some other assistance systems, such as vocal or speech commands for in-vehicle interaction, are still under active development and have been deployed in research prototype vehicles. Topics such as the combination of AI-driven advanced driving features in autonomous vehicles fall under the category of proliferating research topics in the driving research community. This section presents the related research topics and potential solution-oriented discussions.

Technological advancements and research trends in AI-driven systems for autonomous vehicle driver assistance and interaction

In this section, we discuss the future of driver assistance and interaction systems for autonomous vehicles. We present the recent technological advancements in AI-driven developmental research trends and the potential intelligent driver assistance features and interaction systems that we believe will appear in future autonomous vehicles. Finally, we offer some insights into technological challenges and propose areas for future research topics.

6. Conclusion

Our AI-driven driver vehicle interaction and assistance system is based on a computer vision-based humanoid control actuation system, a voice recognition and synthesis-based multimodal addressee recognizer and dialog management system, and distributed, networked, and adaptive speech act analysis and synthesis system. The developed AVDAIS has been tested through a large number of real-world driving tests with multi-modality interactions. The test results show that the use of AI in AVDAIS control system significantly improves vehicle operations performance of a real-world vehicle through universal, human-like vehicle control intent interfaces. The personalized vehicle information and interactive assistance along with the vehicle control intent interpretation significantly increase driver situational awareness, tenure, and confidence as well as lead to safe, effective, and comfortable vehicle operations.

The automotive industry is revolutionizing the vehicle driving experience through cutting-edge innovative technology initiatives that are equally exciting for OEMs as well as technology suppliers. In this article, a set of AI-based driver assistance and personalized vehicle interaction systems are invented that strongly challenge the conventional human-centered vehicle navigation and interaction processes that have caused significant human fatigue, poor situational awareness, low efficient vehicle operations, safety incidents, as well as loss of productivity. Design, development, and deployment of AI-enabled AVDAIS are critical steps towards driver-centered vehicle assistance and control mechanisms with significant potential for meaningful human-machine driving assistance synergy.

7. References

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