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Trends in Autonomous Vehicles

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***Abstract*—This essay explains some of the current technological trends in autonomous vehicles. Most of the research is regarding the artificial intelligence of autonomous vehicle systems, but also considers strategies for proper tuning of sensors, algorithms for communication between vehicles and their energy efficiency. Some important research questions in the field of cybersecurity in autonomous vehicles are also listed. Finally, there is a comparison between three currently developed vehicle models. The general conclusion is that there is still no real autonomous vehicle, i.e. we are between the second and third level of automation (partial and conditional). It is also necessary to regulate the use of autonomous vehicles and to define procedures for when a system error occurs.**

I. INTRODUCTION

People have always strived to achieve balance between increased productivity and improved efficiency. With the incorporation of machines and computers in every sphere and the automation of lots of difficult and repetitive tasks, life today is unimaginable without the technological devices that make our daily lives easier. However, there are still many tasks that require complex thought processes and intelligence, and despite all the efforts, machines and artificial intelligence still cannot perform them.

This includes driving, due to the fact that it happens in an unpredictable, stochastic and partially-observable environment. Still, many companies are actively trying to develop systems that will be able to drive completely autonomously without the help of humans. In this essay I will analyze the current technological trends in autonomous vehicles and currently developed vehicle models, as well as important open questions for research in this field.

II. DEFINING AUTOMATION

Six technical levels of driving automation [1] [2] have been defined in terms of the roles of the human driver and the vehicle's system while performing the driving actions. The levels start at 0 with no automation, then driver assistance, partial, conditional, high-level, and finally, full automation at level 6.

Following this classification, current autonomous driving systems are located between the second and third levels – partial automation (the system controls the vehicle's movement but the driver detects and reacts to events) and conditional automation (the system performs all necessary driving actions, but the driver must pay attention and be ready to take over in case of error or system failure). The fourth and fifth levels, which include actual autonomous behavior, are still unattainable [3].

III. TECHNOLOGICAL TRENDS

A. Research on artificial intelligence systems

Most of the research in the last ten years related to autonomous vehicles is based on artificial intelligence, especially after the rise of deep learning [3]. Fields where artificial intelligence can mainly contribute to improvement include control, perception, prediction, and modeling driving behavior.

1) Control: One of the main problems of autonomous vehicles from the aspect of control is controlling the speed of the vehicle in parallel with the rest of the dynamic driving tasks. To enable this, PID controllers are commonly used, but various methods are constantly being explored to optimize them, as well as reduce their errors [4]. Professors from the Department of Artificial Intelligence at the Technical University of Madrid have devised a function for global error that allows the use of various heuristic functions to regulate and optimize the control parameters of PID controllers. Using genetic algorithms, memetic algorithms and network adaptive direct search, they have shown increased controller accuracy compared to classical optimization based on other methods.

2) Perception: Artificial neural networks play a leading role in improving the perception of autonomous vehicles. In particular, the application of deep learning methods is explored in object detection, semantic scene segmentation, examples segmentation and lane line segmentation [5]. The application of the Q-learning algorithm, which can be used to solve stochastic problems without a model, is also explored for driving in roundabouts [6], as well as the introduction of a so-called blind intersection planner in the system controller [7].

3) Prediction: Neural networks are also used to improve agent predictions in autonomous driving. One of the most important problems in this area is the prediction of the trajectory of other traffic participants. Different machine learning methods are used to solve this problem. Professors at Hanyang University in South Korea have developed a method based on the Random-forest algorithm, which they have tested in different scenarios. The results showed improved predictions with increased robustness [8]. Scientists at Shanghai University of Science and Technology have developed a model for the sequential dynamics of motion estimation, which has better performance than currently used models for monocular visual odometry, or the use of image information obtained with a single lens [9].

4) Driving behavior modeling: Modeling the behavior of other agents in the environment during autonomous driving is possible only after their successful detection and furthermore, accurate prediction of their movement. The most challenging task appears to be modeling the behavior of the vehicle in front of the agent, especially when they suddenly shift into the lane, brake, or change speed. Many researchers are experimenting with different methods to improve the accuracy of such predictions [10] [11].

B. Sensors

The movement of autonomous vehicles is highly dependent on their ability to orient themselves and navigate around the environment. Simultaneous localization and navigation algorithms show satisfactory results [12]. Various algorithms that use deep learning for vision (rare spatial convolutional neural network) and sensor integration algorithms (sensor-weighted integrated field) are also explored. These algorithms mainly use four sensors: vision, light detection, range of vision, and a GPS sensor [13]. To improve the precision of obstacle avoidance while maintaining a smooth and uninterrupted ride, sensor-based feedback strategies are being explored [14].

Additionally, proper sensor tuning is crucial to ensure their functionality and then to optimize it. In autonomous vehicles, the placement of the cameras has a direct impact on the vehicle's ability to properly orient and navigate the environment. New interactive camera calibration methods have been developed, adaptable to different models, which reduce the complexity and improve the accuracy of the process [15].

C. Communication between vehicles

One of the benefits of autonomous vehicle traffic is their ability to communicate quickly and therefore operate more efficiently. But secure communication between vehicles is still evolving because their systems are at a certain level of risk of cyberattacks. Attempts have been made to develop different models for risk analysis in the early stages of system design [16].

Scientists from the Eindhoven University of Technology have presented a framework for cooperative assessment of the condition of autonomous vehicles. The assessor is analyzed through simulations of three different scenarios (straight line driving, constant curve rotation, and turns in the form of the number 8), which show benefits of vehicle-to-vehicle communication, such as accurate measurements of the components of the states of both vehicles and a reduction in measurement error of over 50%. Additionally, this framework uses a combination of different sensors together with information received from the other vehicle, leading to greater overall robustness of the system in the events of sensor failures or data loss [17].

D. Energy efficiency

As the amount of information processed by the systems of autonomous vehicles increases, so does the energy consumption, i.e., the amount of electricity required for their calculations. Currently used SRAM architectures offer great accuracy, but also consume a lot of energy, which is why methods are being explored that would reduce energy consumption without reducing accuracy. Field effect transistors on carbon nanotubes or fin field effect transistors are potential solutions for high-consumption artificial intelligence devices, but there is also new research on SRAM devices that combine these transistors and offer a low-energy solution [18]. Designs for electronic control units of embedded electronic systems that increase the security of the agent's entire energy management system are explored as well [19].

IV. OPEN RESEARCH QUESTIONS

A. Human factors in cybersecurity of autonomous vehicles

When using autonomous vehicles, there is risk of a cyberattack on the software that controls the vehicle. In such cases, appropriate action should be taken to neutralize the attack or minimize its consequences, which requires human intervention. But compared to machines, humans are far more prone to errors, so to increase efficiency in dealing with software threats and attacks, it is necessary to minimize human errors.

It is crucial to identify potential cyberattack scenarios and the people who are most vulnerable to them, and to create educational materials specifically designed for them [20]. In my opinion, narrowing down the most vulnerable groups and targeting them during any informative processes could result in more efficient appropriation of funds and resources for education on this topic.

Furthermore, it is important to lay the groundwork for what cybersecurity is and what risks there are to autonomous vehicle software. An important research question is how to explain these terms to the average citizen [21], or even exactly how exposed is the average citizen to such threats.

B. Defining regulations

It is important to define the level of attention required by passengers in autonomous vehicles. Research shows that different drivers have vastly different reactions and reaction times to unexpected events while driving [22] [23] [24]. Researchers need to determine the maximum permissible level of distraction of the driver to enact proper legislation [20]. This is especially important for vehicles of levels 2 through 4, since they are not fully automated and require human assistance or takeover in certain cases, which differ through each of the levels.

Lastly, it is important to note that the findings of some of these studies would be truly necessary and useful only when there is daily and widespread use of autonomous vehicles [20]. But even so, I believe that researchers should be encouraged to explore these areas continuously. It is far better to have the answers to these questions early on, so that they can fundamentally affect the development and design of such autonomous systems.

V. CURRENTLY DEVELOPED SYSTEMS

A. Autopilot

Autopilot is a collection of driver assistance software features currently developed by Tesla, intended to increase road safety [25]. They currently offer three system packages:

1) Autopilot – steering assistance and car-speed matching assistance with the speed of surrounding vehicles
2) Enhanced Autopilot – upgraded to include additional assistance with lane changing and parking, as well as a "Summon" feature which can move the vehicle out of a parking spot or tight space
3) Full Self-Driving Capability – includes all aforementioned features and additionally and all necessary hardware for fully autonomous driving.

As of 2019, every Tesla car is equipped with the standard Autopilot package, while the models containing necessary hardware can be upgraded to the additional two packages. The systems of Model 3 and Model Y use 8 external cameras, 12 ultrasonic sensors and an on-board computer which uses neural network processing. The systems of the newer Model S and Model X are additionally equipped with a radar [26].

It is important to note that all system packages require active vehicle control and supervision by the human driver, especially keeping their hands on the steering wheel. The current capabilities of this system are at level 2 driving automation.

B. Toyota Teammate

Toyota Teammate [27] is a suite of driver assistance technologies currently developed by Toyota:

- Advanced Park – performs hands-free parking operations monitored by the human driver
- Advanced Drive – driving assistance including steering, acceleration, breaking, changing lanes and more, with a hands-free option under specific conditions, requiring constant supervision by the human driver [28].

This system is also at Level 2 driving automation, intended to assist human drivers.

C. Drive Pilot

Drive Pilot is an intelligent driving assistance system actively developed and tested by Mercedes-Benz, which has the potential to reach Level 3 driving automation on highways [29]. The user (human driver) needs to be ready to resume driving if the system anticipates that it cannot continue reliably driving. The procedure is precisely defined – the system firstly requests from the user to resume driving, while continuing to operate the vehicle until the user takes over. If the human fails to respond, the system will bring the vehicle to a safe stop and turn on hazard warning lamps.

This system can only be enabled within its Operational Design Domain which includes the required conditions in which it knows how to drive – fully access-controlled highways with medium to dense traffic in fair weather. Additionally, available driving routes are defined within a precise and high-definition map. The system also continuously monitors the user's state and if it detects prohibited actions, such as sleeping, it issues warnings and furthermore, safely stops the vehicle if the user persistently fails to respond [29].

The Mercedes-Benz S-Class models equipped with this system use a variety of sensors, including radar, LiDAR, camera, road moisture, ultrasonic sensors, and microphones, which provide a 360-degree field of view. The input from all sensors is combined to improve the accuracy of the environment. The redundancy of some of the perception sensors ensures proper functioning even in the event of certain sensor failure [29].

Additionally, the system contains thirteen individual functions meant to assist the driver when Drive Pilot is turned off, including speed limit, lane change and keeping, braking, blind spot vision, parking, emergency stop, and more [30].

VI. CONCLUSION

There is no doubt that autonomous vehicles offer many benefits to humans. Statistical estimates show that the vast majority of road accidents occur due to human error. Even if we put car accidents aside, humans are still fundamentally irrational beings who do not have the computing power of a machine and cannot always calculate and take the optimal step. Due to this, there are often traffic jams, delays, and congestion that last for hours and drastically reduce the efficiency of traffic.

Autonomous vehicles, as systems that are completely rational and guided by the rules programmed into them, are a potential solution to many of the traffic problems we face. They would follow all traffic rules without unnecessary speeding or unplanned lane switching, they are not prone to drunkenness and other intoxicating substances, and they have no egoistic tendencies that would influence their decisions.

However, the technological innovations in this field are still insufficient to achieve the fourth or fifth level of vehicle autonomy. Although experts are optimistic that a solution will be found in the next few decades, this requires a lot of resources and research, but also legislation that will properly regulate their use. We must not allow fully autonomous vehicles to be integrated into our daily lives without being completely sure that they are secure and reliable.

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