The State of Autonomous Driving: Progression and Future Adoptability

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ABSTRACT

Introduction

Current Safety and Efficiency of Autonomous Driving

Autonomous driving and autonomous vehicles are currently some of the most heavily studied and publicly followed technologies in the automotive realm. This technology could greatly improve safety, efficiency, and mobility by replacing the driver and relying on vehicles to navigate themselves through traffic. In order to accomplish the vision of autonomous driving, many technical challenges need still to be solved. But there are also many non-technical challenges to be considered on the path toward a vision of autonomous vehicles. The legal challenges being among the most critical. As automobiles are becoming more and more self-reliant in making mission-critical driving decisions, public policies, and technical standards need to be revisited to prepare courts and the public for the new realities of traffic with autonomous vehicles. [Beiker (2012)]

Automatic and Autonomous Driving Assistance Systems

Firstly, it is important to note there is a difference between fully automatic and autonomous driving systems. The question "Does the driver have to stay in the loop, if he is driven by a car, which is completely guided by a computer?" has to be answered. In any case, from an outside view the behaviour of the car should take application dependent, definite rules into account such as road traffic regulations. In other words the vehicle has to act autonomous in terms according to moral law. In the civil area the effective moral law are road traffic regulations, which aim for collision avoidance and physical inviolability. [Hörwick and Siedersberger (2010)]

The study type of active system used is known as the driver assistance system (DAS). This system helps the driver and provides a safer driving experience with technology that provides automated or adaptive driving functionalities. According to the Society of Automotive Engineers (SAE), there are six levels of vehicle autonomy[Curiel-Ramirez et al. (2019)]:

- Level 0: No automation. The driver has full control and performs all driving functions at all times.
- Level 1: Driver assistance. The driver has full control, but the vehicle provides assistance for one or more driving functions, e.g., electronic stability control or assisted braking.
- Level 2: Partial automation. The driver has primary control over the vehicle, but the vehicle can take full control of more than one driving mode, e.g. steering and acceleration/braking in combination.
- Level 3: Conditional automation. The automated driving system has primary control and performs all driving functions under certain conditions. Human driver intervention is requested in many driving modes.
- Level 4: High automation. The automated driving system has almost full control over the vehicle. Human driver intervention is needed only in some driving modes.
- Level 5: Full automation. The automated driving system has full control over the vehicle. No human driver intervention is needed.

Safety Features(CAV'S)

With advances in sensing, machine learning, and computing systems, autonomous driving applications have become feasible and ready to use. This, combined with the use of communication technologies like dedicated short range communications (DSRC), autonomous vehicles can also communicate with each other, pedestrians and the infrastructure in the environment around them. We refer to vehicles with such capabilities as connected and autonomous vehicles (CAVs). As the number of applications and levels of autonomy increase, the complexity of CAVs continues to increase.

CAV systems consists of large numbers of sensors that sense its environment. The data from these sensors are fed into a computing system that runs a variety of software components. These software components process the data, perform calculations and control actuators to achieve autonomous driving applications. The design and modelling of various software components that constitute an important step in the development of CAV systems. This step also includes defining the interactions of these software components with each other and the hardware components. The next step in the development process involves the deployment of these components onto a real system.[Bhat, Aoki, and Rajkumar (2018)]

Problems to Overcome

Most of the available computer vision applications are based on cameras that can only be used under the condition of normal light and clear weather, which makes most of the state-of-the-art models not suitable for night images. Traffic safety statistics show that 51.1% of the U.S. fatal crashes happened at night (from 6 pm to 6 am), especially in rural areas with low illumination. Enhancing night images for a clear traffic environment is a step in the right direction for traffic safety and should be incorporated into ADASs and CAVs.

However, the outline and appearance details of traffic participants are easily blurred at night, making it hard to tell apart target objects from the background. Therefore, restoring the details of low-light images is a hard task, especially for the low-light images. One method to solve this problem is histogram equalization (HE). HE makes brightness better distributed on the histogram, which can be used to enhance the local contrast without affecting the overall contrast. Another method is gamma correction, which increases the brightness of dark regions by compressing bright pixels. However, these approaches only focused on the night situations with external light sources (e.g., urban roads with street light). There is a need for an image enhancement model that can be used in darker areas because crashes and accidents are more likely to happen while driving in rural areas at night without streetlights[G. Li et al. (2021)].

Crashes and the Responsibility of the Manufacturer VS the Owner

Should we hold the manufacturers responsible for any crash caused by the vehicle? If there is some design decision in the system, which causes an accident in certain situations, or perhaps a flaw, they probably knew about or should have discovered. Why should they not have to take responsibility?

On the other hand, there is question of whether we should try to promote the development of autonomous cars to begin with. In other words: should we try to design the liability for autonomous vehicles in such a way that it promotes their continuous development and improvement? Should such vehicles be allowed on our streets? If there are good moral reasons for finding the development and introduction of autonomous cars to be desirable, this can produce a moral obligation for the state to fashion the legal responsibility for crashes of autonomous cars in a way which helps the development and improvement of autonomous cars.

There are many arguments which can be made in favour of or against the introduction of autonomous cars. Possible problems include privacy issues and environmental harm from fully-autonomous vehicles, as these could lead to more vehicle-miles travelled. On the positive side, the introduction of autonomous cars might among other things enable the physically impaired, disabled or elderly to drive their own vehicles.

The development and widespread use of autonomous cars could cause a reduction of accidents, it could therefore save lives. Even if we are talking of a relatively small improvement like a reduction of 5% it would save hundreds of lives a year in countries like the US in which deaths in road accidents go into the tens-of-thousands.

An alternative would be to hold the users of autonomous cars responsible for possible accidents. One way of doing this would be for the driver to pay attention to traffic and take control of the car when necessary. The liability of the driver in the case of an accident would be based on his failure to pay attention and intervene. The problem is that Autonomous vehicles would lose much of their use. It would not be possible to send the vehicle off to look for a parking place by itself or call for it when needed.

As long as there is some evidence that a system in which people must intervene would do noticeably better in terms of number of accidents than one in which autonomous vehicles are left to themselves there is much to be said in favour of such a duty. If the introduction of autonomous vehicles reduces accidents by fifteen percent, and a duty to intervene for the “driver” would lower the death rate by another fifteen, that would seem to create a moral obligation on drivers to be on the lookout for possible failure. Also, it would also give the technology an opportunity to develop gradually. Autonomous driving could slowly evolve, going from the current level of automation through a number of intermediate stages to fully autonomous cars. On the downside, self-driving cars would, in such a scenario, not be useable by physically impaired, disabled or elderly people[Hevelke and Nida-Rümelin (2015)].

Progression of Autonomous Vehicles and Supporting Technologies

Since the constituents that make up autonomous vehicles are vast, we will be focusing on some key elements and how they are progressing. Computing power paired with machine learning is exponentially improving the capabilities and safety of every vehicle and plays a vital role in receiving permits and permission from regulators to operate. Declining battery costs will drive down production costs which directly translates to savings for potential customers and drive-up the rate of adoption. The gap between the total cost of ownership of battery powered electric vehicles and regular cars can be overcome if the cost of batteries drops to around €150/kWh. [Van Vliet et al. (2011)] The synergy between batteries and software will be integral in keeping stable ranges and temperatures [Ali et al. (2019)]. Progress is also being made in establishing charging infrastructure that supports driverless vehicles using sustainable sources of energy such as wind and solar [Nunes, Farias, and Brito (2015)]. These aspects are vital to the success and widespread adoption of these vehicles.

The Importance of AI and Making Decisions

We are now in an age where the progress in technology is accelerating. Along with the help of AI, the world will be a vastly different place in a few years time "The impact of AI technologies can be even more profound than that of both the Industrial and digital revolutions put together, as it holds the potential to affect practically all tasks currently performed by humans,"[Makridakis (2017)]. Autonomous vehicles will come as the result of many rapidly developing technologies converging into a single product. These include neural networks, machine learning, deep learning, battery engineering, renewable energy, software engineering, and much more.

To get to this point, every autonomous vehicle must exhibit some intelligence and ability to make its own decisions if it wants to navigate the constant changing environment. It needs to accept several inputs from the outside such as geometric shapes and signs and output an action that will result in safe and smooth driving. It needs to distinguish between what needs to be avoided, predict the paths of different objects, anticipate where everything will end up due to physics and be able to apply reasoning behind every decision [Pomerol (1997)]. There is no realistic method for developers to manually code every situation as the effort that is demanded is gargantuan.

Artificial Intelligence works in this context because as you feed it more data, it will gradually learn patterns which is not too different from how the human mind learns. Researchers have attempted to imitate the human brain's learning process by creating networks of artificial neurons. To have it recognise faces, they show the network training examples, compare the actual activity of its outputs with the desired activity before tweaking the weight of each connection to reduce the error and subsequently training the network [Hinton (1992)]. In a similar fashion, we also learn through experience and error correcting. This is the ideal method for training autonomous vehicles and handling edge cases that may otherwise not be caught. To best train autonomous vehicles, you must have high quality, real world data which must be retrieved in an efficient manner and have substantial quantity. Errors must be labelled to nudge the neural network towards higher accuracy.

Image-Recognition Training

Many companies have their own approaches at attempting to solve autonomous driving. For example, Google's Waymo team builds "three-dimensional maps that highlight information" using Lidar technology, sending out laser pulses to measure ranges. They have already released their robotaxi service in the Phoenix Metropolitan Area, Arizona, United States of America *Waymo* (2021). For our discussion, we will take a closer look at Tesla's Full Self-Driving team and how they leverage data clips gathered from their vehicles' suite of cameras. At the moment, their team manually label video clips, identifying objects such as road markings and signs to train the neural network. At first, they only labelled individual frames from each of the cameras which can be time consuming. However, by using visual Simultaneous Localization and Mapping or visual SLAM, the cameras can also build three-dimensional maps, allowing staff to label a single three-dimensional scene as opposed to thousands of two-dimensional frames, drastically improving efficiency [Durrant-Whyte and Bailey (2006)].

Unfortunately, scaling this approach will be financially demanding as humans are expensive compared to computers. Soon, big central processing units will make it so that humans are needed less, and the AI will automatically label points based on interventions from clients. Andrej Karpathy humorously named this objective "Mission Vacation", where the final goal is to have most of the engineers go on a vacation while the neural network continues its training, leaving behind only a few staff for labelling. An example of progress made in recognition technology can be found in the paper [Karpathy et al. (2014)], where researchers are able to use neural networks to identify sports in video clips. By training the network using "1 million YouTube videos belonging to a taxonomy of 487 classes of sports", even with weak or inaccurate annotations in the videos' metadata, it was still able to predict what sport was playing with high levels of confidence.

Processing Data with Supercomputers

Another fundamental constraint to the improvement of autonomous driving technology apart from the data set is computing power. To process all of these images and retrain the network constantly, huge computing power is required. Through the use of supercomputers, training can be done more efficiently than traditional graphics processing units. "We show that it is possible to design a multi-chip architecture which can outperform a single GPU by up to 450.65x and reduce energy by up to 150.31x using 64 nodes. Each node has an area of $67.73mm^2$ at 28nm." [Y. Chen et al. (2014)]. Since they're trying to solve computer vision through machine learning with vast amounts of data, Tesla is also developing a huge central computer called "Dojo" to train the neural network with reduced limitations. Thus begins the "March of Nines", where safety can never be 100% assured but we can converge to it as closely as possible, going from 99.9% to 99.99% and so on. From driver interventions, labellers can identify the neural network's weak points. They can request the driving network of every Tesla vehicle fitted with cameras to retrieve similar cases so that they would not get redundant information that the neural network is already adept at handling. [Tesla (2019)]

Progression and Future Development

Before we discuss this topic, it is important to discuss the certain challenges that Electric Vehicles face as Autonomous Vehicles typically only deal with Electric Vehicles. This way we can understand the areas that need to be improved in the first place. Some of the hindering factors might include the driving range, which is currently limited due to the capacity of batteries and the refuelling of them, the cost of these batteries, the performance, and the period it takes for a vehicle battery to recharge and be ready for use. The station infrastructure is a necessary building block for all Electric Vehicles. Without these charging stations we can only utilise our vehicles around a singular charging point, your house for example. These factors hinder the development of Autonomous Vehicles because they depend on the Electric Vehicle. [Bimbraw (2015)]

Barriers of Electric Vehicles

The biggest concern for users would include charging time and battery capacity which affects the range of a vehicle. It is a topic that is discussed a lot in the Electric Vehicle industry and Autonomous Vehicles as they are dependent on each other as mentioned above. There are three types of battery charging methods. The first method is just static charging utilising a cable while the vehicle is parked. This level depends on the power level the equipment provides. This power level gets more expensive the bigger it gets and the time the battery takes to charge decreases accordingly based on the level. The second method is inductive/wireless which would facilitate users the ability to charge their vehicle batteries without the use of a cable. This method does not need the vehicle to be parked necessarily as it just needs charging pads built in the pavement. The third method which is extremely challenging to implement for electric vehicle manufacturers would be swapping your battery. Although this is a good idea it cannot function if the manufacturer does not enable it. Most of the electric vehicle manufacturers do not currently facilitate this last charging method. It in fact even seems unrealistic to an extent.

The limited driving range with these vehicle batteries or battery capacities is another important concern that needs to be further developed. Reports show that customers expect alternative fuel vehicle ranges to be at least 300 miles. From the user's perspective the driving range is one of the predominant barriers. Once we improve these factors, autonomous vehicles become a more enticing option for users. [Alsalman et al. (2021)] [Nieuwenhuis and Wells (2012)]

We need to understand that improving these factors will improve Autonomous Vehicles in general. Now we can discuss some of the things that we can anticipate Autonomous Vehicles will improve in the future, it can reduce traffic congestions, pollution, fuel consumption and facilitate the mobility of disabled and older people further. It is also expected that self-driving will decrease the number of accidents and crashes through vehicle-to-vehicle communication. [Levinson et al. (2011)]

Advantages and Disadvantages of Autonomous Driving

Some may in fact argue that since the internet emergence, Autonomous Vehicles will most likely be the most substantial change and transition that will happen to societies and cities around the world. To achieve these benefits that Autonomous Vehicles might include we need to plan and consider the advantages and disadvantages of these Autonomous Vehicles. Some barriers that we must overcome might include safety, user acceptance and reaction, certification/ regulations and ethics, accurate positioning and mapping, computer software and hardware and communication systems. These are some of the sectors that we invest in for the benefit of our future. If we manage to help minimize these barriers into something negligible then these factors loose importance in our further development of Autonomous Driving. [Bezai et al. (2021)]

The Improvements of Autonomous Driving on Traffic Congestion

Autonomous Driving will most likely change urban mobility within the next few decades. It is believed that soon autonomous vehicles will share the road with human-driven vehicles in many cities worldwide. Certain studies discussed certain systems effects on traffic patterns and discovered that the sole transition to Automated Vehicles, even of small size, would not change the existing traffic patterns significantly. But when we implement certain control algorithms, such as the formation of vehicle platoons, this can dramatically increase the capacity of the city roads. Some of these results showed that with an Automated Vehicle penetration ratio higher than 40% and with the ability to form the platoons discussed above, certain travel times could be 50% shorter than what it could currently take to achieve. This would benefit thousands of people and it would decrease the environmental impact while doing so. [Santana et al. (2021)]

There are various studies that have been conducted on the improvements Autonomous Driving might have on traffic congestion. This is a current issue due to human error and once this is eliminated with Autonomous Driving this can be drastically improved. For example, a study taken from a traffic scenario of Duisburg city inner ring where two different data sources have been generated and compared. Vehicles with different automation levels were simulated continuously in this city inner ring scenario for more than 24 h of a day. Based on this real traffic volume collected in 2019, research can conclude that vehicles with automation Level 2 and Level 5 have positive effects on traffic. The higher automation levels show more positive effects in these studies. [Ma et al. (2021)]

Future Autonomous Driving Concepts

These discuss certain aspects of Autonomous Driving when this co-exists with regular drivers but there are also huge benefits to a full Autonomous Driving society. They will need to include intersection management, smart parking, ride sharing, ramp merging, platooning and traffic flow optimization. Some of these can be achieved while the regular driver co-exists but in an ideal world the regular driver does not exist as it minimizes human error. These are just some of the features that the future will possibly offer us. All of these features have a similar goal in mind, to minimize travel length and improve the safety of vehicles on the road. [Mariani, Cabri, and Zambonelli (2021)]

Conclusion

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