Machine Learning in Self-Driving Vehicles

CS4106 Research Project

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Introduction

The idea behind a self-driving vehicle is simple, outfit the vehicle with cameras and other types of sensory equipment that can track all the objects around it and have the vehicle react if it's about to steer into one. Teach in-car computers the rules of the road and set them loose to navigate to their own destination.

It was previously thought that at this stage, the majority of cars on the road would be self-driving. However, it has proven more difficult to get to that stage than initially anticipated - we will discuss why later. Even though we aren't at the level that was planned for self-driving cars in 2020 - the hype around self-driving vehicles, especially cars, is growing with more big tech companies getting behind the concept.

The advantages and disadvantages of driverless cars can be argued and we will take a closer look at both sides of this argument in this report. This report is also going to look at the machine learning aspect in self driving vehicles. We will take a look at what it takes for a self-driving vehicle to be considered a success and some of the "training" the vehicles go through to get to a stage where they are competent and able to drive as humans do.

In this report, we will look into some of the leading companies in this field and what they are doing to advance the field of self-driving vehicles. We can see where advancements have been made and the different stages in reaching a self-driving vehicle and how machine learning is a vital aspect of a self driving vehicle.

Self-Driving Vehicles Overview

Self driving vehicles are vehicles that can bring you from one location to another with little to no human input [2]. Developing these vehicles involves gathering a lot of data and information in order for the vehicle to know what to do in any given situation. Gathering this information was tedious and involved a lot of manual work, that was until the advancements in machine learning came. Since machine learning and AI have developed, it has added the ability to act as the brain of a self driving vehicle. It uses the data obtained from the sensors on the vehicle such as the cameras and radars, and performs various machine learning algorithms to process the information and gather all the important pieces of information, e.g, if there are other vehicles around you, how big they are, and their speed and distance from the car [2]. This information is then used to decide the best way to handle any situation. It is clear that machine learning is a vital part in a self driving vehicle as it does act as the brain

of the car and is in charge of deciding what information is relevant in making a decision.

Nvidia and Self-Driving Cars

Nvidia is one of the world's top graphics card designers and manufactures the world has ever seen. They specialise in high-end graphic card designs for computer enthusiasts all around the world, with some of their products costing easily over €1000 [4]. Recently however, Nvidia have started to enter the world of artificial intelligence (AI), unveiling their technology around artificially intelligent self-driving cars. This use of AI gives the cars of the future the ability to see, think, learn and navigate through the world's most complicated and demanding driving scenarios. Nvidia and the use of their technological advancements provide data collection, model training and testing in simulation which help advance the future of self-driving cars [4]. Nvidia has called this large scalable cloud based computer platform NVIDIA DRIVE which was first showcased at CES in 2015.

Nvidia have created the world's first processor designed specifically for autonomous driving. The new Xavier system-on-a-chip (SoC) can run complicated AI algorithms, provide sensory processing, mapping and driving. This in turn allows Nvidia's platform to process data from its camera, radars, ultrasonic sensors in real time to allow itself to drive in a safe path in its 3D environment. This processor is called “Orin”, which contains 17 billions transistors that can deliver 200 trillions operations per second [4].

In order to understand what are the necessary conditions for a car to reach full autonomy, the Society of Automotive Engineers (also known as “SAE International”) established six categories of autonomous capabilities to lay out a set of clear benchmarks in this area of technology where many elements come into play [5].

Level	**Example**	**Introduction**	**Description**
0	Fiat Punto, Ford Escort 	1900 - Now	• Zero automation • Seat, wheel, engine • Lane departure warning • Total human dependence

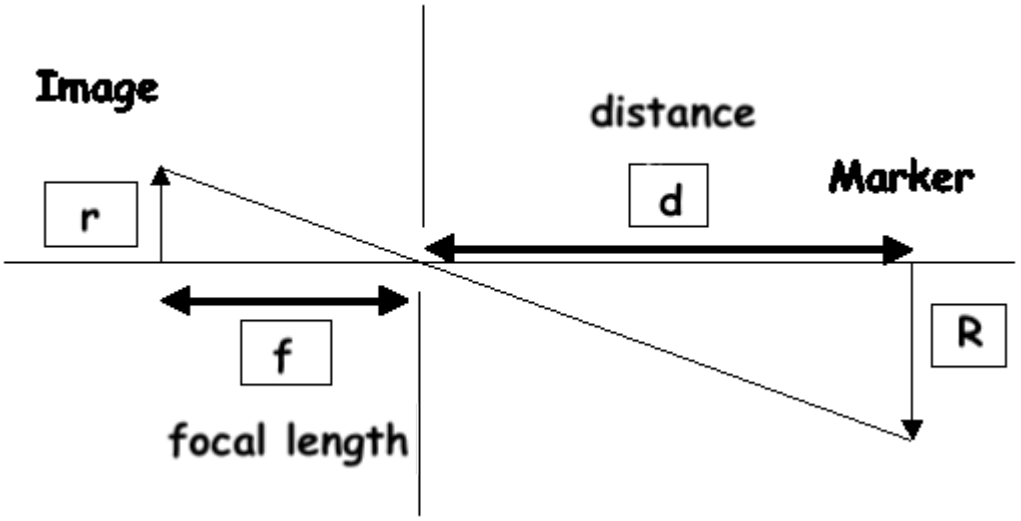
1	Opel Astra 	2007	• Sensors/cameras • Speed limiters • Intelligent cruise control • Minor speed assistance • Minor steering assistance • Both not possible at the same time
2	Tesla Model S 	2014	• Controls both speed and steering at the one time • Lane centering (limited to easier road conditions e.g. highways) • Basic computer vision • Human input still required
3	Audi A8 	Est 2020	• Controls speed and steering • Safely passes other road users • Maneuvers through traffic jams • No touch of wheel or pedals necessary • Touch only required if requested by the car
4	Alphabet's Waymo 	2021/22	• Drives itself safely without human interaction • Responds appropriately when a human doesn't respond when requested • Still has a steering wheel in case it's needed
5	None so far Audi Aicon concept car 	Mid - late 20s	• Only human interaction is final destination location • City and off road driving • Car is fully in control

How does a self-driving car see

One could say that in order for cars to be able to drive better than a human, they must be able to see the world around us in a better way than humans can. The average human field of view is about 200 degrees horizontally, yet thanks to cameras and lasers being fitted on these cars, a field of view of 360 degrees can be achieved. The three main sensors of these modern AI cars are camera, radars and lidars.

Different cameras can be used and multiple cameras can have their images stitched together to create a full 360 degree view. Some cameras provide short field of view but long range visuals, while other cameras contain a complete 360 degree fisheye lens - providing a complete all-in-one view of the world around it. These cameras are good for distinguishing objects around the vehicle, but lack the ability to tell a distance as they must be calculated using computer vision algorithms. They also lack full visibility and accuracy in conditions such as fog and nighttime.

We can obtain this distance using the principle of similar triangles



We then use this formula to obtain the distance

$$\frac{f}{d} = \frac{r}{R} \tag{1}$$

$$f = d \times \frac{r}{R} \text{ pixels} \tag{2}$$

$$d = f \times \frac{R}{r} \text{ cm} \tag{3}$$

This formula can be run on openCV to calculate live realtime distances [1].

Cars also use radars to provide more accurate detection of objects in low visibility conditions and improve the general detection and safety of the car. These radars are usually stored in the car's bumpers as this obtains no interference from other car parts. These radars send out radio waves and wait for their return when they bounce off other objects to provide a variety of data such as speed and location. Cameras and radars are sufficient for lower levels of autonomy, such as level 2, but they still need human assistance.

This lack of data is where lidars come in, these are laser focusing sensors which are very important in providing full autonomy for vehicles. These pulsing lasers help provide a 3D model of the world around the car by providing depth and shape to surrounding objects and road geography. These lasers are instantaneous and provide point clouds of the area around it. Point clouds are datasets that represent objects or space. These sensors however have a limited range and cost up to ten times more money than a radar and a camera, but only one or two are needed to be effective.

These sensors must come together with the use of sensor fusion. An AI computer such as Nvidia Drive AGX can be used to combine this data and ensure each sensor is reliably recording and accurately returning data.

Thanks to the use of these sensors, cars are able to have an up to date real world 3D model which can be used to avoid blindspots and constantly analyse the world around them. These sensors can all be fed back into a central machine learning system which will lead to cars having a way of thinking all by themselves.

TensorFlow

TensorFlow is recognised as a powerful AI software, created by Google and their Google Brain Team, supplying power to many services and initiatives within Google. [14] TensorFlow succeeded DistBelief(2015), which was the first generation of

large-scale machine learning implementation. The purpose of creating TensorFlow was to try and mimic the way a human brain works through a computer system. The system, known as neural networks, should perform on multidimensional data arrays referred as “tensors”.[14] The goal of this, would be to train these neural networks to detect and decipher patterns and correlations just like the human brain.

TensorFlow is unique as it can cover hardware ranging from low level mobile devices to large scale multi-GPU servers. It offers scalability to users of machine learning to a large range of devices without having to alter a large amount of code.

Google made this technology open source in 2015. This enabled companies across the world with various products and/or research projects, to help speed up the growth of machine learning and take it to the next level. TensorFlow quickly became one of the most popular machine learning frameworks used by developers because of this stroke of genius. Google also went a step further by creating a computer chip that has integrated TensorFlow, optimizing the use of machine learning. It is called the Tensor Processing Unit (TPU) ASIC chip. [14]

One of the companies that has implemented TensorFlow deep learning framework into their work is Nvidia. In 2018, members of NERSC (National Energy Research Scientific Computing Centre) and Nvidia tapped into the power of Nvidia's GPU(Graphics processing unit) units.[13] These Tensor cores are the most advanced data center GPU ever built to help accelerate AI and machine learning. They used both Python and TensorFlow to express the application of the network and workflow. TensorFlow enables high performance, providing developers an environment in which it is fast and free flowing.

The Application of TensorFlow to Self-Driving Vehicles

TensorFlow has rapidly developed over the last few years, thanks to Google making it an open source technology. Self-driving vehicles have been progressing in areas such as object detection and speech recognition with the help of TensorFlow.

Object Detection

One of the most utilized areas of TensorFlow is the object detection API, an area vital in the world of self-driving vehicles, giving you the ability to construct, train and develop object detection models. The definition of object detection refers to the image processing that deals with detecting instances of semantic objects of a certain class. This allows self-driving cars to perform just like a normal car without any kind

of human input. Object detection is mixed with a variety of techniques like radar, laser light, odometry, computer vision and GPS, making it efficient for road use. [20] Computer systems have become so advanced that they can navigate a path that is appropriate for the driver at the wheel, but once the car's image sensors recognise any living object in front of the car, it should stop.

Speech Recognition

TensorFlow allows users to construct neural networks that can recognise spoken words. This can be done by using RNN (recurrent neural networks). RNN is a type of architecture which processes inputs organized as a sequence.[21] RNN variants are supported by TensorFlow and can become very complicated once large scale models are used.

In conclusion, Google has presented a path to machine learning for the entire world to discover and to innovate on. The application of TensorFlow in self-driving vehicles is becoming more commonly implemented, while the use of TensorFlow in both object detection and speech recognition showcases their vital roles in the development of machine learning in self-driving vehicles.

Leading self-driving vehicle companies

Waymo

Google has a sister company called Waymo, which is an american autonomous car development company. Waymo's goal is to make it safe and easy for people and things to get where they need to be - and in doing so, save thousands of lives lost to traffic crashes. Waymo made these vehicles keeping in mind that humans have a lot of assumptions when it comes to how things should work out when driving [8]. However, after training their cars with thousands of miles worth of data, Waymo have designed it to think of worst possible scenarios and are therefore able to avoid them and prevent crashes. This is done as the vehicle "never takes its eyes off the road", it has cameras and radars that are consistently looking around and seeing what is happening from every angle and in some cases, like a ball rolling across the road, it is able to calculate its velocity and trajectory to see if or when it could come in contact with the car and therefore avoid it.

Waymo began in 2009 as "Google Self-Driving Car" project. They started out with a Toyota Prius with their first milestone of driving over ten uninterrupted 100 mile routes. They then added the Lexus RX450h to their testing fleet and began asking

Google employees to test the cars on highways. After this they decided the best move was to build their own cameras and sensors from the ground up. After this , they moved their focus to navigating city streets, pedestrians and more complex algorithms for driving in more enclosed and complex areas. In 2015, the Google Self-Driving Car project tested the limits of what was possible with a fully self-driving car, the Firefly. The firefly had no steering wheel or pedals and made its first trip in Austin, Texas with a legal blind man as it's passenger. The Google self-driving car project was officially changed to Waymo in 2016. In 2017, Waymo partnered with Fiat Chrysler Automobiles to add the Chrysler Pacifica Hybrid to their fleet of cars, with this hybrid being the first one to be mass produced. 2017 was also the year that Waymos self-driving vehicles began testing on public roads with no one in the driver's seat. Waymo's latest achivement started in 2018 with the launch of Waymo One in phoenix and was upgraded in 2019 to fully driverless rides [8].

From this brief history of Waymo it is clear they are one of the leading companies in designing and producing self-driving vehicles with many already on the road. They have accomplished this while always keeping the safety of it's passengers in mind with the goal of limiting crashes.

Valeo

Valeo is a world-leading global automotive supplier, designing and manufacturing components and systems for cars and trucks. It was founded in 1923 in Paris, France. Valeo Vision Systems belongs to Valeo and designs and manufactures multi camera systems for the automotive industry. Valeo Vision Systems was set up in Ireland in 2007 after Valeo bought Connaught Electronics [7]. The headquarters of the Valeo Vision Systems Product Line is set up in Tuam along with one of Valeo's largest research & development centres [9].

Valeo Vision Systems specialise in front, rear, top and side cameras for vehicles. In 2016, they produced 5.2 million of these cameras. Their Irish site currently employs more than 900 people. Valeo was the first to bring reversing cameras for vehicles to the European market, via Tuam. They are now focusing on more sophisticated cameras such as cameras with a 360 degree view to assist low speed, safe maneuvering [10]. This is done using four different cameras to work cohesively to form a single image of the vehicle's surroundings. They have also developed a wide angle camera that is being used to generate cross traffic alerts, improving views at junctions, detecting pedestrians and providing aid to towing trailers.

Park4U is an automated parking system that Valeo developed. It combines ultrasonic sensors and vision systems to scan the sides of a road to detect a suitable parking space [11]. If the vehicle has stopped and the driver engages the vehicle into reverse, the system takes over the steering while the driver still has control over the speed of the vehicle with the accelerator and brake. It's the same as a regular parking manoeuvre except handsfree. If the driver wishes to stop the procedure at any time, they can do so by placing their hands on the steering wheel and the system will deactivate. Park4U first debuted in 2007 in a Volkswagen Turan, but it is still evolving and can now parallel park and also park at an angle to a curb [11]. The system only needs 40cm of space to the front and rear of the vehicle to successfully park it. It can also help the driver exit a parking space, by measuring the amount of space at the front and rear of the vehicle and then calculating the best strategy to exit the space. Like parking, the system takes over the steering wheel and allows the driver to control the speed of the vehicle. It detects the best moment to leave the parking space and deactivates to allow the driver to go back into traffic.

Park4U Remote is not in market yet but it is a fully automated parking system that allows the driver to leave the vehicle before it is parked. The system then takes over and parks the vehicle itself while the driver can maintain control via a smartphone.

Valeo has contributed massively to the autonomous vehicle industry from their research and development of cameras and sensors for vehicles. Research & development is at the core of Valeo's growth strategy and their identity as a technology company. As cameras play a large role in a self driving vehicle and have a major input into the machine learning algorithms within the vehicle, it is an important aspect to have right when developing a self driving vehicle. That is why we considered valeo an important contributor to self driving vehicles.

Advantages & disadvantages

Advantages

Less accidents

In 2016, a study carried out by the National Highway Traffic Safety Administration (NHTSA) concluded that over 94% of vehicle collisions were caused by human error. Obviously with AI, there is no room for human error as there's nothing to distract it whereas humans are prone to interruption. Self-driving vehicles also use complex algorithms that can determine the correct distance to stop before another vehicle which dramatically lessen the chances of collisions.

Efficiency

Self-driving vehicles are more efficient than regular vehicles. This is not just due to self-driving vehicles being electric - a study carried out by National Renewable Energy Laboratory on behalf of Volvo showed that there was a 5%-7% drop in fuel consumption with autonomous vehicles that used adaptive cruise control compared with human drivers. A decline in fuel consumption leads to more savings and less of a negative effect on the environment.

Less traffic

Self-driving vehicles have the ability to communicate with each other. This communication enables vehicles to send out and receive information about subjects such as road conditions, traffic flow, speed and direction. With the ability to see traffic jams, autonomous vehicles can calculate their moves and re-route their journey. Self-driving vehicles can also partake in platooning, the act of a group of vehicles all travelling within close proximity at a similar speed [18]. Platooning reduces traffic congestion by improving traffic flows and reducing tail-backs.

Disadvantages

Legal issues

If there were to ever be an accident involving an autonomous vehicle, the liability would fall onto the manufacturer of the vehicle rather than the owner of the vehicle. It's hard to establish product liability and claims as customers may not know whether to blame the vehicle's software or hardware. Consumer expectations and interest are high, regarding self-driving cars, but their knowledge is low. It is necessary to provide full training and education to improve safety and avoid manufacturer liability.

Security

Since self-driving vehicles consist of a lot of technology, the issue of security comes into play. These vehicles could be a target of a hacker due to the large amount of data it collects from its owner. As well as personal data being stolen, hackers could also take control of the vehicle itself. Researches in Manhattan, USA conducted a study and found that if 20% of self-driving vehicles were to be hacked and stalled during rush hour, it would cause total traffic [19]. Hackers have huge potential to cause havoc in multiple ways when it comes to autonomous vehicles.

Complacency

Fully autonomous vehicles have the potential to make drivers less attentive. With drivers paying less attention to their surroundings, problems can arise such as a lack of responsiveness to issues on the road and also to potential problems with the car itself.

Conclusion

In conclusion, it is evident that there has been huge advancements in AI technology for self-driving vehicles in recent years. Self-driving vehicles have gone from a sci-fi concept to a reality. This could not have been achieved without the huge research and development carried out by companies such as Nvidia, Google and Valeo. The advancements in self driving vehicles also couldn't have been achieved without the advancement in machine learning, that made processing data and coming to conclusions a lot easier than it was and since this is such an important part of a self driving vehicle it is the reason they have become more popular in recent years. Whilst we are not quite at the level where there are driverless cars commuting alongside us on roads, we are not far from it, with cars like the Tesla Model 3 that are accessible to all members of the public to purchase, that can drive on auto-pilot once there is a driver to supervise the driving. With everything that is going on in the world at the moment, self-driving cars are needed now more than ever to practice concepts such as social distancing etc. We can only assume that the future of self-driving vehicles is very near and that it won't be long before self-driving vehicles will be alongside us on our roads.

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