A Summary of Self-Driving Cars – Challenges and Opportunities

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The rapid advancements in technologies such as artificial intelligence and machine-learning in recent years has led society to begin questioning the possibility of fully autonomous cars. Companies such as Waymo, Pony.ai, Tesla and Uber are currently head to head in the race to provide such a product. However, the idea of a self-driving car is not a recent one. The idea first came to light in 1939, when General Motors employee Norman Bel Geddes designed the world's first self-driving car. The vehicle was directed using radio-controlled electromagnetic fields produced by magnetised metal spikes embedded in the pavement it navigated over. Sensors on the car's front bumper called pick-up coils determined how much current flowed through a wire in the road, and this current was modified to manoeuvre the vehicle. Decades later in the 1970's and 1980's respectively, Japanese and German companies both improved on this concept, using camera systems to detect objects and guide the vehicle. This use of cameras is still to this day a primary technology used in the development of the self-driving car.

Despite predictions throughout the 2000's that self-driving cars would have flooded the market by the year 2020, companies developing such vehicles have experienced multiple unprecedented drawbacks. As of today, there is no vehicle on the market which is truly autonomous. Out of the levels one to five of autonomy determined by SAE international, with level five being truly autonomous, only a handful of companies have produced vehicles which rank as far as level four. At level four, the vehicle can adapt to the majority of road and weather conditions and the vehicle theoretically requires almost no driver input [1]. The Tesla Model S is a prime example of a vehicle which can operate at such a precedent, using its full self-driving capability which can be purchased with the vehicle as an added expense. This capability comes with limits however, requiring the driver's full attention as a back-up for the system at all times as is stated on Tesla's official website - "The currently enabled features require active driver supervision and do not make the vehicle autonomous"[2].

So arises the question, why have these companies not reached the end-goal of level five autonomy? While there is a multitude of hurdles currently holding back the development of a fully autonomous vehicle, many of them lead back to the same issue – safety. The current hardware technologies such as sensors and cameras are capable of capturing the required real-time data for the operation of such a vehicle, and modern day computers have more than enough processing power to make sense of this data. However, a software bottleneck exists within the training of self-driving cars machine-learning algorithms. As of yet, the amount of data captured to train the vehicles with regards decision making and the like is nowhere near enough to safely deploy them as fully-autonomous. There is an almost infinite number of unprecedented situations a vehicle may encounter when driving autonomously, and in these events the vehicle may likely not know how to react correctly and result in taking a hazardous action. This provides a huge risk to passengers and other road users. A prime example of this shortfall was when a semi-autonomous Uber vehicle struck and killed a pedestrian in Tempe, Arizona on the 18th of March 2018. This was the first ever recorded case of a pedestrian fatality via an autonomous vehicle [3]. Despite the local police department first stating that the collision was unavoidable and there was no correlation between the incident and the fact that the car was operating in semi-autonomous mode, further investigation from self-driving car expert Michael Ramsey led him to categorize the incident as "a complete failure of the system to recognize an obviously seen person who is visible for quite some distance in the frame”. Uber were quick to counter this argument, providing hard evidence that the passenger in the vehicle was not providing the adequate attention required when operating a semi-autonomous vehicle. That being said, the incident was a clear indication to the world that we are still a long way from being able to produce fully-autonomous cars with the required amount of safety to operate freely on public roads.

Unfortunately, there is no getting away from the fact that the success of the self-driving car will come down to when enough training data has been gathered. The point at which this will be achieved will be when it is proven the vehicle has the knowledge to navigate a high enough percentage of situations safely, so that the risk is minimal enough to regard it as a safer alternative to being operated manually. One solution companies have begun to utilize in order to gather training data for self-driving vehicles is to run simulations. In these simulations, a virtual depiction of the vehicle can be put through an infinite number of situations, gathering data for training the algorithms used in self-driving vehicles in the real world. The advantages of these simulations are fewer physical vehicles are being trained on roads with other drivers, resulting in cheaper costs and less of a threat to road users.

Aside from the issues presented by this bottleneck, companies are continuously developing and upgrading their approach to the end-goal of a full-autonomous vehicle. The collection of real-time data around the vehicle is currently being achieved using two main approaches:

1. **Radar, Sonar and Cameras**
   Using a combination of three technologies, this approach is the cheaper but less accurate of the two. Radar has been used since the 1930’s and is installed in some format in practically every vehicle on the road today. Radar stands for ‘Radio Detection and Ranging’ and it works by emitting electromagnetic (EM) waves that reflect when they meet an obstacle. Since it uses EM waves, it can work under any condition [4]. Unfortunately, the integrity of radar is not always to be trusted, as it can produce misleading results due to noise interference caused by waves being reflected and the like. Sonar stands for ‘Sound Navigation and Ranging’. In a self-driving car, ultrasonic sensors use sonar to send out impulses, which are reflected when they bounce off obstacles. The echo signals are then received and processed. These sensors are commonly used in human operated vehicles to provide parking assistance. An advantage of using radar and sonar for self-driving vehicles is that both technologies can see through objects, unlike LiDAR. However, they lack the ability to comprehend objects moving at high speed and smaller objects, as well as differentiate between colours.

2. **LiDAR Augmentation**
   LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) [5] and optical characteristics of its surroundings . This involves firing the laser and calculating the amount of time it takes for the laser to return considering the speed of light, to calculate the ranges of objects from the vehicle. An objects optical characteristics are calculated from other attributes of the laser beam when it returns, such as reflectivity and absorption. This technology enables self-driving cars to map out their surroundings. Most commercial LiDAR sensors are capable of sensing up to 100 meters, with more advanced ones capable of reaching 200 meters [6]. Experts believe LiDAR augmentation will ultimately become the approach favoured [7] by the companies pioneering the self-driving car, as it offers much more granularity than what can be achieved using radar, sonar and cameras. The drawbacks of LiDAR augmentation are the high cost and the large amount of computational power required.

Whatever approach used by the vehicle to map out the world around them, the use of machine-learning algorithms is at the core of how all autonomous vehicles work. Four main categories of machine-learning algorithms are used – Regression, Pattern Recognition, Cluster and Decision Matrix algorithms [8].

1. **Regression Algorithms**
   Regression algorithms are used explicitly for predicting events. Bayesian regression, neural network regression, and decision forest regression are the three main types of regression algorithms used in self-driving cars. In regression analysis, the relationship between two or more variables is estimated, and the effects of the variables are compared on different scales. Regression analysis is mainly dependent on three core metrics - the number of independent variables, the type of dependent variables and the shape of the regression line.

2. **Pattern Recognition Algorithms**
   Also known as data reduction algorithms, pattern recognition algorithms are designed to rule out unusual data points. Recognition of patterns in a data set is an essential step before classifying the objects. These algorithms help in filtering the data obtained through the sensors by detecting object edges, and fitting line segments and circular arcs to the edges. Pattern recognition algorithms combine the line segments and circular arcs in many different ways to form the ultimate features for recognizing an object.

3. **Cluster Algorithms**
   Cluster algorithms excel at discovering structure from data points. It may happen that the images obtained by the ADAS aren't clear, or it may also occur that classification algorithms have missed identifying an object, thereby failing to classify and report it to the system.
   This may happen due to the images being of very low-resolution or with very few data points. In such situations, it becomes difficult for the system to detect and locate objects in the surroundings.

4. **Decision Matrix Algorithms**
   Decision matrix algorithms are essentially used for decision making. They are designed for systematically identifying, analysing, and rating the performance of relationships between sets of values and information in them. The most widely used decision matrix algorithms in autonomous cars are gradient boosting (GDM) and AdaBoosting. These algorithms determine the moves of the self-driving car. So, whether the car needs to take a left or a right turn, whether it needs to brake or accelerate, the answer to such questions is determined by the accuracy of these algorithms concerning classification, recognition, and prediction of the objects' next movement.

Due to the nature of a fully-autonomous vehicle having to constantly access a network, security has become a major concern for those involved in the development of the vehicles. Protection from malicious activity such as hackers is of the highest priority, as a compromised system could easily result in a plethora of accidents. Examples of how a hacker might exploit vulnerabilities in a self-driving car include hacking cars and holding the passengers inside for ransom, confusing the transport system in an area causing major accidents and traffic delays, and stealing personal data from the vehicle such as its destination. Like with all software, bugs and vulnerabilities often appear after commercial roll-out, and it's a common belief that many of the issues that will exist security wise with self-driving cars will not become apparent until after they are exploited. That being said, there have already been occasions where hackers have successfully compromised one of these systems. At the annual Pwn2Own hacking event in Vancouver Canada, white hat hackers Cama and Zhu successfully infiltrated Tesla's Model 3 'infotainment' system via a weakness in the browser [9], resulting in them being able to print a message onto the cars control screen using their own code.

Another issue is the fallout when fully autonomous cars become involved in accidents. While it is predicted that when self-driving cars become somewhat the norm the number of road deaths will fall drastically, but there is still going to elephant in the room when an accident does occur. Who is to blame? When a driver on the road is involved in an accident in today's world, the reaction which the driver takes, such as swerving to avoid an obstacle, is exactly that, a reaction. If a self-driving car takes a course which leads to an accident, it made a pre-calculated decision to make that move. The companies who create this vehicles may possibly come under heavy fire from lawsuits filed by those injured and who lose family members etc due to the decision taken by the computer of a self-driving car, even when it may have been the correct decision which resulted in the least amount of damage.

As a whole, the progression of a world filled with self-driving cars is moving at a much slower pace than previously anticipated. The reality is that even when such vehicles become available with an acceptable safety rating, the extortionate price per vehicle will result in individual ownership being very low. Also, the high maintenance of such a vehicle where cameras and sensors have to be constantly recalibrated in order to ensure safety is not a desirable factor for the everyday consumer to have to deal with. Where we can expect them to becoming mainstream quickly is for services which require a fleet, such as taxiing and long-haulage. But until then, the human population will have to keep their eyes on the road.

References

[1] https://cars.usnews.com/cars-trucks/cars-that-are-almost-self-driving

[2] https://www.tesla.com/support/autopilot

[3] https://en.wikipedia.org/wiki/Death_of_Elaine_Herzberg

[4] https://medium.com/think-autonomous/how-radars-work-1eb523893d62#:~:text=In%20self%2Ddriving%20cars%2C%20RADAR,an%20awesome%20sensor%20fusion%20module.

[5]https://oceanservice.noaa.gov/facts/lidar.html#:~:text=Lidar%20%E2%80%94%20Light%20Detection%20and%20Ranging,the%20surface%20of%20the%20Earth.&text=Lidar%2C%20which%20stands%20for%20Light,variable%20distances)%20to%20the%20Earth.

[6] https://interestingengineering.com/what-is-lidar-technology-and-what-are-its-main-applications

[7] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/self-driving-car-technology-when-will-the-robots-hit-the-road/de-de

[8] https://www.upgrad.com/blog/how-machine-learning-algorithms-made-self-driving-cars-possible/#:~:text=1)%20Regression%20Algorithms,-Regression%20algorithms%20are&text=Bayesian%20regression%2C%20neural%20network%20regression,used%20in%20self%2Ddriving%20cars.

[9] https://physicsworld.com/a/how-to-hack-a-self-driving-car/