Newnham Engineering Essay Prize 2019, Question 2 iii

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Rapid technological advances have brought autonomous vehicles closer to reality, with the UK government planning to introduce them on the roads by 2021[i]. While bringing opportunities including environmental benefits, increased road safety and mobility, there are still many challenges to be overcome.

Taking the main sensors used in autonomous vehicles as an illustration, this essay will first discuss some of the technological challenges and solutions. This is followed by a consideration of the socio-economic benefits and implementation challenges. This essay focuses on vehicles with high or full automation, where the human driver does not take control.[1]

Whilst many feel it is the technology of autonomous vehicles which restricts its widespread use, I would suggest overcoming implementation challenges is also a priority for the industry and wider society.

Sensing the environment

A crucial aspect of autonomous vehicles is the array of sensors used to map and evaluate its environment which most autonomous behaviour relies on. The main sensors used - radars (Radio Detection and Ranging), cameras and LIDAR (Light Detection and Ranging) form part of the vision in autonomous vehicles. (Figure 1)

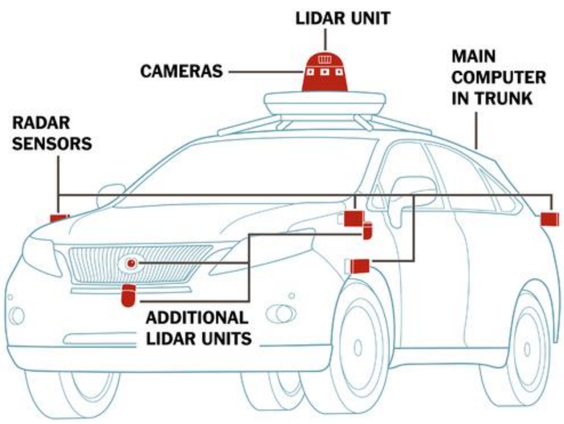

Figure 1: Sensors on an autonomous vehicle[ii]

Radars work by emitting radio waves into the surroundings and measuring if and when the waves are reflected back to the sensor, allowing radars to detect objects. The speed of objects can also be measured using the Doppler Effect – when an object moves in relation to the radar, a change in frequency can be detected and used to determine whether the object is moving away or towards the sensor, and the speed of the object. This technology is already utilised in cruise control and parking assist systems in many commercial vehicles. Reflected waves can also be analysed to determine the shape and material of the object which is useful for object identification.

Cameras are used to detect road signs, lane lines, zebra crossings and pedestrians with the help of computer-aided vision and object detection systems.

[1] This corresponds to Level 4 and 5 under the Society of Automotive Engineers' categorisation. Level 4 vehicles can only operate in a specific environment while Level 5 vehicles operate under all road conditions.

LIDAR works in a similar way as radar but it uses laser beams instead of radio waves. LIDAR emits laser beams rapidly - up to 150,000 beams per second. In order to capture a 360° image of its surroundings, the laser beams are spun around and deflected in different directions using a series of spinning mirrors. It then receives reflected beams and distance is calculated by using this formula:

$$distance\ of\ object\ detected = speed\ of\ light \times \frac{time\ taken\ for\ beam\ to\ return\ to\ LIDAR}{2}$$

The calculated distances are processed and used to generate a 3D model of the surroundings known as a point cloud. (Figure 2) The resolution of the model generated increases with the number of laser beams emitted - Google's autonomous vehicle, for example, uses a 64-beam laser.

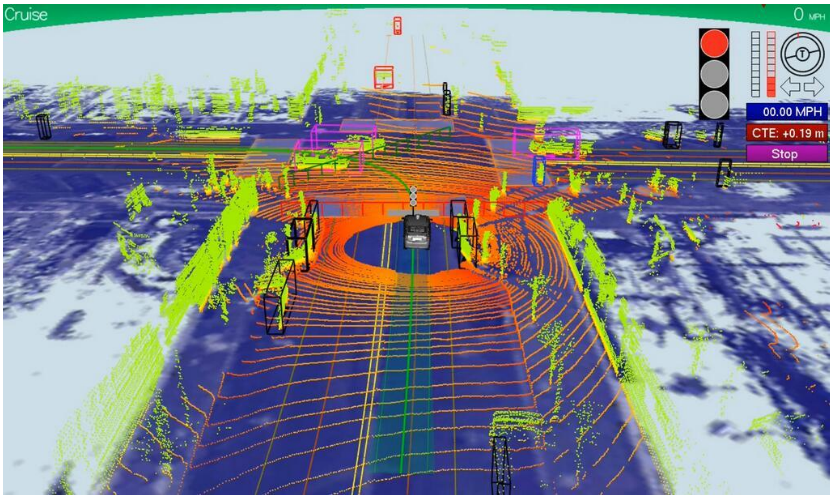

Figure 2: 3D model generated by LIDAR[iii]

Using this point cloud, the autonomous vehicle can navigate the road and detect upcoming obstacles such as other vehicles and pedestrians. The point cloud is constantly being updated as new data from the sensor are collected.

Sensory challenges

Each sensor has its own weaknesses and strengths, which is why a combination is used. Perfecting the combination of sensors and deciding how data from different sources can be combined and processed has been a major challenge.

Radars are robust sensors – the nature of radio waves means that poor weather conditions such as snow, fog and light levels do not undermine its ability to collect data. However, radars are relatively low-resolution and do not generate a sufficiently accurate representation of its surroundings like a LIDAR.

Cameras give almost real-time, high-resolution feedback but are affected by external conditions. Precipitation, fog and dust reduce a camera's range, extreme lighting conditions (e.g. a passing vehicle's headlights) can compromise the data collected. Dirt and moisture on the camera itself can also obscure the image.

Whilst LIDAR excel in precision, they fall short in speed. The data generated by LIDAR cannot be processed in time by the computer for emergency decisions, including collision avoidance. The sensitivity of LIDAR may also lead to unnecessary detection of small objects (discussed later).

Detection errors and possible solutions

The detection of false positives or failure to detect an object can have catastrophic consequences. A fatal accident involving an Uber self-driving car occurred in March 2018. It is thought that the systems in the car detected the pedestrian but initially categorised it as a false positive. The failure of the emergency brake system and the slow reaction of the human operator meant that by the time the car registered the pedestrian, it could not brake in time.[iv]

The combined use of different sensors seeks to reduce detection errors. One example involves the detection of false positives when a road sign is reflected in a puddle. (Figure 3) The camera might detect a duplicate of the road sign in the reflection, thus confusing the computer system. This can be avoided by combining data from other sensors. While the camera detects two signs, data from the radar and the LIDAR will show that there is only one physical sign.

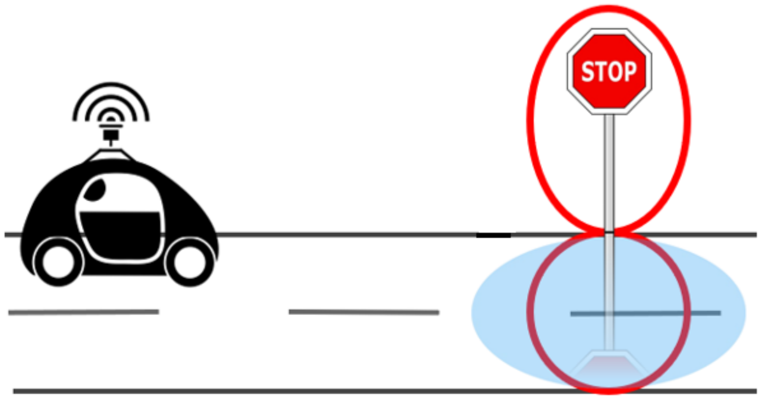

Figure 3: Detection of duplicate road signs

Another example of detection error occurs in rainy weather. Since LIDAR are so sensitive, there have been cases (such as in the Eurecar Turbo developed by KAIST) where raindrops were detected by the LIDAR as obstacles, thus halting the car's movement. This was solved by excluding objects smaller than a given size when processing LIDAR data.[v] Another solution is to combine sensor data – the less sensitive radar will not detect small objects like raindrops and falling leaves as radio waves pass through them. Radars can, therefore, be used to verify the supposed "obstacles" detected by the LIDAR.

One of the main challenges in combining sensor data is deciding which sensor's data is the most reliable in a given situation should the data returned contradict each other. For example, in conditions with heavy fog, camera data might be less reliable than LIDAR and radar data and therefore, should be weighted with less importance when combining data. Calculating how data should be weighted and combined to draw a conclusion based on external conditions is a virtually impossible task using traditional "hard-coding" methods – there is no way to account for every condition and combination of conditions.

Deep learning offers possible solutions to these challenges. Deep learning allows a computer to perfect algorithms through analysing data sets using a neural network, similar to how humans learn from experience and observation. (Figure 4) The layered structure of a neural network resembles the networked structure of neurons in the human brain with layers of connected nodes. Neural networks learn from a set of training data – this can be a set of photographs with typical objects seen on roads or a set of external weather conditions. Training data (an input) have a specified output assigned to it (this may include which sensor to prioritise, or the objects in an image). The input is then processed through many 'hidden layers' in the neural network which extract features and assign weights signifying the importance of that feature in returning the correct output. Initially, the weights are randomly assigned but as more data are fed through the network, the network adjusts its weights to improve the accuracy of its output. The output is returned as a probability, telling us how certain the neural network is that the output is correct.

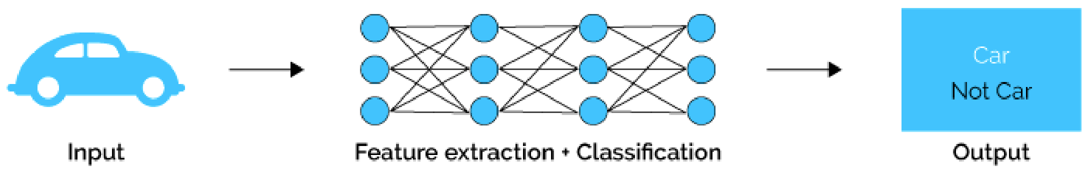

Figure 4: Illustration of deep learning process[vi]

Companies like Waymo derive training data from millions of autonomous miles, some actually driven and some simulated[vii]. In the context of object detection, the input might be the external conditions (light level, weather etc.) from situations where data from different sensors have contradicted each other. The output would be whether the object is there in reality and the neural network can "check" its output against records from the actual drive. (Figure 5)

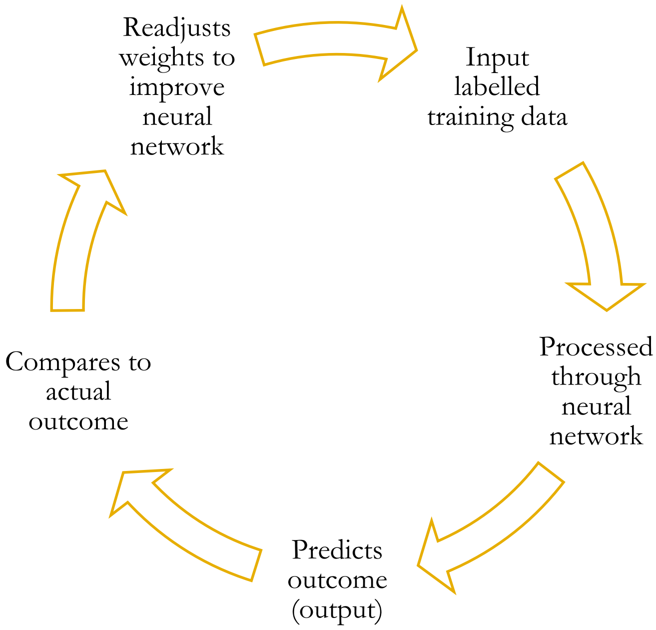

Figure 5: Flowchart of neural network training

Deep learning is instrumental in developing computer vision, a key part of autonomous vehicles. Traditional methods, involving multiple parameters (e.g. size, colour, right-angled edges) being coded into the software to determine whether an object exists struggle under uncontrollable conditions. Orientation, light-level, partial obscuration, and backdrops can all hinder the software's ability to recognise the object. Furthermore, the software will only be able to recognise a limited set of objects which the programmer has set parameters for. Computer vision has made remarkable progress with deep learning. In 1957, Frank Rosenblatt built one of the first neural networks which recognised shapes (circles, squares and triangles). Today, computer vision can recognise almost any object to an impressive degree of accuracy (Figure 6). In an image identification competition in 2012, the winning neural network had a 15% error rate whilst in 2015, Microsoft's neural network had a 3.57% error rate (better than the 5% average human error)[viii].

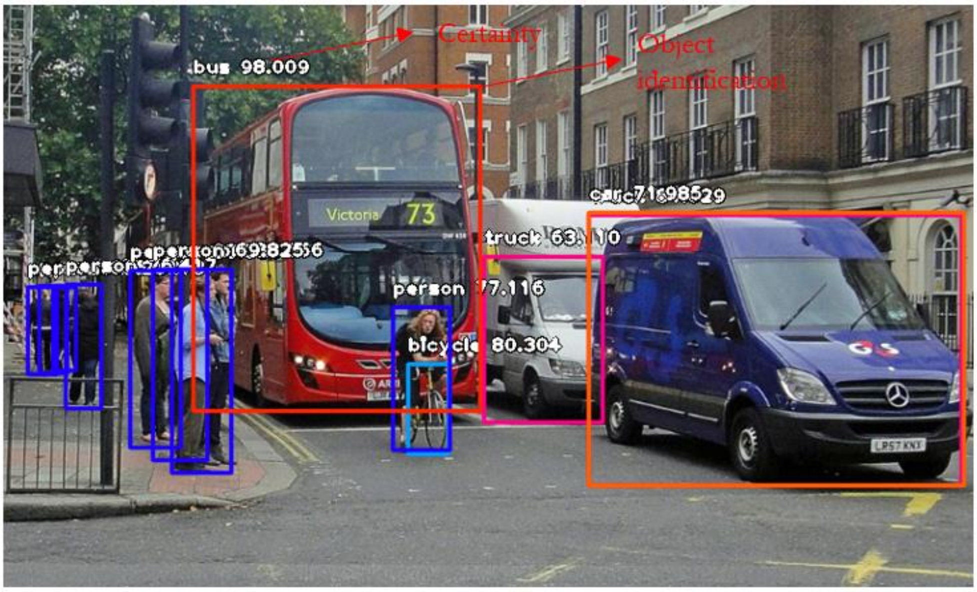

Figure 6: Example of object detection through computer vision[ix]

The progress of deep learning will only increase the accuracy of crucial sensor systems in autonomous vehicles. Once autonomous vehicles become widely used, the increase in data harvested from actual journeys will be most valuable for deep learning technologies. (Figure 7)

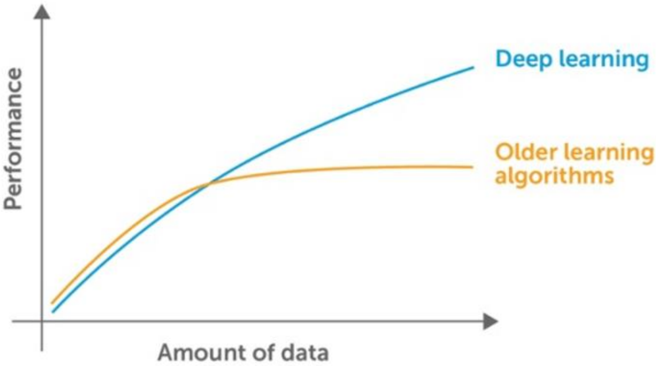

Figure 7: Improvement of neural network with increased data[x]

Socioeconomic benefits

Arguably the greatest opportunity autonomous vehicles offer is an improvement in road safety and efficiency. The World Health Organisation recorded 1.25 million deaths globally in 2013 from road accidents[xi]. With autonomous vehicles, the negligence and error of the human driver are eliminated. Autonomous vehicles are programmed to obey speed limits and road signals, maintain suitable distance between cars, and have wider sensory perception than the human driver. Vehicle-to-vehicle communication systems allow vehicles to broadcast their planned manoeuvres such as changing lanes and turning to other nearby vehicles. The benefit of this will increase with the number of autonomous vehicles on our roads.

Increased communication between vehicles and connectivity to centralised traffic analysis systems (such as Google Maps) can reduce congestion through efficient route planning. The aim is to distribute the density of vehicles across the road system more evenly. With 90% of vehicles on the road being autonomous, it is thought freeway congestion could reduce by 60%, thus doubling freeway capacity[xii]. A similar method can be used to direct vehicles to free parking spaces, thus encouraging efficient road-use.

Increased transport efficiency through route mapping not only shortens commute time, but also reduces pollution and fuel wastage. Optimised acceleration and deceleration in autonomous vehicles is thought to be capable of reducing fuel consumption by around 5%[xiii].

Autonomous vehicles may improve the quality of life for many. Being free to pursue other activities while the car is driven autonomously may appeal to many commuters. In addition, autonomous vehicles can increase the mobility of the elderly and people with disabilities, especially those living in rural areas. However, much needs to be done to ensure driverless technology is accessible to them; for instance, the development of wheelchair accessibility is crucial.

Economically, autonomous vehicles create many opportunities, with the possibility of a US$7 trillion industry[xiv]. The price of autonomous vehicles has always been a concern with some of the LIDAR technology alone costing $75,000[xv]. However, with increased demand as autonomous vehicles become widely available, it is expected that the price will drop significantly and become more economically feasible.

It is expected that private ownership of vehicles will reduce, with greater opportunities for an autonomous taxi market. UBS predicts urban car ownership to fall by 70% by 2035[xvi]. Reduction in vehicles numbers conserves resources and is likely to have a positive environmental impact. Taxi services will benefit from increased demand as well as lower operational costs as there are no human drivers. The success of the 'robo-taxi' industry is promising, as suggested by the popularity of app-based taxi services like Uber and Lyft.

Implementation challenges

Autonomous vehicles are arguably a disruptive technology – while it brings many new opportunities, it also displaces established markets and industries. Trucks, bus, delivery and taxi driving jobs will be lost with an estimated 4 million job losses in the United States if this technology is adopted rapidly[xvii]. The process of reallocation and compensation is a huge challenge. The impact might be mitigated by retraining workers for jobs created by the new autonomous vehicle industry such as remote vehicle management and surveillance.

The legal and regulatory framework must also be developed before autonomous vehicles can be widely used. One issue under consideration is where liability lies in the event of an accident – would it be the human operator, car owner or manufacturer? Yet another issue relates to data privacy – how can the vast amount of data collected from vehicle users be protected?

Another area of concern is the susceptibility of autonomous vehicles to hacking. Research conducted by the University of California and Zhejiang University shows that sensors in Tesla's Autopilot system can be jammed by radio technology, thus compromising the car's vision system[xviii]. Whilst hacking is a technological challenge to be addressed by the developers, governments also need to ensure that autonomous cars are secure enough to withstand global security threats.

Above all, more needs to be done to increase public confidence in autonomous vehicles. In a 2018 survey, the American Automobile Association found that 73% of subjects were afraid to use a fully-autonomous vehicle, largely stemming from safety concerns[xix]. Many people are reluctant to cede complete control over their vehicles. While this may suggest humans should retain a degree of control in autonomous cars, allowing human judgment to override automation in an emergency, research suggests human participation does not make driving safer. The fatal Uber accident discussed earlier involved a human driver who failed to take control in time for an emergency.

Accidents involving Tesla's Autopilot also involve drivers who did not react in time. Due to the relatively passive role of humans in autonomous vehicles, human complacency means people often fail to pay attention and react in time. Research suggests complete automation without human intervention is safer, but adopting this route depends on gaining more public support.

So far, autonomous vehicle development has mainly focussed on meeting technological challenges. There are many areas for improvement, but progress has been impressive. Deep learning, for example, has opened opportunities for a safer vehicle. To me, the next step in making autonomous vehicles viable is to overcome the implementation challenges. This requires the collective effort of all sectors of society, not only scientists. The technology may be ready, but the public needs to be ready for it too. Once autonomous vehicles are publicly used, I have no doubt that the opportunities will be beneficial and widespread. The implementation of autonomous vehicles will push humanity further into the ever-changing technological age, fuelling further development and research.

[Word count: 2,480 words]

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