Autonomous Vehicles

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Transportation is a fundamental component in society and with the numerous advancements in artificial intelligence, autonomous vehicles may soon be the common means of transportation. A self-driving car or autonomous vehicle is a vehicle that can drive and make decisions on its own with little or without any human input. Many positive impacts come along with self-driving vehicles. However, there are also some problems and ethical concerns involved with the decision-making of these autonomous vehicles which causes some people to be skeptical of them. Autonomous vehicles are safer and more efficient than non-autonomous vehicles, thus they should be adopted everywhere.

Autonomous vehicles are created by using a variety of technology and computer programming to allow them to perceive objects and signs around them as well as to make decisions on the road. According to the article “How Do Self-Driving Cars See? (And How Do They See Me)?” written by Alex Davies, “Dozens of companies are trying to build self-driving cars and self-driving car technology, and they all approach the engineering challenges differently. But just about everybody relies on three tools to mimic the human’s ability to see.”[1] The three tools that all self-driving cars utilize to have perception are radar, cameras, and lidar. According to the article, the radar allows the computer system in the car to be able to detect moving objects and their speed and direction which is useful for helping the self-driving car to avoid crashes.[1] Additionally, cameras are placed around these vehicles which allows the computer system to perceive lane lines, road signs, hand signals, and a lot of other useful information.[1] Furthermore, autonomous vehicles make use of lidar, which stands for light detection and ranging. The way lidar works according to the article is it “builds a map of the world around the car by shooting out millions of light pulses every second and measuring how long they take to come back. It doesn't match the resolution of a camera, but it should bounce enough of those infrared lasers off you to get a general sense of your shape. It works in just about every lighting condition and delivers data in the computer's native tongue: numbers. Some systems can even detect the velocity of the things it sees, which makes deciding what matters far easier."[1] In other words, lidar is what allows the computer system in the car to detect its surroundings and the speed and distance of the objects around it. Some autonomous vehicles also make use of ultrasonic sensors for close-range work and microphones to listen for sirens.[1] By using all this technology, the computer system in autonomous vehicles can gather data about their surroundings.

After knowing the hardware and technology needed for an autonomous vehicle to perceive and reason with its surroundings, it is important to know the computer programming side that allows autonomous vehicles to process information and make decisions. According to "VITS – A Vision System for Autonomous Land Vehicle Navigation" written by Matthew A. Turk, one of the first autonomous vehicles known as The ALV was able to successfully navigate the road by using cameras and separating the colors of the pixels that the camera views. The ALV team first mapped the colors of the pixels on a red and blue color graph. Then, to get the projection of the image points in RGB space onto a line they used the dot product on every pixel vector with a vector in the direction of the line.[2] By being able to project the pixels onto a line, they were able to separate the road pixels from the non-road pixels which would allow the autonomous vehicle to successfully navigate a road. However, there are issues with this color-based segmentation approach for road navigation due to shadows, insufficient color differences between road and non-road, and subtle changes to road boundaries. Modern autonomous vehicles today do not use the color-based segmentation approach for road navigation.

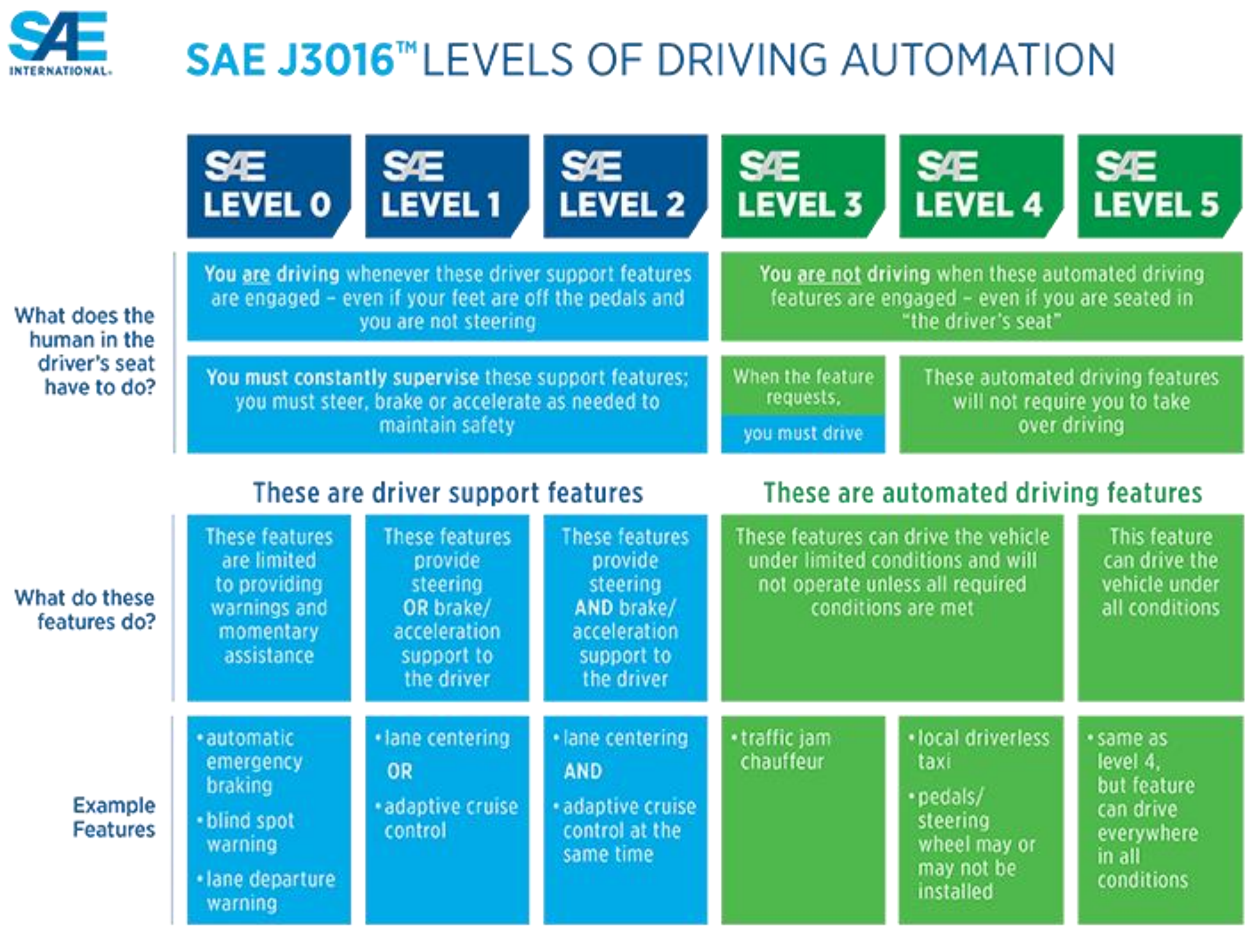
Another approach for autonomous vehicle land navigation is to introduce an artificial neural network to learn how to steer a vehicle. According to “ALVINN: An Autonomous Land Vehicle In A Neural Network” written by Dean A. Pomerleau, ALVINN (Autonomous Land Vehicle In a Neural Network) is a 3-layer back-propagation artificial neural network used to control the NAVLAB, the Carnegie Mellon autonomous navigation test vehicle.[3] Pomerleau’s approach called for supervised learning, which means both an input image as well as the corresponding steering angle from a human driver to learn from is needed. According to Pomerleau, “After 40 epochs of training on the 1200 simulated road snapshots, the network correctly dictates a turn curvature within two units of the correct answer approximately 90% of the time on novel simulated road images.”[3] ALVINN’s steering becomes almost as accurate as a human’s steering using only images and human steering angles. Pomerleau’s approach is also known as end-to-end learning and was a major advancement in the field of autonomous vehicles. However, an issue with Pomerleau’s approach was that if it came across a situation that it was not trained to deal with, the network would need to be retrained.

A more modern approach to autonomous land vehicle navigation is by using deep learning systems. According to the article “How Drive.ai Is Mastering Autonomous Driving With Deep Learning” written by Evan Ackerman, “The most common implementation of the piecemeal approach to which they’re referring is the use of deep learning solely for perception. This form of artificial intelligence is good for, say, recognizing pedestrians in a camera image because it excels at classifying things within an arbitrary scene. What’s more, it can, after having learned to recognize a particular pattern, extend that capability to objects that it hasn't actually seen before. In other words, you don't have to train it on every single pedestrian that could possibly exist for it to be able to identify a kind old lady with a walker and a kid wearing a baseball cap as part of the same group of objects."[4] Using deep learning, the autonomous vehicle is able to react to situations that it has not seen before which is the opposite of the end-to-end training approach. Additionally, deep learning systems thrive from more data, so well-annotated images can be used to train the deep learning model so that they can learn and classify what certain objects look like even more accurately. Deep learning systems show huge promise in advancing the field of autonomous vehicles.

After the computer system of the autonomous vehicle can perceive the objects around its location, the computer system needs to localize itself into that environment. It is crucial for the computer system to be accurate about its location, otherwise, it could be on the sidewalk hitting things. According to the article "Drive Labs: How Localization Helps Vehicles Find Their Way" written by Jordan Marr, Yu Sheng, and Amir Akbarzadeh, "Localization provides the 3D pose of a self-driving car inside a high-definition (HD) map, including 3D position, 3D orientation and their uncertainties. Unlike the use of a navigation map with GPS, which only requires an accuracy on a scale of a few meters, the localization of a self-driving car has a much higher requirement of accuracy relative to the map, usually on the order of centimeters and a few tenths of degrees."[5] Using localization, a more accurate position of the car on a high-definition map can be determined. Additionally, with localization, the car can make decisions in the future using the information it currently has, such as the map signaling to the car that the current lane will end somewhere down the road, so the car can then exit the lane when it can. Overall, by using localization, a very accurate position of the autonomous vehicle can be pinpointed on a map.

After figuring out how the world around the autonomous vehicle looks like as well as where it is located, the next step is to implement path planning to help the car navigate its way across the road. According to “Path planning for autonomous vehicles” written by Mengzhe Zhang, “This requires them to have a path planning algorithm helping them in navigation. On one hand, the algorithm should control robots proceed with their tasks. On the other hand, it should integrate collision avoidance in case of hitting obstacles or other robots.”[6] Therefore, with path planning, the computer system should be able to generate a path for the car the travel as well as making sure that the path will not result in any collisions. This is done by the computer system making predictions on where the other cars or objects around it are going to move and figuring out what maneuvers the vehicle should take. Moreover, autonomous vehicles need to be able to control the steering wheel, brakes, accelerator, and other car functions to traverse the trajectory that the pathfinding algorithm created. Overall, autonomous vehicles work by being able to sense their surroundings, know its exact location on the map, generating paths to reach a destination, and controlling the car functions to move around and stop.

There are several different levels of autonomy associated with vehicles that determine how much control they have over the vehicle. According to the Society of Automotive Engineers (SAE) International there are six levels of driving automation, from no automation to full automation.[7]



(Image source: https://www.sae.org/news/press-room/2018/12/sae-international-releases-updated-visual-chart-for-its-%E2%80%9Clevels-of-driving-automation%E2%80%9D-standard-for-self-driving-vehicles)

According to the SAE, driving automation of levels 0, 1, and 2 classifies the person behind the wheel as driving even if the driver support features are activated. Additionally, the driver must always supervise the vehicle and pilot the car if necessary. What differentiates levels 0, 1, and 2 is that at level 0 the driver must perform all the driving, however they can be given warnings and momentary assistance such as automatic emergency braking. At level 1, the vehicle can either steer or brake and accelerate to support the driver, however, it cannot do both. Additionally, it has either a lane-centering feature or adaptive cruise control, but not both. At level 2, the vehicle has all the features of level 1 and it can do both steering and acceleration and braking.[7] Furthermore, according to the SAE, driving automation of levels 3, 4, and 5 classifies the person behind the wheel as not driving if the automated driving features are activated. What differentiates levels 3, 4, and 5 is that at level 3 the driver must drive if the feature requests that the driver do so, whereas, at levels 4 and 5, the driver will not be required to take over driving. At levels 3 and 4, the vehicles can drive under limited conditions and will not operate unless they are all met. At level 4, the pedals and steering wheel may or may not be installed. At level 5, the vehicle can do anything that a human driver can do as it is can drive on its own under any condition.[7] The overall goal in the field of autonomous vehicles is to have working level 5 autonomous vehicles because as of right now there have been no demonstrations of a working level 5 vehicle.

If fully autonomous vehicles were to be integrated into society, there would be numerous positive impacts. According to “Public Perceptions of Self-driving Cars: The Case of Berkeley, California” written by Daniel Howard, “Automobile travel, particularly single occupancy vehicle (SOV) driving, contributes intensely to traffic congestion, traveler delays, and vehicle pollution. Traffic congestion costs the U.S. economy more than $120 billion, and produces 56 billion pounds of CO2 (1). Automobile accidents are a major concern as well. In 2010, there were approximately 35,000 vehicle fatalities in the U.S.; 90% of vehicle crashes can be attributed to driver error (2). Moreover, cars consume valuable resources. On average, cars sit unused almost 22 hours out of every day (3).”[8] By introducing self-driving cars, the problems of traffic congestion, automobile accidents, and resource waste can be solved. According to Howard, “Improvements in safety could be realized soon after widespread adoption of self-driving vehicles. Self-driving car sensors can follow traffic rules and be more alert and responsive than drivers today. In 2010, there were approximately 35,000 vehicle fatalities in the U.S.; many of these fatalities were caused by distracted driving, drunk driving, and other impairments (3). Research on connected vehicles has shown that vehicle-to-vehicle communication systems potentially address 81% of all police-reported vehicle target crashes annually (15). Self-driving technology includes elements of connected vehicle technology and is likely to gain these safety benefits as well."[8] Therefore, since the computer system in the autonomous vehicle is programmed to make the car follow the rules of the road, accidents are much less likely to happen since human error is no longer involved. Additionally, according to Howard, "Adoption of self-driving vehicles at the city or regional level is likely to result in reduced congestion across the network once the market penetration of these vehicles passes a certain threshold. As self-driving vehicles have not been deployed on such a scale, empirically determined values for optimum market penetration do not exist. However, one can imagine centralized, demand responsive routing will enable self-driving vehicles to choose a route that minimizes delay for all users in the system and "reserve" a spot in the network. These vehicles would then be able to avoid bottlenecks and congestion prone areas before they begin to slow down traffic."[8] Therefore, as more autonomous vehicles enter the road, the likelihood of traffic congestion will die down since all the self-driving cars may be connected to the same network so that they can plan accordingly on which paths will avoid congestion. Furthermore, according to Howard, "Another opportunity for self-driving cars lies with fuel efficiency and environmental benefits. Platooning vehicles offers immediate benefits to efficiency, regardless of fuel type. The cars behind the lead vehicle reap aerodynamic benefits and reduce their energy consumption by up to 25% (18). A 2013 Japanese study showed truck platooning improved fuel economy by 15% for heavy commercial vehicles (19)."[8] Thus, by the autonomous vehicles traveling in a platoon formation, the consumption of resources will overall decrease leading to much more efficient resource use. Overall, by replacing every car with an autonomous vehicle, road congestion, vehicle accidents, and resource consumption will all decrease.

Self-driving cars will also allow certain groups of people to have fast and accessible transportation that they did not normally have before. For example, people with disabilities and the elderly can make use of a self-driving car to help them travel on their own. Additionally, according to Howard, "people younger than the legal driving age, or those who do not have the physical or mental capabilities to drive a car, are restricted from the benefits of automobile use. With self-driving vehicles, these barriers can be lessened as one does not necessarily have to know or be able to drive to reap the benefits."[8] So autonomous vehicles also open up opportunities for younger people to get the benefits of car transportation. When fully autonomous vehicles start being mass-produced, there may very well be children and teenagers owning and traveling with them as they are not required to learn how to drive a car to operate and use them. Self-driving cars will allow more groups of people to have access to the benefits of traveling on a car that they normally would not have.

While there are many positive impacts with introducing autonomous vehicles into society, there are also problems that may arise. According to "Impacts of Autonomous Cars from a Traffic Engineering Perspective" written by Tamas Tettamanti, "Highly automated and autonomous vehicles have dedicated control functions for longitudinal and lateral vehicle control (e.g. turn right or left, change lane, brake or accelerate). Comparing the hacking threat of externally changing the radio station or activating the wind-shield wiper to an intentionally wrong driven vehicle, there is a magnitude difference. The most threatening scenario is that if someone would like use the intelligent vehicle functions for malicious purposes, e.g. to make accident intentionally."[9] There are already hackers today and there is no doubt that hackers will find security flaws in the computer systems of autonomous vehicles. A hacker with malicious intent could very well cause a lot of vehicle accidents by controlling the functions of the car such as steering and accelerating. Additionally, another problem is that autonomous vehicles could eliminate a lot of jobs. According to the article "Op-Ed: Autonomous vehicles could cost America 5 million jobs. What should we do about it?" written by Steven Greenhouse, "Driverless cars will create some big winners — imagine how Uber's and Lyft's profits will jump when they can keep 100% of fares instead of letting drivers keep 70%. But they will produce some big losers too, notably the 5 million people nationwide — including 600,000 in California — who make their living driving taxis, buses, vans, trucks and e-hailing vehicles. That's almost 3% of the workforce, according to Lawrence Katz, a labor economist at Harvard. Incidentally, most of these drivers belong to the same demographic cohort as many factory workers — men without college degrees — who've already been hit hard by the loss of 5 million manufacturing jobs since 2000."[10] There is a cause for concern as driverless cars will replace the jobs of those who drive others around for transportation. The people who work as transportation drivers usually have no other options so getting rid of their jobs may put these individuals in financial trouble. Furthermore, wide adoption will be necessary to get the benefits of reduced traffic congestion, reduced vehicle accidents, and reduced resource consumption, but this may not be so easy since not everyone is open to trust autonomous vehicles quite yet. Overall, autonomous vehicles do bring a fair amount of problems and concerns that need to be addressed.

There are many ethical concerns involved with fully autonomous vehicles being allowed to make decisions. The well-known ethical dilemma, the trolley problem, is often compared to the ethical concerns of autonomous vehicles. The trolley problem has many different variations, but in its simplest form, the trolley problem gives a situation where there is a trolley hurtling down the tracks with broken brakes. In the individual's current view, they can see that the trolley will inevitably run over five workmen who cannot escape. However, the individual notices a lever in front of them that when pulled, will change the trajectory of the trolley onto another track containing only one workman who also cannot escape.[11] The dilemma here is that if the lever is not pulled, the individual is allowing five people to die. However, by pulling the lever, the individual is directly responsible for killing one person to save five people. Now if an autonomous vehicle were in a situation like the trolley problem, the vehicle would need to decide. Consider the following scenario where given the situation where a self-driving car finds itself being forced to crash into a group of pedestrians and killing them or turning to save the pedestrians but crashing into a wall killing the driver, which is the correct decision to make? Should the autonomous vehicle prioritize saving its owner or should it prioritize minimizing casualties for the greater good? There is no easy answer to this problem as some people would not want to own a car that does not guarantee the driver and their passenger's safety. Additionally, another scenario to consider is that suppose there is a situation where the self-driving car must make a left or right turn on a highway, otherwise it will crash into a truck in front of it. On the left of the self-driving car is a person on a motorcycle with a helmet on, and to the right is a person on a motorcycle without a helmet on. Should the self-driving car turn left and crash into the person with the helmet on as they are more likely to survive or should the self-driving car turn right and crash into the person without a helmet on? If the car crashes into the person with the helmet on, then it is not fair for the car to punish the more responsible motorcyclist, and if the car crashes into the person without the helmet on, then the car has just betrayed its goal of reducing casualties from the previous example. There is no clear line to draw when it comes to the right and wrong decision for a fully autonomous vehicle to make during these scenarios.

There are also ethical concerns involved with fully autonomous vehicles and where accountability falls under if an accident were to occur. According to “The Ethics of Accident-Algorithms for Self-Driving Cars: an Applied Trolley Problem?” written by Sven Nyholm and Jilles Smids, “Consider now the following scenario. A self-driving car with five passengers approaches a conventional car (e.g. a heavy truck) that for some reason suddenly departs from its lane and heads directly towards the self-driving car. In a split-second, the self-driving car senses the trajectory and the likely weight of the oncoming truck. It calculates that a high-impact collision is inevitable, which would kill the five passengers, unless the car swerves towards the pavement on its right-hand side. There, unfortunately, an elderly pedestrian happens to be walking, and he will die as a result if the self-driving car swerves to the right and hits him. This is the sort of situation in which the human passengers of a self-driving car cannot take control quickly enough. So the car itself needs to respond to the situation at hand. And in order for the five passengers in the self-driving car to be saved, as they are likely to be if the head-on collision with the heavy truck is avoided, the car here needs to make a maneuver that will most likely kill one person."[12] In the scenario provided here, the ethical dilemma is whether the autonomous vehicle should prioritize the safety of the passengers or should it prioritize other factors such as fairness and overall good. There is no clear answer as to which is the ethically correct choice. Additionally, suppose that the autonomous vehicle was to crash into and kill the elderly pedestrian, then who would the accountability fall under? For this situation, one might say that the blame falls under the driver, however, the driver at no point had control of the vehicle during the crash. Then perhaps the blame falls under the truck driver since they left their lane and are charging towards the self-driving vehicle. However, suppose that the truck driver was pushed onto the lane of the self-driving car out of their own free will, then maybe the blame would fall under the self-driving car company for the elderly pedestrian being killed. There is no clear answer to who should be held accountable as it depends on the situation at hand. As one might see, various ethical problems that arise with self-driving vehicles and it is important to address them all.

There is criticism of comparing the trolley problem to the ethical dilemmas of autonomous vehicles. According to the article "Why the Trolley Dilemma is a terrible model for trying to make self-driving cars safer" written by Marcus Baram, "It might seem like the equivalent to the Trolley Dilemma: Either sacrifice yourself, or run over two people in the crosswalk. But it's actually much more complicated because there are many more things going on and potentialities involved."[13] According to Baram, the reason that the trolley problem is not a good comparison to self-driving cars is that the trolley problem is a binary problem whereas, with autonomous vehicles, there are many more possible decisions and outcomes. The trolley car problem situation is very likely to never occur. If it were to occur, the autonomous vehicle has more choices to avoid any accidents from occurring such as using the horn to alert others of impending danger, using the brakes, and turning the wheel. The trolley problem is just simply to flip the switch or not, whereas, with the autonomous vehicle problem, there are a lot more options. Autonomous vehicles are designed and programmed to reduce the risk of accidents, so it is very likely that in the previous scenarios, an outcome is possible where no one must die. Thus, the trolley problem is not the perfect model to compare to the ethics of self-driving vehicles.

Autonomous vehicles can detect their surroundings using a variety of technology and software, which allows them to make efficient and safe maneuvers. By introducing fully autonomous vehicles into society there will be fewer accidents, traffic congestion, and resource consumption thus increasing the efficiency of road travel. They will also allow other groups of people such as people too young to drive, the elderly, and the disabled to be able to have access to car travel. However, several problems will also arise such as malicious hackers hacking into the computer systems of the cars, a decrease in transportation labor, and ethical concerns regarding the vehicle's decisions. Autonomous vehicle development is growing rapidly and with the increase in productivity, efficiency, and safety that these vehicles bring, there is no doubt that they will be the future of road travel.

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