Autonomous vehicles and their use of waves in the task of recognition

How does a self-driving car use waves to determine how far away an object is and at what time it needs to slow its velocity to make a safe stop?

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Introduction

While studying waves in my physics class, I was intrigued with what exactly waves could be used for in the real world. I began looking through my physics textbook and the internet when I came across an exhilarating topic, autonomous vehicles. This topic inspired me to dive into deeper research on the aspects of self-driving cars and how they detect objects in their surroundings. While researching, I predominantly analyzed online websites. This research allowed me to also gain a deeper understanding of waves, which was one of the topics that I couldn't quite grasp when learning about it in class. This topic led me to an interesting question, how does a self-driving car use waves to determine how far away an object is and at what time it needs to slow its velocity to make a safe stop? This newfound interest led me to countless hours of studying resources that were available to me and even allowed me to learn about another aspect of self-driving cars and their task of recognition, the inherent misidentifications of the technology that determines its surroundings. This topic is important because, despite the fact that autonomous vehicles are still in their infancy, they are likely going to be the most common method of transportation in the future.

Figure 1

How autonomous vehicles use waves to "see" objects

Autonomous vehicles are vehicles which use a set of multiple different technologies that allow the vehicle to recognize its surroundings and determine many different factors. The vehicle needs to follow these factors so that the vehicle can find the safest possible route to maintain the safety of its passengers and itself (Meyer). The vehicles use three main ways to recognize its surroundings, LiDAR waves, radar waves, and camera technology. The main recognition system that autonomous vehicles use is LiDAR sensors that utilize LiDAR waves (Meyer). LiDAR stands for Light Detection and Ranging, and the system uses pulses of light to measure the range between two objects (Port). The reason behind the higher use of LiDAR sensors in autonomous vehicles is the fact that LiDAR waves are the most efficient of the three waves for all aspects of recognition. LiDAR waves can recognize both size and speed of an object much like radar sensors yet it has the added benefit of a higher resolution than the radar sensors, this fact is hard to understand without a viewable source demonstrating this fact. To demonstrate this, an image was created by the writers at "The Zebra", in the image the differences between the radar and LiDAR sensors can be visually seen (Meyer).

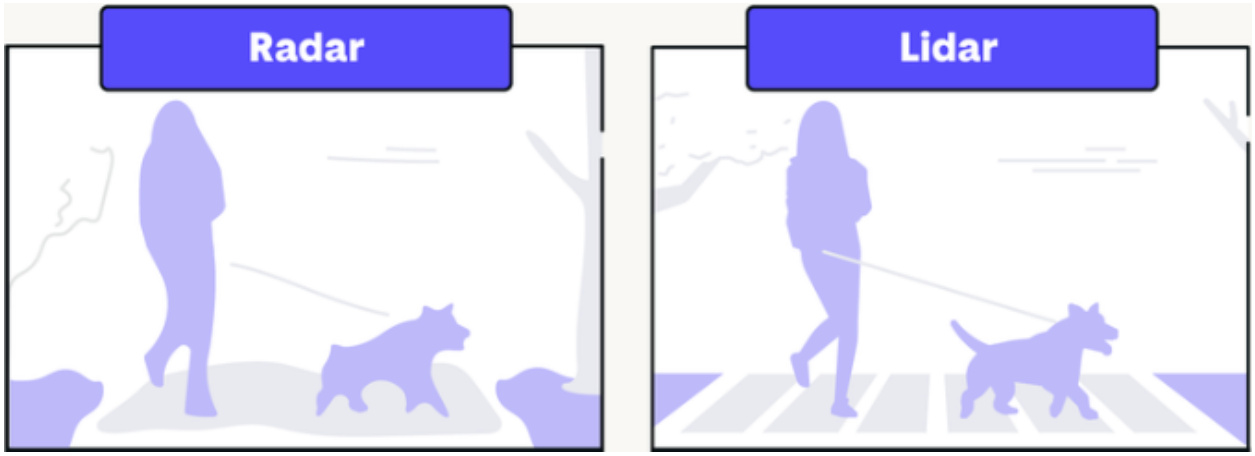

Figure 2

After looking at the image you can see just how much of a higher resolution the LiDAR sensor can produce. Additionally, the LiDAR sensor can not just detect shape and size like the radar sensor but it can also identify the objects, as demonstrated in the image instead of just being two unidentifiable blobs with the radar sensor, the vehicle can identify the two blobs as a woman and her dog that she is walking (Meyer). The final difference between radar and LiDAR is the type of wave that each sensor uses, radar sensors use radio waves to determine their surroundings while the LiDAR sensor uses laser light pulses to determine its surroundings. One reason that the vehicle is equipped with both sensors rather than just the LiDAR sensor is because of the nature in which both sensors work, because the LiDAR sensor uses light pulses in certain weather it does not work, or more specifically in fog and extreme rain, the LiDAR sensor cannot detect its surroundings when the fog is covering the ground as the light is unable to pass through the fog (Meyer); a good rule of thumb is if you cannot see in front of you because of the weather, the LiDAR sensors cannot either.

Map-Building

A LiDAR sensor is the main tool that an autonomous vehicle utilizes in its task of recognition, additionally LiDAR is utilized in the map building that the cars must have before being able to drive on a road. How LiDAR works is extremely fascinating as first the sensor must shoot out a short pulse of light then once this light rebounds from a point of impact with an object, for example, the rear of the car in front of you, it is relayed back to the sensor in the LiDAR unit. After this the data is then relayed back to a computer in the car which measures the time it takes for the light to bounce back to the sensor (Port), the computer can do this through a simple equation of d = $v \times t$, where d representing distance, v representing speed, and t

representing the time taken for the light to bounce back (BBC). As v represents just speed, in general, the equation can be changed to d = $c \times t$, where c represents the speed of light (Cannon). Autonomous vehicle companies such as Tesla, owned by Elon Musk, commission cars with LiDAR mounts on their roofs to drive around as many of the areas of the world as they can to build a map that these cars can follow, on top of their own collected data the companies will utilize already collected data with resources such as google maps to complete their mapping progress (Boudette). This map-building process must undergo a check from human engineers in which they have to sift through the data and make sure that it can be used in the maps that they are building or have built. This necessary human evaluation causes companies to not only rely on the LiDAR system which is so prominent in the process used to map building as now humans must analyze the collected data (Boudette). Since a human is left to analyze data for multiple years as they attempt to map-build, the companies also add a camera system onto the cars that they send out for the task, and rely more on the photos taken from things such as google maps. The reason that they rely on this camera technology also is because human engineers have to be able to see what they are looking at and not just a blob on the screen. To demonstrate what a human engineer would see with only LiDAR sensors, an image taken from a video which was part of a report on how autonomous vehicles "see" where they are going by "COSMOS" is the best possible way to represent what LiDAR recognizes (Port).

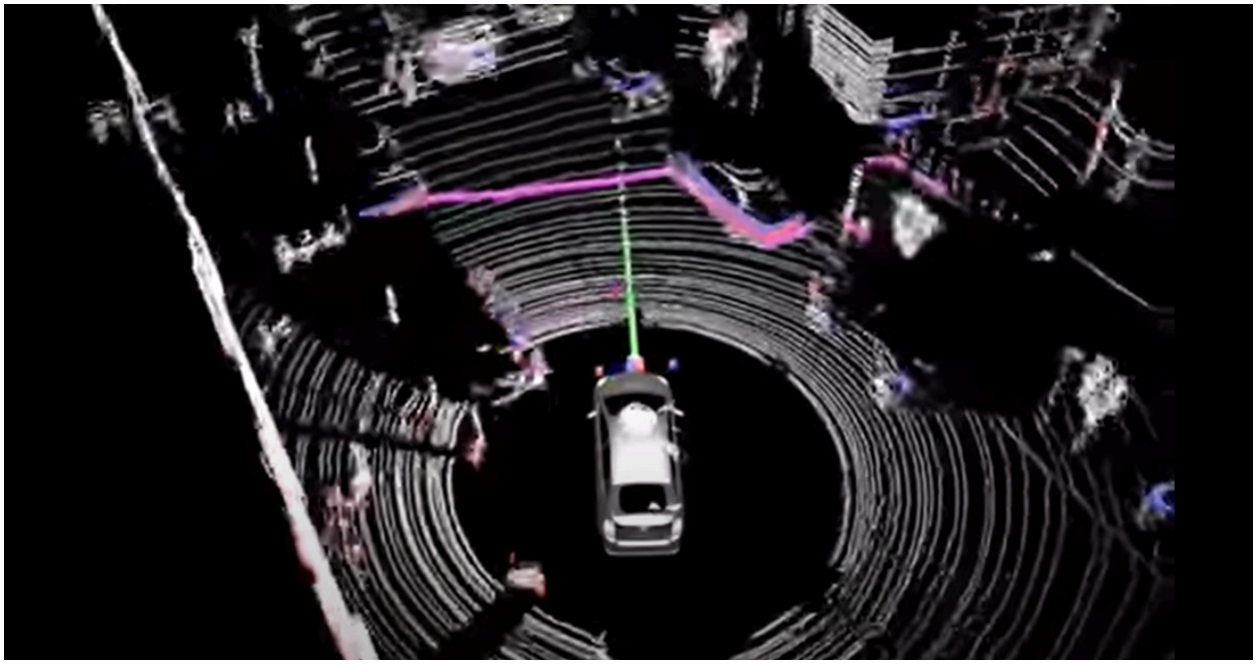

Figure 3

The human engineers elect to use the camera systems as they have the highest resolution and ability for the engineers to fully analyze what had been taken from the map-building software (Meyer). There is one major downside to the use of camera technology for both the map building process and the task of recognition in autonomous vehicles, that being the fact that cameras do not have a long range of sight. Though camera technology is great for making out exactly what something is when map building, the process is also prolonged because now the human engineers have to sift through more data as more pictures or longer videos must be taken (Boudette). Additionally, in the task of recognition, a vehicle solely using camera technology may be able to make out what something is once close enough, yet once it can realize that something or someone is in its path it may be too late. An additional downside to this camera technology is the fact that cameras need some sort of light around them to work, this may be a no-brainer that light would be emitted by your cars headlights and that light shouldn't ever be a problem but the fact of the matter is that there are too many variables for this to be true. The final

downside, the camera system does not work in all weather (Meyer). If the car is driving in the night time on the highway while it's raining with no other light for miles as there are no other cars other than it on the road, how would it recognize a deer that runs from the woods onto the highway? The car would not be able to see the deer running from the side if it was only using camera technology because there would be no light on the side of the car, this demonstrates why there must be the trifecta of radar, LiDAR, and camera systems in the task of recognition.

Obstacle Avoidance

Though LiDAR was used for the majority of the beginning process of automation with map-building, in real-time obstacle avoidance, radar is the most important sensor. Radar is used for obstacle avoidance because you don't need to know what a large object in the middle of the road is to know that you need to stop or avoid the object in the road, whether it be a person, deer, or even a large rock, the knowledge of what an object is, is not necessary for the avoidance of said object a majority of the time (Ogier). The extended use of radar in this instance is an extremely intelligent one because the car can detect the size of an object and speed of the object as well, also the radar sensors work in all types of weather as it works off of radio waves. Additionally, these waves are not affected by the level of light like cameras are, as radio waves can work in the sun when it's too bright to see or in the darkness when there's minimal light for miles and you can't see very well yourself (Ogier). The use of radar is a safety feature as the car can detect objects and avoid them even before you can see them yourself. Radar sensors are used for the braking of a car and the cruise control of a car as well, the radar sensors send out radio waves and wait for them to return to the sensor once it bounces off of an object and relay back to it. The radar sensor works extremely similar to the LiDAR sensor, yet there is one large

difference between them, the LiDAR sensor uses light to determine objects' distance while a radar sensor uses radio waves to determine what an object is and how far away it is. The radar utilizes a wave phenomenon called "the doppler effect". To demonstrate what the doppler effect is as an image, the image below can be referred to (Moebs).

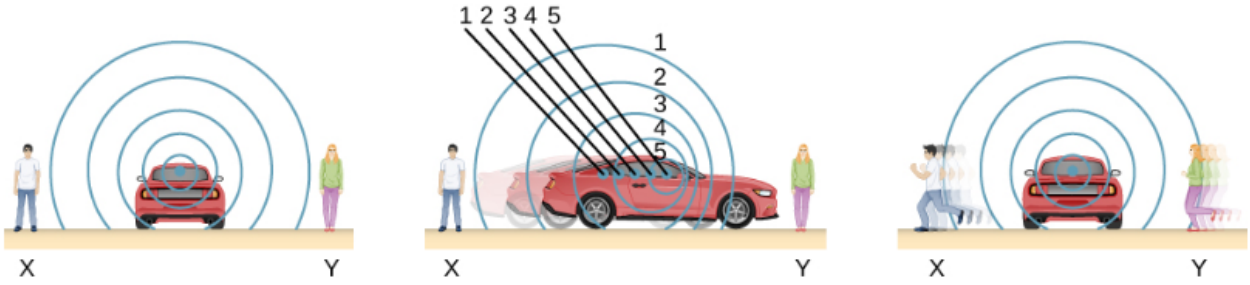

Figure 4

Doppler Effect

The Doppler effect occurs in all of the waves that are used by the autonomous vehicle, "The Doppler effect occurs not only for sound, but for any wave when there is relative motion between the observer and the source. Doppler shifts occur in the frequency of sound, light, and water waves" (Moebs). Since there is a relative motion between the vehicle and the objects around them as either the vehicle or the objects around the vehicle are moving, whether that be a car driving next to them or a person running across the street, there must be a doppler effect occurring. This doppler effect occurs not only in radar sensors but also in the LiDAR sensors too, though this will focus on the radar sensor as it is the primary sensor used for obstacle avoidance. In the image above from "University Physics Volume 1," you can see the doppler effect between a car and two humans labeled X and Y. In my hypothetical, it must be determined that X and Y are one object and that they are the car that is being studied; for example, in the third image, you can see X and Y running perpendicular to the car driving away, in this example, the self-driving

car would be driving perpendicularly left to the other car and the doppler effect is produced. The Doppler effect is the change in frequency in any waves that are produced by a moving object concerning the person viewing it. The other possible outcome of the Doppler effect occurring is when the person is moving while the waves are staying in one place effectively creating the Doppler effect from the viewpoint of the person. Autonomous vehicles utilize both types of these Doppler effects during the attempt at obstacle avoidance, when the doppler effect is occurring the car can determine if an object is moving and if so how fast said object is going through the utilization of the equation $v=f\lambda$, where v is the fixed speed of sound or light, f is frequency and λ is the wavelength (Moebs). The computer or artificial intelligence uses values that are observed with both the LiDAR and radar sensors in the car and plug those known values into the equation to determine the distance an object is away from the car. The frequency is observed during the doppler effect process and the velocity is a fixed value, this allows you to determine the wavelength which is the variable needed to determine distance.

Driving process

During the driving process, the vehicle uses mapped-out surroundings through the previously made maps that utilized LiDAR waves. The vehicles then use the trifecta of sensors to determine their exact location in correlation to the map that was created in the map-building process. Before driving to its desired location the autonomous vehicle performs path planning which entails the vehicle planning the fastest and safest route possible to get to the driver's desired location (Choudhary). The vehicle does not only have to plan the path before driving though, as the vehicle must constantly change its path to account for delays such as an accident that has occurred or something such as road work. During the drive the car uses radar to

determine how far away an object is for quick changes in vital driving resources such as braking and cruise control, the radar sensors can sense that there is an object in front of it or around it and adjust the different parts according to what it senses (Meyer). If an object is obstructing its path, such as a downed tree, the car will apply its brakes to make a safe stop after the artificial intelligence compares it to the map and notices that there is a difference. The vehicle also applies this same ideology to cruise control in the fact that as it notices on the map that the speed limit moves from, for example, 30 to 55 it also speeds up to the speed limit, as well if the autonomous vehicle notices that the vehicle in front of it is slowing down for any reason it will slow down so that it is a preset distance away from the car that is in front of it (Nice). To be able to do any of these things that are necessary for the driving process the car must utilize all sensors that it has available to it, the car uses the LiDAR sensors to compare what it senses to the maps that the vehicle connects to while also using the radar sensors to make any quick changes that it needs to ensure the safety of the driver and any other occupants of the car, finally the car uses the camera system to verify the objects that the other two systems detected were something that should be avoided or if the object is something, such as a shadow, that can be driven through with no harm to the object or the vehicle (Meyer).

Communication

Though autonomous vehicles are very proficient on their own, the goal for the future of autonomous vehicles is to be able to set up a communication system that allows all of the vehicles on a street at a time to “talk” to each other. Though in its infancy, autonomous vehicle manufacturers have already begun implementing a form of communication. For example, if an autonomous vehicle notices that an accident occurred while driving the car can warn traffic that

is also heading in the same direction. Jeff Kovacs, the CEO of Commsignia (Oster), a provider of software and hardware solution for connected cars had this to say about the possibilities of communication in self-driving cars, “The benefits of safety and awareness of V2X as a sensor – with its ability to ‘see around the corner’ – have already been proven beyond doubt as a means to providing relevant and reliable early warning messages for advanced driver assistance systems” (Oster). As Kovacs stated the ability to “see around the corner” is a great development in the future of self-driving cars as this ability of communication to other cars in the area allows for a route change when it is necessary for safety and or efficiency. As well the cars could alert emergency services without the distraction of the driver having to call themselves, the car could send an alert to 911 and also send them images picked up on their camera systems and a pin directly on the map to aid them in their efforts of providing services to anyone in the accident (Oster). My hope for the future of self-driving cars is the ability for emergency services, such as an ambulance, to also utilize the technology that these cars can provide and allow for the communications previously stated to be sent directly to the cars and have them immediately drive, if not already in use, to the injured victims of said accidents. Additionally, these communications will only get better with time as services that these cars use for communication will develop and become more efficient, right now the cars use 5G to communicate with not only the cars around them but also the autonomous vehicle uses 5G to make the calls necessary to the emergency services directly in near-instant times (Oster). The capabilities of these self-driving cars are only in their infancy and I hope that eventually, the price for these cars will be able to lower so that there can be as many of these cars in the world as possible once the cars have all problems are fixed as these cars can help the would be a safer, accident-free, place if everything works properly.

Faulty Detection

Though the hope is for these cars to be able to be perfect as they could make the world safer, the reality is there are many bugs in the software and many instances of faulty detection that have caused the opposite and made the world less safe. These faulty detections also have an underlying bias of the creators of these algorithms which determine what an object is through the sensors. Since algorithms and systems learn from images and examples that are used in the process of attempting recognition, for example if the algorithm doesn't get enough images of, for example, a woman of color then once these algorithms are put to use they will have a significantly higher chance of misidentification (Samuel). Though the industry is still in its infancy there have been multiple studies done on just how much the cars are unable to detect people of color, Alex Hern, a writer from, "The Guardian" put this perfectly "Garbage in Garbage out; train a self-driving car to recognize human figures by showing it millions of pictures of white people, and it might struggle to identify pedestrians of other races"(Hern). The most widely accepted study on this topic, from the Georgia Institute of Technology, stated that there is 5-10% less detection of darker-skinned individuals compared to people with lighter skin (Samuel, Hern). Luckily many of the autonomous vehicles are equipped with sensors, such as radar, that do not require any form of light and only the detect size and shape so even though there is a lowered detection for people of color there is a safety feature, with the radar sensor, that allows all people to just look like a blob that needs to be avoided in the car's mind.

Misinterpreting Objects as Important Indications for Traffic

There have been many instances in which there was a misidentification of certain objects as very important indications of traffic in the process of identification for autonomous vehicles.

During an interview with the CEO of Tesla, Elon Musk, Musk was speaking on the attacks that Tesla was facing regarding the misidentification of objects and even spoke on the potential attacks that the cars could witness when he talked about how he tricked the autopilot system by showing the car a t-shirt with a stop sign on it. Musk stated, “I actually have a T-shirt with a stop sign on it. If you flash the car, it will stop ... I've proved it." Musk even spoke about a viral tweet that was being spread that talked about how on the highway the full moon that was occurring tricked the Tesla into thinking that the moon was a yellow light (Towey). Though this seems like a big issue with the detection of autonomous vehicles, the fact that the CEO of a major self-driving car manufacturer was joking about it means that they likely are already looking into how to fix the misidentification of these objects. To combat this problem Tesla released a "Traffic Light and Stop Sign Control" feature, via a software update in early 2020, though it is still in beta, and owners have to switch it on manually (Towey).

Market Pressure to Lower Prices

Though there is a high demand for the manufacturers of autonomous vehicles to lower their prices, the parts that these companies would have to get rid of on the cars to lower the production costs are not the parts that they can ethically get rid of. For the price to lower to what the market pressure intends it to the manufacturers would have to move to nearly a solely camera-operated autonomous vehicle and this would not be good as the camera system is the most likely to misinterpret a person of color as something else, such as a shadow, as it only operates off of light (Hern). Not only will the cars have a higher chance of misinterpreting the data, but the camera system has the shortest detection range out of any of the trifecta of detection systems on the cars as well as has the most problems in different types of weather. With all

factors considered, though it would be nice to be able to lower the cost of autonomous vehicles so that the average person could own one, the bad outweighs the good as the safety features of the car goes down tremendously while the price only lowers 10-15% (Hern)

Conclusion

Though autonomous vehicles have the potential to completely change the dynamic of driving and make the roads a safer place, the technology is still in its infancy. These vehicles still have many bugs that need to be addressed in the algorithms and hardware that makes these vehicles work. Though these bugs are still very prominent, the way that these cars utilize waves is the best possible outcome for safety as the trifecta that the cars use - radar, LiDAR, and camera technology - allows for additional safety measures by allowing multiple forms of detection for the car to determine if it needs to slow its velocity or make a complete stop. All things considered, these autonomous vehicles would never be able to properly drive if it wasn't for the utilization of waves. Furthermore, the future possibilities of these autonomous vehicles is unimaginable as the possibilities of advancement in wave technology means that these vehicles will only get safer in the future.

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