Report of Findings on the Safety of Autonomous Vehicles

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Team #: 1

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Team Topic: Autonomous vehicles are a safer means of transportation than human-controlled vehicles

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Executive Summary

According to the National Highway Traffic Safety Administration, in 2016, 37,461 people were killed in motor vehicle crashes in the U.S. Furthermore, U.S. safety regulators claim that 94% of all automotive accidents are caused by human error. Thankfully, human errors could be eliminated from motor vehicle accidents with autonomous vehicles and would allow multiple road deaths to be prevented.

Autonomous vehicles rely on multiple sensors to function. One type of sensors used by autonomous vehicles are proximity sensors. They are used by autonomous vehicles to detect metal objects which surround the vehicle. Proximity sensors emit an electromagnetic field towards surrounding metal objects and measures the disruption in the field to determine a metal object's distance from the vehicle. Proximity sensors generate this electromagnetic field by making use of the Hall Effect theory. The Hall Effect can compute the distance a vehicle has to another vehicle. This analog information is processed by computers by using analog to digital converters.

Currently, autonomous vehicles require more development to safely transport passengers. Improving the safety of autonomous vehicles is possible by improving the technology which is used by autonomous vehicles to detect surrounding objects. This technology is called LIDAR and could be improved by implementing active learning to the machine learning algorithm used by LIDAR. Doing this would shorten the time taken for LIDAR to classify surrounding objects. Furthermore, with multiple wireless connections, autonomous vehicles must be made secure to prevent them from being hacked remotely. Even though autonomous vehicles can be difficult to hack, Blackberry has developed a tool called Jarvis which scans automotive binary code for security vulnerabilities. Jarvis can therefore help design more secure software for autonomous vehicles.

The safety of autonomous vehicles is also related to the automatic emergency braking system. The emergency brake actuators are the hardware responsible for braking the vehicle when instructed to by the vehicle's sensors. The emergency braking system also has built-in active safety systems which help prevent motor vehicle crashes. To improve the mechanism of the braking system, the dynamics involved in the braking system must be enhanced. This is achieved by enhancing the major components of the braking system. Specifically, this is possible by using superior friction materials for the brakes and by implementing the regenerative braking system.

All of the safety features present in autonomous vehicles demonstrate that they are safer than human-controlled vehicles. In fact, if autonomous vehicles are deployed, they could help prevent road deaths; an issue that, if solved, could allow many lives to be saved. Hopefully, the findings from this report provides enough information for investors to feel interested in supporting the development of autonomous vehicles for safer roads.

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1.0 Introduction

This report presents findings on the safety of autonomous vehicles. Specifically, the aim of this report is to prove that autonomous vehicles could potentially be a safer alternative to human-controlled vehicles.

On September 18th 2018, it had been decided by the instructor of the CCDP 2100 course for section L that teams would be created to perform research on a cutting-edge technology for a term project. Team 1 has been assigned to perform research on autonomous vehicles to demonstrate to society the safety autonomous vehicles could bring to public roads. In fact, the deployment of autonomous vehicles would help prevent many road deaths from occurring.

According to the National Highway Traffic Safety Administration, in 2016, 37,461 people were killed in motor vehicle crashes in the U.S. [1]. This issue is also present in Canada where, in 2016, 1,171 people were killed in motor vehicle crashes [2]. As a matter of fact, U.S. safety regulators claim that 94% of all automotive accidents are caused by human error [3]. Considering the latter, autonomous vehicles could eliminate human errors from motor vehicle accidents and would allow, in two years, to save as many people as the number of Americans lost in the Vietnam war in the U.S. alone; a total of 58,220 lives [4], [5]. The safety autonomous could bring to public roads has even gathered the attention of the U.S. government which now plans to spend four billion dollars over the next decade to make autonomous vehicles a reality [6].

This report will highlight the safety of autonomous vehicles and will emphasize how they could be the solution for eliminating road deaths. In Section 2.0, research findings on the subtopics will be presented by answering two research questions for each. The subtopic for Section 2.1 is the sensor system. Section 2.1.1 will answer how autonomous vehicles detect objects with sensors, and Section 2.1.2 will answer how the Hall Effect is used in proximity sensors. The subtopic for Section 2.2 is security. Section 2.2.1 will answer how autonomous vehicles could be improved to be more secure, and Section 2.2.2 will answer how autonomous vehicles could be the targets of cyberattacks. The subtopic for Section 2.3 is the automatic emergency braking system. Section 2.3.1 will answer how the emergency braking system works, and Section 2.3.2 will answer how the mechanism of the braking system could be improved.

This report also contains a glossary for technical terms which can be found on page 24. Terms which are defined in the glossary will appear in italics throughout the text. Hopefully the findings from this report provides enough information for investors to feel interested in supporting the development of autonomous vehicles for safer roads.

2.0 Research Findings:

This section has been divided into three sub-sections, each of which presenting the findings of the subtopics. Each sub-section is further divided to present two research questions related to the subtopic. Lastly, the findings for each research question will be based on a relevant engineering principle. The subtopics presented are Sensor Systems in Section 2.1, Security in Section 2.2, and Automatic Emergency Braking in Section 2.3.

2.1 Sensor Systems (by Anil Menon):

This section covers the sensor systems involved in autonomous vehicles. Section 2.1.1 presents findings on how autonomous vehicles detect objects, based on the engineering principle Analog to Digital Converters. Section 2.1.2 presents findings on role of the Hall Effect in a proximity sensor, using the engineering principle Hall Effect. Answering these questions will help understand the safety of autonomous vehicles in society.

2.1.1 How Does an Autonomous Vehicle Detect Objects?

For an autonomous vehicle to detect an object in its surroundings, it will need to use a proximity sensor. A proximity sensor is a device that can detect metal objects around its surrounding without any physical contact [7]. This sensor has two main components, a sine wave oscillator that generates *oscillating* voltage and an *electromagnetic field* emitter [8]. This emitter will project an electromagnetic field around the body of the car to detect any metal object, shown in Figure 1. If the field lines of the electromagnetic field are interrupted by a metal object, it will cause a disruption to the *sine wave* oscillator proportional to the distance of the metal object [8]. This change in the sine wave will then resemble the *analog signal* produced by the proximity sensor.

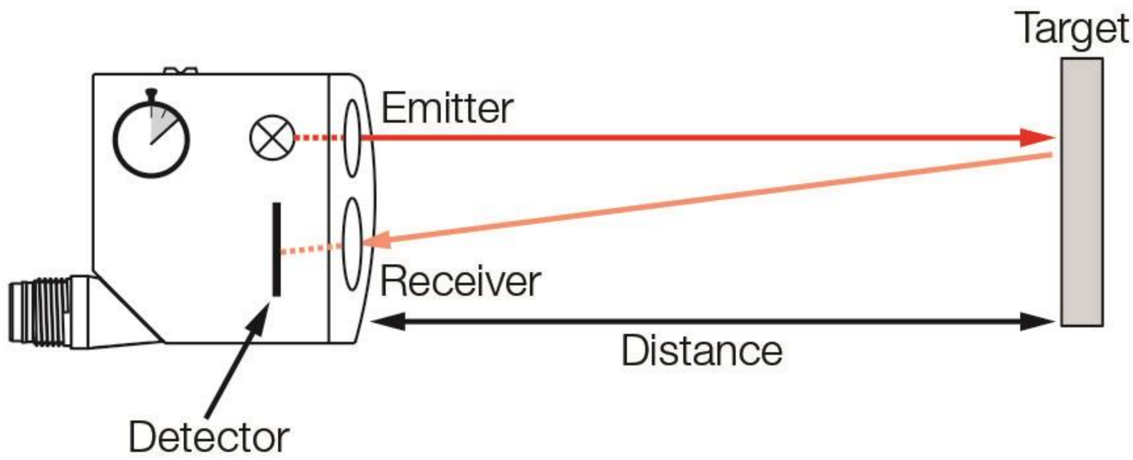

Fig. 1 On the left side of diagram is the proximity sensor. The coil in the sensor emits electromagnetic waves to detect metal objects [9].

For the autonomous vehicles to understand information, it requires analog information to be converted into digital. Hence, the analog signal produced by the proximity sensor, will then be stored in a memory called Hold in the Analog to Digital Converter seen in Figure 2. Let this signal be referred to as V_{in}.

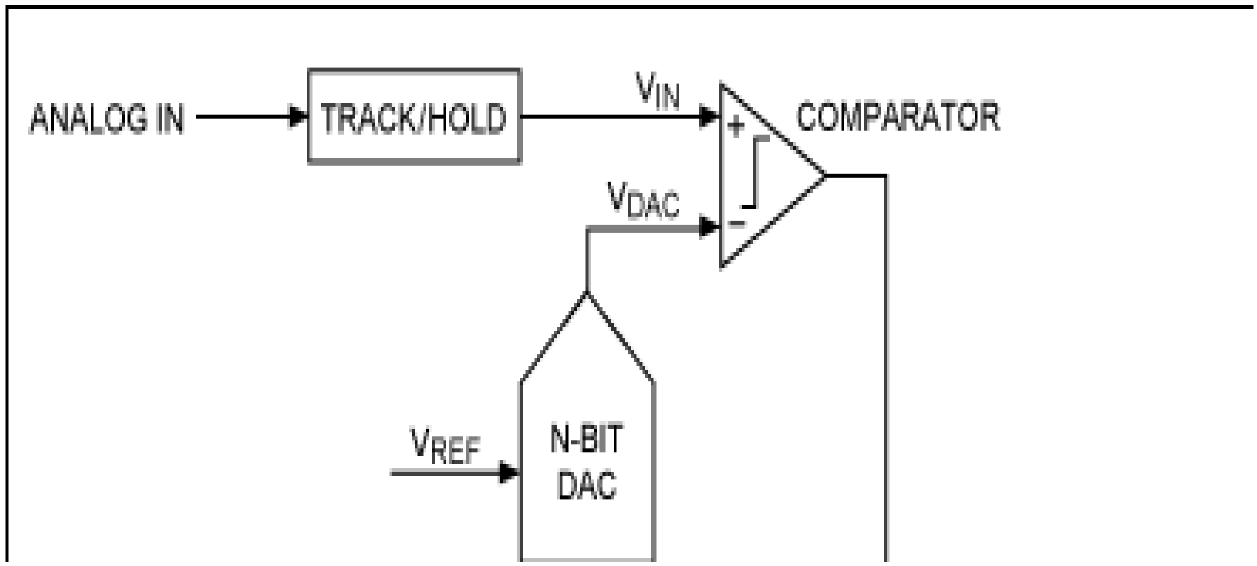

Fig. 2 The Analog to Digital Converter [8].

V_{in} will be compared with voltage (V_{ref}) in order to convert from analog to digital. V_{ref} is computed by applying Binary Search Algorithm. This algorithm in short terms, takes a few points of interest from the analog signal and computes an average point for that sample shown in Figure 3.

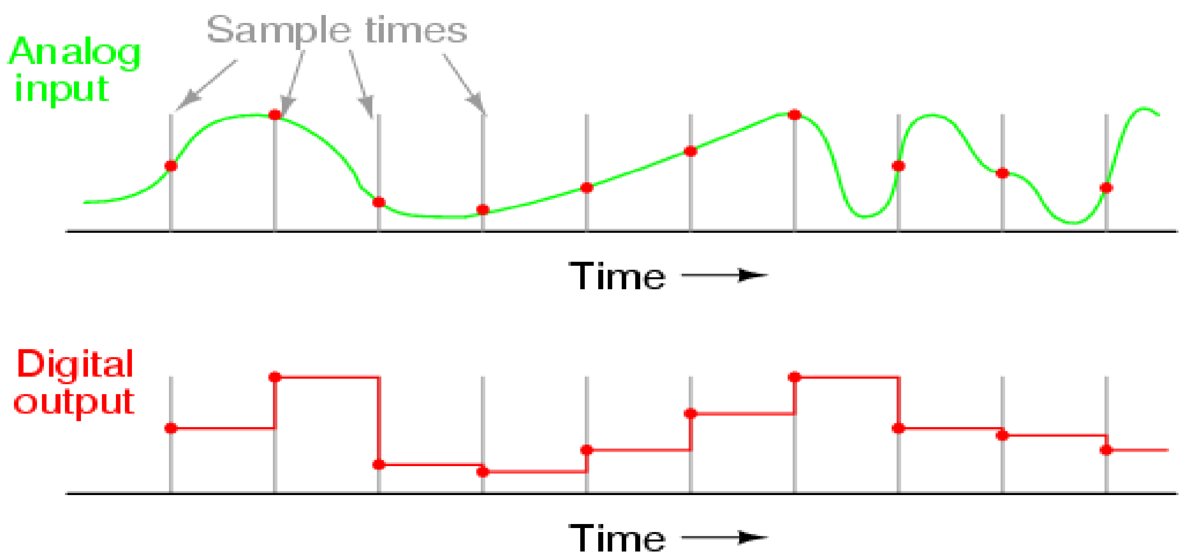

Fig. 3 V_{ref} or in this case, sample times, is calculated using Binary Search Algorithm on the analog input to produce a digital output [10].

Within the sample time, any values of V_{in} greater than V_{ref} will be considered *High* or a 1 and any values of V_{in} less than V_{ref} is considered *Low* or 0. This process of sampling and comparing is done for every section of the analog signal (V_{in}) resulting in digital outputs that are used by the microprocessor [8].

The importance of having Analog to Digital converters in autonomous vehicles are crucial since self-driving cars require stable communication within the sensors around the car to operate smoothly and navigate in the physical world.

2.1.2 How Does the Hall Effect Play a Role in the Proximity Sensor?

As described in section 2.1.1, a proximity sensor is a device that can detect an object without any physical contact [7]. A part of this sensor is the Analog to Digital Converter; however, the proximity sensor relies on the Hall Effect as well. For the proximity sensor to produce analogous information, it uses the theory of the Hall Effect to send electromagnetic waves around the body of the car in order to detect objects.

Section 2.1.1 describes how the electromagnetic field emitter emits electromagnetic waves to produce analog signals. However, how does it work? In Figure 4, there is a wire connected to a metal plate and has electrical current flowing through it.

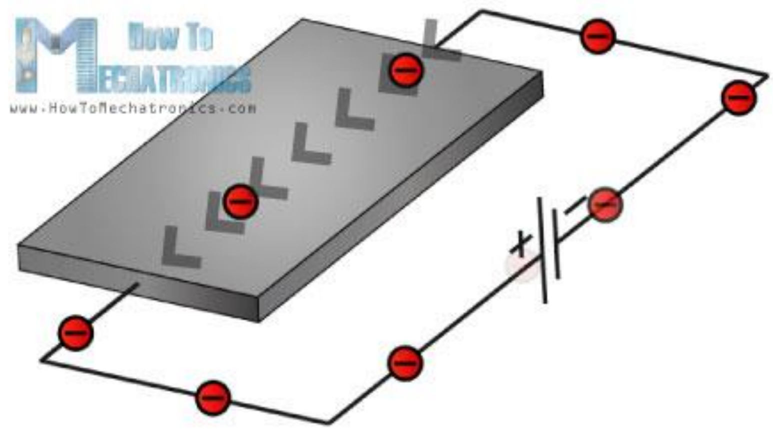

Fig. 4 Step 1 of the Hall Effect. Electric current passing through the metal plate in a linear motion [11].

Depicted in Figure 5, when a magnet is placed on top of the metal plate, it disturbs the straight flow of the electrons and will force the current carriers to *polarize* the plate. The measure of voltage between the two ends of the plate is what is called the Hall Effect [11]. Essentially, by *Lorentz force*, the plate gets divided into a positive side and a negative side. This is due to the magnet placed above the metal plate deviating the flow of electrons. This creates a *potential difference* between the two ends of the plate and makes a Hall Effect [12]. This is the idea behind the Hall Effect and this is the principle that is used to detect other metal objects.

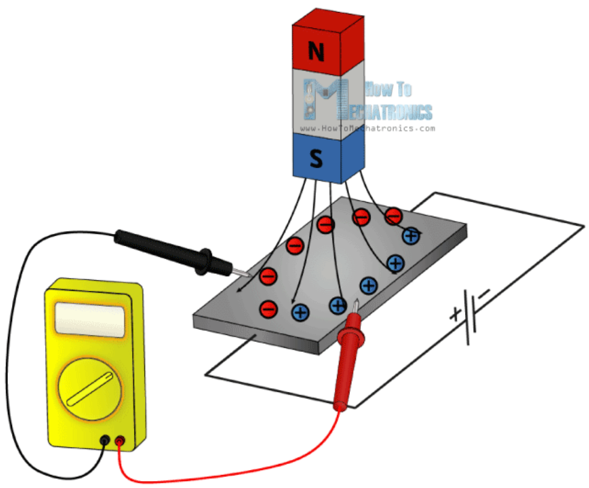

Fig. 5 Step 2 of the process of Hall Effect. Magnet placed on top of metal forcing (i.e., Lorentz Force) the flow of electrons to deviate producing a positive and negative side on the metal plate [11].

How does the Hall Effect play a role in the proximity sensor? In the proximity sensor, the metal plate conductor is replaced with a metal coil. When electrical current flows through the coil it induces a magnetic field. This is the magnetic field that surrounds the body of the car. As the car comes closer to a metal object such as another car, the metal object will act as a magnet. By Lorentz force, this magnet forces the coil to polarize and essentially creates a potential difference between the two ends of the coil (also known as the Hall Voltage) [13]. The potential difference between the coil is directly proportional to the size of the magnetic field. In other words, as a metal object such as a car arrives closer to the proximity sensor, the magnetic field gets stronger and in turn causes a greater potential difference between the coil. This is because, the bigger the magnetic field, the greater the deflection of electrons causing a greater potential difference between the two ends of the coil [14]. Overall this means that, as a car approaches the proximity sensor, the Hall Voltage slowly increases and therefore the self-driving car must slow down or change lanes as a result.

This increase and decrease in the Hall Voltage create the analogous information for the proximity sensor. When no metal objects surround the proximity sensor, the magnetic field is constant and does not change the Hall Voltage. This in turn causes the sine wave oscillator found in a proximity sensor to oscillate normally. In other words, the car does not detect any metal objects in its surroundings as it continues to drive straight. However, when a metal object is detected, the change in magnetic field will change the Hall Voltage and will cause discrepancies in the sine wave oscillation. This alteration in the sine wave oscillator becomes the analog signal needed in an Analog to Digital Converter to convert to binary.

The application of the Hall Effect in sensors, not just in proximity sensors, helps the microprocessors in autonomous vehicles visualize a clear understanding of its surroundings and react accordingly [15].

2.2 Security (by Dylan Leveille):

This section covers the security involved in autonomous vehicles. Section 2.2.1 presents findings on how autonomous vehicles could be improved to be more secure and is based on LIDAR (Light Detection And Ranging) as an engineering principle. Section 2.2.2 presents findings on how autonomous vehicles could be the targets of *cyberattacks* and is based on the CAN (Controller Area Network) bus as an engineering principle.

2.2.1 How Could Autonomous Vehicles be Improved to be More Secure?

To improve the safety of autonomous vehicles, the technology which allows an autonomous vehicle to detect surrounding objects must be improved. The technology responsible for this is called LIDAR. LIDAR sends commands to an autonomous vehicle to avoid colliding with the objects it has detected around the vehicle [16]. Therefore, improving LIDAR would allow autonomous vehicles to better detect surrounding objects and would prevent fatal collisions from occurring.

2.2.1.1 How Does LIDAR Work

LIDAR is located on the roofs of autonomous vehicles and it is always spinning on itself to see everything around the vehicle [16]. To detect objects, LIDAR fires laser beams towards surrounding objects and measures the time taken for its laser beams to hit these objects and return [16]. With this value of time, and knowing that the laser beams are constantly travelling at the speed of light, LIDAR can calculate an autonomous vehicle's distance from an object using the equation shown in Equation 1 below:

Eq. 1 $d = \frac{t \cdot c}{2}$ [16]

Where c is the speed of light, t is the time taken for the laser beam to return, and d is the autonomous vehicle's distance from the object.

By firing more than one laser beam at once, LIDAR can create a map of every point its laser beams hit [17]. This map is referred to as a point cloud and is used by LIDAR to classify the objects which surround the autonomous vehicle [17]. The classified objects are associated with a movement pattern which is used by LIDAR to predict possible collisions [17]. Figure 6 below demonstrates how objects can be classified from a point cloud:

Fig. 6 Classifying objects from a point cloud [17]

2.2.1.2 Improving LIDAR's Ability to Identify Objects Faster

Improving LIDAR's ability to identify objects faster would allow potential collisions to be detected sooner. This is possible by improving AdaBoost. AdaBoost is the *machine learning* algorithm used by LIDAR to classify objects from point clouds [18]. For example, for AdaBoost to detect a pedestrian, collected *clusters* from a point cloud are searched by AdaBoost for human parameters, such as legs [19]. Once found, these parameters are compared to the statistical features of human legs which AdaBoost uses to calculate the probability of that cluster being a human [19]. Therefore, improving AdaBoost would make the process of classifying objects faster.

Improving AdaBoost to classify objects faster is possible by implementing active learning to AdaBoost's machine learning algorithm [20]. With active learning, AdaBoost queries a database as to which objects it should classify from a point cloud, and disregard the rest to save time [21]. A simplistic example depicting how active learning works is demonstrated in Figure 7 below:

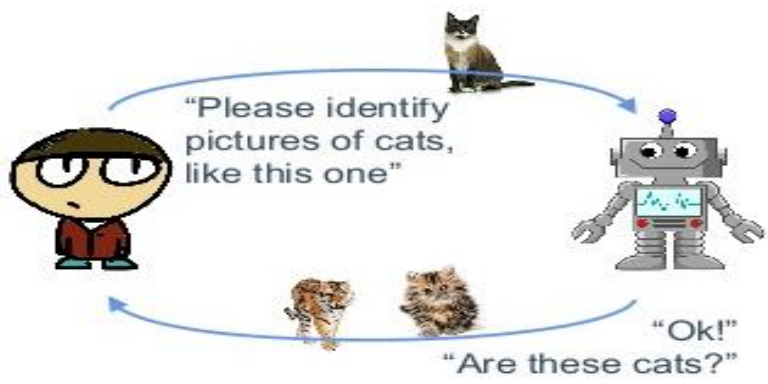

Fig. 7 An example of how active learning works [22]

The example in Figure 7 shows that the machine only tries to classify the objects demanded from a database. In the case of autonomous vehicles, the machine is LIDAR and one of many objects requested by the database would be pedestrians.

In a survey of annotation projects for natural language processing tasks, only 20% said they had ever decided to use active learning [23]. According to this survey, many were against active learning due to the high development cost required to implement it [23]. However, the speed at which objects can be classified with active learning is a considerable advantage to autonomous vehicles for preventing collisions sooner and should not be disregarded.

2.2.2 Could Autonomous Vehicles be Targets of *Cyberattacks*?

Hacking an autonomous vehicle could be possible by gaining access the vehicle's CAN bus. If an autonomous vehicle is *hacked*, it could be controlled to put passengers' lives at risk. Thankfully, there are ways to prevent an autonomous vehicle from being hacked.

2.2.2.1 What is the CAN Bus?

The CAN bus is the network inside every modern vehicle which performs most of the vehicle's internal communications [24]. The CAN bus is comparable to the vehicle's central nervous system since it allows the vehicle's *status* to be modified [24]. Figure 8 below illustrates the components of a vehicle's CAN bus:

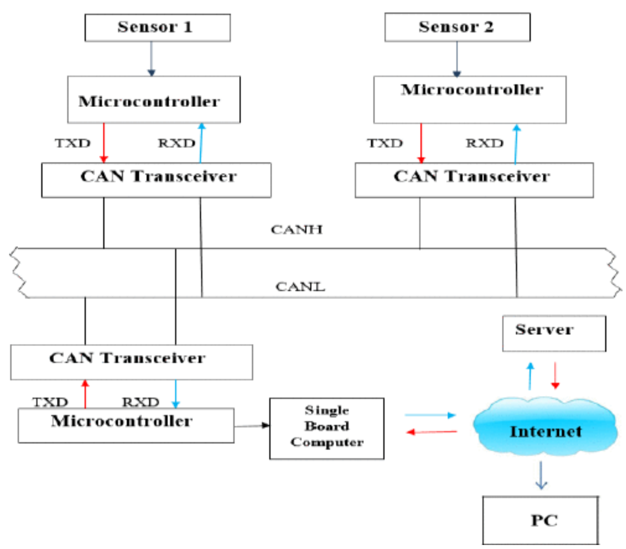

Fig. 8 Diagram of the components of a vehicle's CAN bus [25]

From Figure 8, it can be noted that most *nodes* in the CAN bus are composed of the following elements: a *CAN transceiver*, a *microcontroller* (or CAN controller), and a *sensor* [25]. These elements work together to send and receive information about the vehicle's status [25]. They can also send commands to manipulate the vehicle's status [25]. It can be noted that, for some of the nodes, the microcontrollers are connected to *single board computers* rather than sensors. These microcontrollers are referred to as wireless modules and allow the integration of wireless technologies, such as Wi-Fi or Bluetooth, in the CAN bus [25], [26]. An example of an autonomous vehicle's CAN bus requiring an internet connection is to receive traffic information to find the shortest route to the passengers' destination [27].

2.2.2.2 Hacking the CAN Bus from the OBD-II Port

The easiest way for a *hacker* to access the CAN bus is through the OBD-II port [24]. For any modern vehicle, the Onboard Diagnostic port, also known as the OBD-II port, is the most direct interface to a vehicle's CAN bus [24]. The OBD-II port can be described as an unprotected point of entry into the vehicle's most sensitive embedded system [24]. It can be found underneath a vehicle's dashboard, as seen in Figure 9 below [24]:

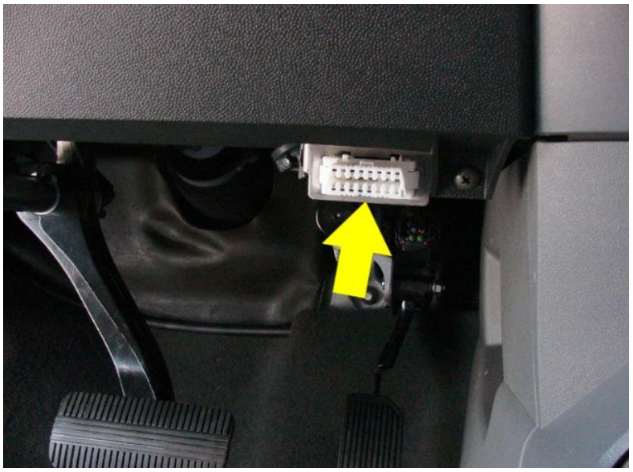

Fig. 9 Location of an OBD-II port on a 2005 Nissan Titan [24]

For a hacker to access the CAN bus from this port, a CAN to USB interface device called CANtact is connected from the hacker's computer to the OBD-II port [24]. CANtact can be compared to a USB adapter which allows the hacker's computer to communicate with the CAN bus through a *socket* [24]. This socket is referred to as socketCAN and can, after importing a few socketCAN utilities, allow the CAN bus to be controlled from a computer's terminal [24]. For example, the following command in Figure 10 would change a vehicle's gear to park [24]:

```
cansend slcan0 188#000000010000
```

Fig. 10 Command to change a vehicle's gear to park [24]

If the command from Figure 10 is executed while a vehicle is in motion, the vehicle could be involved in a fatal collision. In fact, once a hacker has gained access to the CAN bus, they could disable many crucial components in the vehicle to cause harm.

2.2.2.3 Hacking the CAN Bus Remotely

Although hacking the CAN bus from the OBD-II port can be considered simple, a hacker will most likely prefer hacking an autonomous vehicle's CAN bus from a distance to avoid having to break into the vehicle [24]. A hacker would be able to do this by accessing the access points created by the wireless modules described in Section 2.2.2.1. In fact, it is expected that *road-ready* autonomous vehicles will have many wireless modules integrated within their CAN bus [24]. This results in many access points where a hacker could access the CAN bus to cause harm [27]. Thankfully, autonomous vehicles are difficult to hack since they rely on multiple sensors to function [28].

Specifically, for a hacker to control an autonomous vehicle, they would have to simulate a realistic world within the CAN bus by tricking all of the vehicle's sensors at once [27]. In fact, if the sensors detect that they aren't getting realistic data, then the autonomous vehicle will come to a stop to protect its passengers [27]. For example, if an autonomous vehicle's CAN bus was hacked to have LIDAR unable to detect pedestrians, the vehicle's other sensors, such as various cameras and radar, will contradict the data received by LIDAR which will force the vehicle to stop [27].

2.2.2.4 Preventing the CAN Bus from Being Hacked

Although remotely hacking the CAN bus of an autonomous vehicle may be difficult, the possibility cannot be neglected. A solution that could prevent the CAN bus from being hacked remotely is a tool developed by Blackberry called Jarvis which scans automotive binary code for security vulnerabilities in the software [29]. It can assess code for security in 7 minutes [29]. This process would normally take researchers approximately 30 days to complete by hand [29]. The results obtained by Jarvis give engineers the necessary information to design software that prevent the CAN bus from being hacked remotely [29]. With Jarvis, passengers of autonomous vehicles can rest assured that no hackers will take control of their vehicle.

2.3 Automatic Emergency Braking (by Anandarajah Yathuvaran):

This section discusses the Automatic Emergency Braking involved in autonomous vehicles. Section 2.3.1 contains findings on how the Emergency Braking System (EBS) works in autonomous vehicles, using the emergency brake actuator as an engineering principal. Section 2.3.2 presents findings on how to improve the mechanism of the braking system in autonomous vehicles using dynamics as the engineering principal.

2.3.1 How does the Emergency Braking System work?

2.3.1.1 The Emergency Brake Actuator:

Actuators are hardware that perform physical actions such as braking when instructed to by the car’s computer. Processors analyze data from the car’s sensors and command the brake actuator as required [30]. They can be compared to the muscles in the human body responding to signals sent from the brain [31]. Brake actuators are a crucial component in the emergency braking system, as they control the braking of the vehicle depending on the data received by the sensors [32].

2.3.1.2 How the Emergency Braking System Works:

Once the actuator receives instructions, the brakes are applied. This causes a *piston* to be pushed in the master cylinder, which forces a fluid down a pipe [33]. The purpose of the master cylinder is to multiply the amount of the force applied on the brake pedal [34]. The fluid then gets distributed to the slave cylinders and fills it at each wheel; which expands pistons within the slave cylinder and applies the brakes [33]. Figure 11 illustrates this process by presenting a diagram of the braking system.

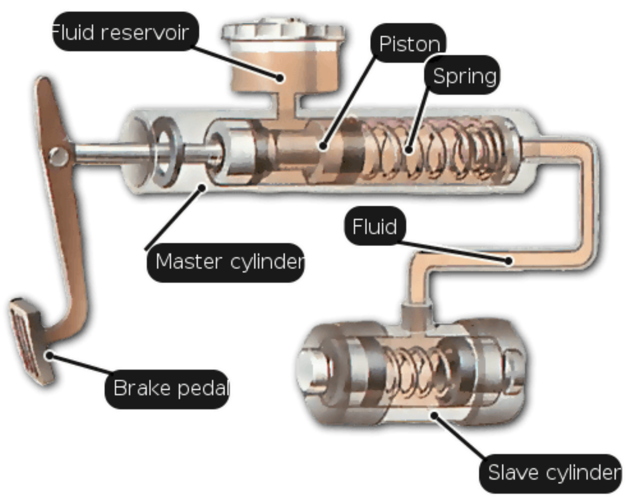

Fig. 11 Diagram of the braking system in vehicles [33]

2.3.1.3 Types of Brakes used in the Emergency Braking System:

There are two types of brakes found in the braking system, drum brakes, and disc brakes. Drum brakes house its components within a drum that rotates with the wheel. Once the brakes are applied, a set of shoes inside the drum are forced against the walls of the drum to slow the wheel [35]. Whereas disc brakes use a disc and a caliper to slow the wheel. The brake caliper contains two brake pads, one on each side of the disc. When the brakes are applied, the brake pads clamp together between the disc, generating friction against the disc to slow the wheel [35]. Figure 12 provides an illustration of drum brakes and disc brakes.

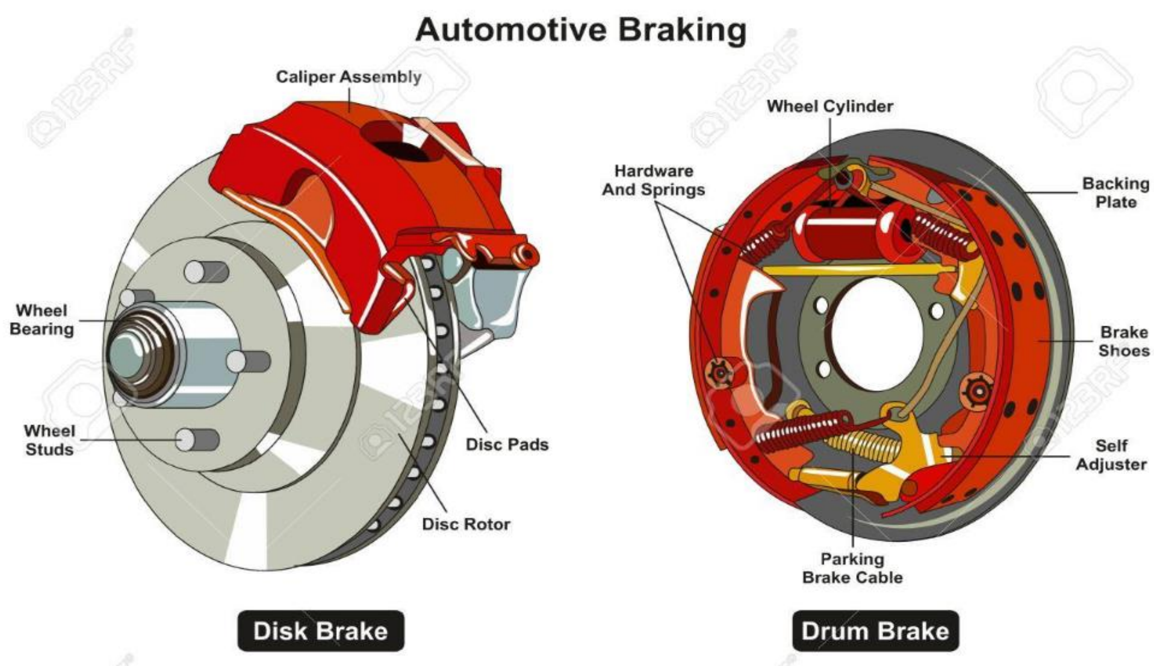

Fig. 12 Types of brakes used in the emergency braking system [36]

2.3.1.4 Active Safety Systems in the Emergency Braking System:

The following Active Safety Systems are implemented in the EBS to further enhance safety. The Anti-lock braking system (ABS) uses sensors that track the rotational speed of each wheel. In wet road conditions, sudden braking can cause the wheels to lock up and the tires to skid; due to the loss of contact with the road. Once skidding is sensed, the ABS reduces the wheel speed by pulsing the brakes on and off in rapid succession; thus, allowing the tires to regain contact with the road [34]. The Forward collision warning system alerts the driver by using visual, audio or tactile cues right before the driver can pull a maneuver to avoid the upcoming collision [37]. The Pre-crash brake assist system is activated when the vehicle detects an impending collision and multiplies the braking input received from the driver [37]. The autonomous pre-crash braking system is activated last, when the collision is unavoidable and automatically applies brakes regardless of driver input [37].

2.3.2 How can the mechanism of the braking system be improved?

2.3.2.1 The Dynamics involved in the braking system:

When torque is exerted on an object, its rotational speed will alter [38]. The *friction* exerted by the break pads on the wheels of a vehicle produces torque on the main *axle*, which slows it down and brings the vehicle to a stop [38]. To improve the mechanism of the braking system, the dynamics involved, such as torque, friction, and *pressure*, can be enhanced with improved brake components [39].

2.3.2.2 Components of the mechanism of the braking system that can be improved:

The two major components of the mechanism of the braking system that can be improved are brake line pressure and clamping force. The brake line pressure is the *hydraulic* force that activates the braking system when the brakes are applied, it can only be enhanced by increasing the *mechanical pedal ratio* or by reducing the diameter of the master cylinder [39]. If the mechanical pedal ratio is increased, it would increase the force multiplication; thus, resulting in a greater applied force when braking [39]. The Clamping force is the force applied onto the brake discs by the *caliper pistons* [39]. The Clamping force can only be enhanced by increasing the brake line pressure or by enlarging the diameter of the caliper pistons [39]. Furthermore, drilled or slotted brake discs as illustrated in Figures 13 and 14 respectively, can help vent the gasses caused by braking from the friction generating surfaces. As a result, the drilled or slotted brake discs create more surface contact which allows for greater braking power [40].

Fig. 13 Drilled Brake Disc [41]

Fig. 14 Slotted Brake Disc [41]

2.3.2.3 Materials of the braking system that can be improved:

Different vehicles use different friction materials based on their use. Formula one race cars use carbon fiber composites. High-performance vehicles such as rally cars use *sintered metal*. Most modern road vehicles use resin-bonded composite [42]. However, there are several important factors to consider when considering a friction material: [42]

- The material must provide a constant reliable force of friction when braking

- The material should be durable, being both physically and thermally strong to endure the loads applied upon it when braking
- The material should be environmentally friendly and cost efficient

Ceramic friction material provides consistent high friction for use in high duty applications. However, they require expensive brake disc materials [42]. Carbon fiber composite material can endure high duty applications for long periods of time. However, they are susceptible to temperature and humidity [42]. Sintered metal material provides high friction under extreme conditions of use. Sintered metal material also supplies constant frictional performance against stainless steel discs, especially during wet conditions [42]. Therefore, using sintered metal as a friction material can improve the mechanism of the braking system.

2.3.2.4 Implementing the Regenerative Braking System:

The Regenerative Braking System (RBS) captures and reuses the vehicle's braking energy that would be lost otherwise. The energy would be then stored in areas, such as batteries or *supercapacitors* [42]. Reusing this energy would help improve the fuel efficiency and provide additional range to electric or hybrid vehicles [42]. When the brakes are applied in the RBS, the electric motors on each wheel spin in reverse. Consequently, slowing the vehicle's wheels, and causing the motor to preform as a generator to produce electricity, which is then stored for later use [43]. Figure 15 illustrates this process by presenting a diagram of the RBS. However, back up friction brakes are also implemented for when the RBS does not produce enough braking power [43].

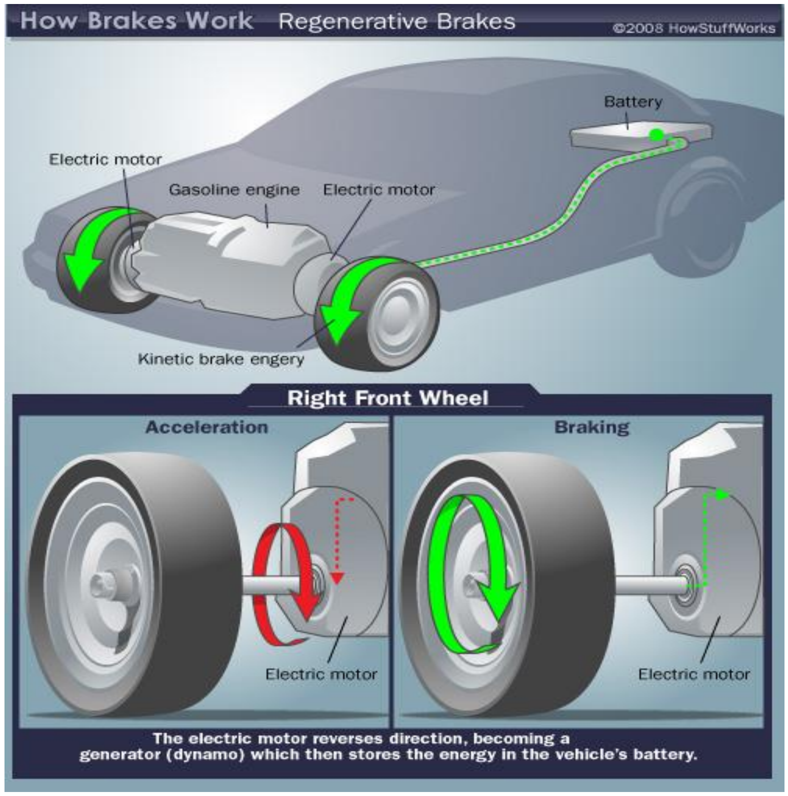

Fig. 15 Diagram of the regenerative braking system [44]

3.0 Conclusion

This report presents enough information to support the claim that autonomous vehicles are safer than human controlled vehicles. In fact, the safety of autonomous vehicles is noticeable in the sensor systems they use. Specifically, the sensor systems can prevent collisions by detecting nearby objects which could be unseen by a human driver. Furthermore, the fact that LIDAR can be improved to detect objects faster allows potential collisions to be detected at a faster rate than is possible by a human. Also, the fact that autonomous vehicles are difficult to hack results in passengers feeling safe knowing that their vehicle won't be hacked to put their lives at risk. Lastly, all the data received by an autonomous vehicle's sensors is used by the automatic braking system to allow the vehicle's brakes to be applied faster than is humanly possible. When considering all the information presented in this report, it can be concluded that autonomous vehicles are a cutting-edge technology which could allow road deaths to be prevented. Hence, the deployment of autonomous vehicles will result in society having safer roads for its citizens. Hopefully this report has given enough information for investors to feel interested in supporting this life-saving technology. The team leader is willing to provide answers to any questions about this report and can be contacted at any time by email at the following address: dylanleveille@cmail.carleton.ca. Team 1 is looking forward to the deployment of autonomous vehicles.

Sincerely,

Dylan Leveille, Team Leader for Team 1

Glossary

Analog signal: a continuous sine wave that may differ in amplitude and time. These signals have no breaks [45].

Axle*:* A shaft or pin on where a pair of wheels revolve [46].

Caliper Pistons*:* The pistons responsible for causing the brake pads to clamp onto the brake discs [47].

CAN transceiver: The device which allows communication between the CAN bus and the microcontroller [25].

Clusters: Data points which are grouped from a large set of randomly distributed data points based on their similarities [23]. Three cluster can be seen in Figure 1.

Cyberattacks: Cyberattacks are malicious attempts to access or damage a computer system which, in the case of autonomous vehicles, can lead to endangering one's life [48].

Digital signals: analog waves that are appraised in intervals and then converted to a computer language that is deciphered in one's and zero's [49].

Electromagnetic field: EMF is the field produced by electrically charged objects and can affect other electrically charged objects in its surrounding [50].

Friction: A force which resists the motion between two solid objects in contact [51].

Hacked: A device that has been breached by a hacker [24].

Hacker: A person who attempts to breach the security measures implemented by a device to access and/or control that device's information [24].

Hydraulic*:* Involves or works using a fluid under pressure carried through a pipe or tube [52].

Lorentz Force: the force caused by a magnetic field applied on current carriers of moving charge [53].

Machine learning: A branch of artificial intelligence based on the idea that that systems can learn from data and identify patterns to make decisions [54].

Mechanical Pedal Ratio*:* The ratio of the length of the pedal and, the distance between the pushrod mount and pivot point [55].

Microcontrollers: Manipulate the data received by a device (such as a sensor) in order to send commands to the CAN bus [25].

Node: A group containing a CAN transceiver, a microcontroller, and a sensor (or single board computer) that is connected to the lines of a CAN bus [25].

Oscillation: The back and forth motion of values within the center of axis creating a periodic motion. Most common type of oscillation is the sine wave [56].

Piston*:* A cylinder or disc that slides in a hollow cylinder [57].

Polarize: to attain a polarity. Polarity is the term used in electricity or magnetism when metal objects have more electrons on one side of the object than the other side. The pole with relatively more electrons has a negative polarity and the side with the least number of electrons has a positive polarity [58].

Potential Difference: the difference in electrical charge from one end to another. In this case, the potential difference between the negative side of the plate and the positive side [59].

Pressure*:* The perpendicular applied force on an object per unit area [60].

Road-ready: Autonomous vehicles which can properly function on all public roads [61].

Sensor: A device which determines a property of the vehicle's status, such as the vehicle's speed [25].

Sine wave: a mathematical wave that flows in a sinusoidal motion and has a periodic motion [62].

Single board computers: A computer that is built on a single circuit board and contains computer components such as a microprocessor and memory [63].

Sintered Metal: A metal product made by a special process from various types of metals and alloys [64].

Socket: Allows communication between two different processes on the same or different machines [65].

Status: Refers to the vehicle's attributes, such as the vehicle's speed, the engine's RPM, the gear selection, the gas pedal position and more [24].

Supercapacitors*:* Similar to a capacitor as both use static electricity to store energy. However, supercapacitors can store larger amounts of energy than typical capacitors. Supercapacitors are used when large amounts of energy need to be stored for a short amount of time [66].

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