AUTONOMOUS VEHICLES

Master Thesis

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Submitted to the School of Engineering of the

Lebanese International University

Beirut, Lebanon

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRONICS ENGINEERING

Spring 2019 - 2020

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DEDICATION

This thesis is dedicated to all our loving families, instructors, colleagues and everyone who have supported us all the way throughout the process, and who taught us the value of hard work. In addition, we dedicate it to all our annoying friends who stood by my side through bleak times.

Thank you for being the source of our strength and hope.

“If you’re going to try, go all the way. Otherwise, do not even start. If you are going to try, go all the way. This could mean losing girlfriends, wives, relatives, jobs and maybe your mind. Go all the way (...) you will ride life straight to perfect laughter, it’s the only good fight there is.” C. Bukowski, Roll the dice.

ACKNOWLEDGEMENTS

I would like to acknowledge all the help, patience, guidance, enthusiastic encouragement and useful critiques of this research work provided by The Lebanese International University, as well as my gratitude to Dr. Mohammad Taki's effort.

I would also like extend my deepest gratitude to all the amazing people who were very supporting in one way or another throughout this whole journey, and for those who took part in making the daily day routine infinitely special and memorable. I will forever be grateful to the infinite pieces of advice, shared laughs, shared screams, weird looks and conversations, and most of all, food deliveries in the middle of the night that have helped me achieve what I once started.

Finally, I would like to take a moment to appreciate my parents' constant support, sacrifices, encouragement, ability to put up with me overstressing throughout the years, and for trusting me and providing me with the necessary facilities to get this job done.

After all, Gary Keller said:" Don't let small thinking cut your life down to size. Thinking big, aim high, act bold and see just how big you can blow up your life", a quote that inspired me and helped me get through it all.

ABSTRACT

With the improvement of the economy, there is a big notice in the dramatic increase in the number of vehicles around various cities. Unfortunately, there is a big issue considering this increase, such as traffic blockage, auto collisions, air and noise pollution that are on the top worst problems in different countries. Thinking about the present province of IT technology, and how it benefits in different categories, the best answer for most of these problems is the self-driving car. However, the change from regular vehicles to autonomous vehicles will not occur from one day to the next, rather, it will be a procedure of quite a while in which, slowly, new automated functionalities will be prepared for the vehicles and acquainted with the clients.

Our project aims to implement a complete autonomous driving model. Such a model should allow any car to drive autonomously using various types of sensors such as LIDARs, IMU, Cameras and a radar.

In order to accomplish this objective, the approach is to implement a virtual world where our autonomous car can travel through the built simulator as if it is a real world. This simulator will have all the necessary things that needed to test a car, lanes, pedestrians, buildings, traffic signs, traffic lights, day & night and more. The realism is one of our goals to guarantee that our model should work in real life.

The designed model tested and verified in the simulator where safety and cost efficiency are at its maximum.

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LIST OF SYMBOLS AND ABBREVIATIONS

AI: Artificial Intelligence.

ADAS: Advanced Driver-Assistance Systems.

ADS: Automated Driving System.

DSRC: Dedicated Short Range Communication.

GPS: Global Positioning System.

NHTSA: National Highway Traffic Safety Administration.

RAND: Research and Development Corporation.

U.S: United States.

FCC: federal communication commissioning

GPU: Graphical processing unit

LSD: Limited slip differential

RPM: ripple per minutes

WEBRTC: WEB real time communication

CHAPTER 1. INTRODUCTION

Around 1.25 million deaths, every year, are due to the street accidents and are the result of driver error. That is equal to 3287 deaths per a day 0! As a young person figuring out how to drive, this is a terrifying fact that waits at the rear of my mind. In addition to that, there is a ridiculous measure of traffic that we need to endure. In 2017; statistics shows that people spent an average of 83 hours stuck in traffic [2], which just makes a superfluous disappointment for most people.

This make anyone think, can we have a solution? Is there another way that can recreate the driving of people, yet 20 times better?

For every problem, there is a solution that is simple, and that is why self-driving discovered. Moreover, what has to come is at last mysterious, yet arranging requires expectations of impending conditions and needs.

1.1. HOW SELF-DRIVING CARS WORK?

With autonomous vehicles, the objective is to have the option to operate the vehicle like a human driver. So self-driving car is a vehicle that uses many sensors, cameras, radar and computerized reasoning (AI) to go between goals without human administrator[3].

The main catch is that there is no driver behind the seat. You are most likely wondering, how does a car approach human insight while doing something so complex. To have an answer, there should be total understanding for the components that the self-vehicle consists of: Computer vision, sensor fusion, localization, path planning and control [4].

1.1.1. Computer Vision

Like a human driver, the car should have the option to see the surrounding environment, regardless of searching ahead for traffic or reading street signs, so the vision is the key to the driverless car.

For a computer vision, the goal is to have the option to distinguish objects near the car. This is done by utilizing an image classification network called “Convolutional Neural Networks” [5].

1.1.2. Sensor Fusion

How about going back and considering a human driver reaction. Assume the driver is stuck in a lot of traffic. The driver realizes this by examining the environment.

This is proportional to the possibility of sensor combination: having the option to analyze the environment in a detailed manner. Since there are many sensors prepared on a self-driving car, so all the essential information and wire, those to give a richer diagram to our car, hence the name sensor fusion.

1.1.3. Localization

In any case, every passenger would want to know precisely where he is now. Therefore, in self-driving cars, there should be an option to make sense where the vehicle is in reality to settle on better choices on how to get from Point A to Point B,

This is where things get complicated and require complex math calculations. For the present, simple consider localization such as the GPS on the phone. Figure 1.1 clarifies how the position of the car could be examined by using the GPS.

Figure 1.1: Car localization.

1.1.4. Path Planning

Taking human driver for instance, all through the ride, the driver is thinking all over the road about avoiding some streets and wanting to arrive on time. This is actually, what a self-driving car does too.

1.1.5. Control

When we make sense of our way, all the vehicle needs to do is have the option to control the wheel. Where the main test is to drive the vehicle like a human, and this needs a ton of training.

1.2. GOALS

As demonstrated in the first part, the autonomous vehicles are a solution of traffic and accidents that happen in high percentage every year. In addition, the main and most important car for any vehicle manufactures is building a simulator to influence the safety and reliability for autonomous vehicle[6]. So the goal is to build a simulator from zero and train a car to be autonomous, through detecting traffic light, traffic signs other cars and pedestrians so that the car can drive flawlessly through the surrounding environment.

1.3. ADVANTAGE & DISADVANTAGES

1.3.1. Simulator advantages

- When using a simulator, we will get nearly no error:

  Compared to analytical calculations that are time-consuming and contain a bunch of tradeoffs, a simulator offers much precise results. Such a result can be interpreted visually, which may make it easier for an engineer to figure out what might face its project in real life.

- We can test a full autonomous system and avoid traffic light:

Even if the traffic light can simplify the life of a driver, it worth nothing for a fully autonomous city of cars where all the vehicles can exchange data between each other before making any decision. Although traffic lights played a crucial role in road safety for centuries, sometimes a reflected light can lead to misinterpreting its current state leading to fatal accidents. For the upcoming century, there is no doubt that traffic lights will still an essential component in traffic safety, but that will change.

- Simulator can help shaping the city:

  Not only human error is a major cause of accidents, but also the poor infrastructure and road design of a city. Take an example of sharp corners where the driver will never be able to see the horizon until approaching it; time is out to take any crucial decision if necessary. On a simulator, you have the ability to recreate such extreme scenarios in order to find a proper solution for it before implementing anything in real life.

- Using simulator, you can push a car to it extreme power:

  In order to guarantee the full functionality of a car, it is of high importance to push it to its extreme power. In a virtual world, discovering a fatal error in a car will help to save a real-life, without putting the life of a tester in danger.

- Suppress the danger of prototyping model:

  A prototyping model of an autonomous driving car may crash or stop working due to unexpected errors, thus putting the life of pedestrians and other drivers in danger, which is not the same when it comes to simulations.

1.3.2. Simulator disadvantages:

- High production cost:

  A realistic simulator requires a big team of engineers, physicists, and programmers to be produced. Such a problem can be tackled by relying on some free to use engines that implement most of the physics work to be done.

- High maintaining costs:

  Finishing the production of a simulator does not means that the costs are over. A dedicated team should keep working on improvements and bug fixing which also time-consuming.

- Requires special hardware:

  When it comes to physics simulations and graphics realism, it is of high importance to have powerful GPUs in order to handle the entire load. Although it might be a big deal for individuals, that is nothing for companies or small teams.

1.3.3. Autonomous vehicles advantages

- Save lives:

  The most parts of the fatal accident is due to a human error. At its lowest level autonomous driving can help drivers to take the correct decisions. Going on to fully autonomous cars that might leads to zero accidents in the future

- Decrease traffic load:

A fully autonomous car can communicates with others on its area in order to equally distribute the load on all the city streets and help approaching the destination in the shortest possible time.

1.3.4. Autonomous vehicles disadvantages:

- Decrease jobs opportunities:

  Since autonomous vehicles can diverse in every aspect of the economy, that will lead to replacing some workers, which by the way most of them have a limited skills; making it hard on them to change its job. On the other hand, new jobs will be founded for the more skilled persons. The time to transition, the whole life to skillful one will represent a challenge.

1.4. AUTONOMOUS VEHICLES APPLICATIONS

Autonomous vehicle has a huge field of application not just with self-driving car as robot for civil application, farming crops, planting seeds, space, and submarines. Autonomous vehicles could be applied in every field: agriculture, industry, tourism etc…

1.4.1. Agricultural applications:

- An autonomous tractor is one form of Agricultural application. Such a tool can cover a large farms and plant crops in a way faster compared to humans. Since machines plant it, it will follow a certain pattern, which makes it easy for autonomous tractors also to harvest them. In the shadow of high population increase, this tool can help keeping food safety by increasing the production speed and quantity. The idea of autonomous tractors[7] started early in 1990 John Deere that suggested to create an autonomous tractor based on a product he created. The idea took some time to mature and it is going to advance in a faster way compared to autonomous driving cars that still looping on the political issues.

1.4.2. Industrial applications

- With around 16million tones of goods and raw materials transported in USA only, a bunch of startups and companies started its work on the next generation of trucks. The autonomous driving trucks or Simi-autonomous ones are in development for years by large companies such as Mercedes-Benz and VOLVO but still on its early stage of being certified to use the public roads due to political issues. Such a truck can carry a full load and deliver it in the best time and condition. DHL One of the biggest players in the domain of logistics and transportation started testing autonomous trucks back in 2018 [8]. Yet there is not much information about the testing results.
- Autonomous drones can be considered as autonomous driving vehicle that is on its advanced state of entering the production. This technology will help mainly in delivering goods locally. Such as foods and internet purchased products. Amazon one of the biggest internet stores started

using autonomous drones for delivery back in 2016 [9]. Such type of delivery can shrink the time from hours our even days to half an hour, leading to increase the power of goods supply in shorter amount of time.

1.4.3. Touristic applications

- Taxis and busses play an important role in tourists' transportations. Autonomous driving cars and busses can simplify the way tourists moving. With a car that knows your language and knows every single road in the city it will be easier for a foreign person to attend its destination on time and with the lowest possible costs. UBER one of the biggest taxi transportation companies has its own prototyping autonomous taxi that is co-developed with VOLVO[10]. This company's vision is to support the entire world by autonomous taxis to increase the safety and the reliability of public transportations.

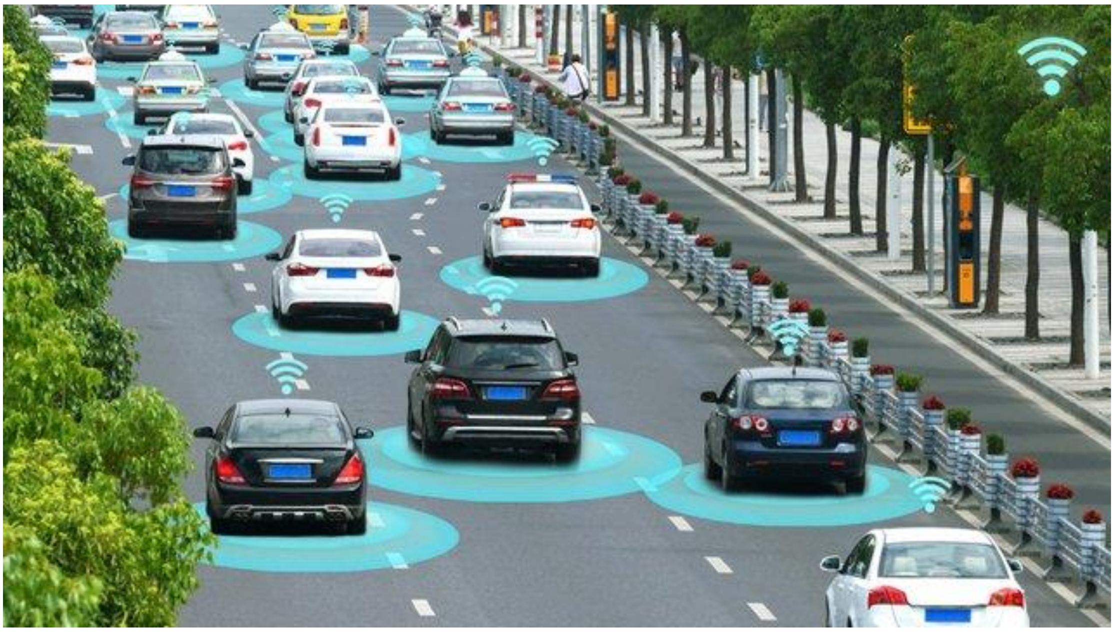


Figure 1.2: Fully controllable multi-agent driving simulator

CHAPTER 2. LITERATURE REVIEW

2.1. AUTONOMOUS VEHICLE

An autonomous vehicle, or driverless vehicle, is a vehicle that can detect its environment like other vehicles, pedestrians, traffic instructions, and performing necessary functions without human interference such as navigating the roads, avoid the obstacles and follow traffic rules. In order to sense its surrounding environment, this vehicle will use different techniques such as radar, GPS, laser light, cameras and Computer Vision [11].

2.1.1. History of self-driving cars

Experiments of automating driving has been started since at least 1920s, where it was called “Phantom motor car” (The Milwaukee Sentinel, 1926) [14]. These experiments have continued to achieve the truly autonomous car that appeared in the 1980s, with Carnegie Mellon University’s Navlab project [15]. This project represents a self-driving vehicle that can work in real time to control the steering wheel, where it analysis raw images from the road by neural networks. In 2009, with the development of technology, some companies that manufacture vehicles such as Toyota, BMW and Ford have designed automatic parking assistance for their products [16]. In 2012, Tesla Model S was released, where it is considered the first autonomous car in the world [17].

Since 2016, self-driving cars have pushed toward partial autonomy, with highlights that assist drivers with remaining in their path, alongside ACC innovation and the capacity to self-park [18].

Self-driving cars are not freely accessible yet and may not be for a long time. In the U.S., NHTSA gives government direction to presenting ADS onto open streets and, as self-driving car technologies advance, so will the division’s direction.

Self-driving vehicles are not yet legitimate on most streets. In June 2011, Nevada turned into the primary purview on the planet to enable driverless autos to be tried on open roadways; California, Florida, Ohio and Washington, D.C., have followed in the years since [19].

At present, many vehicles have opportunities to be considered as a semi-autonomous vehicle, due to safety features like assisted parking and braking systems, and almost all vehicle manufactures and Internet Companies such as Google, Uber and Baidu are working on autonomous vehicles.

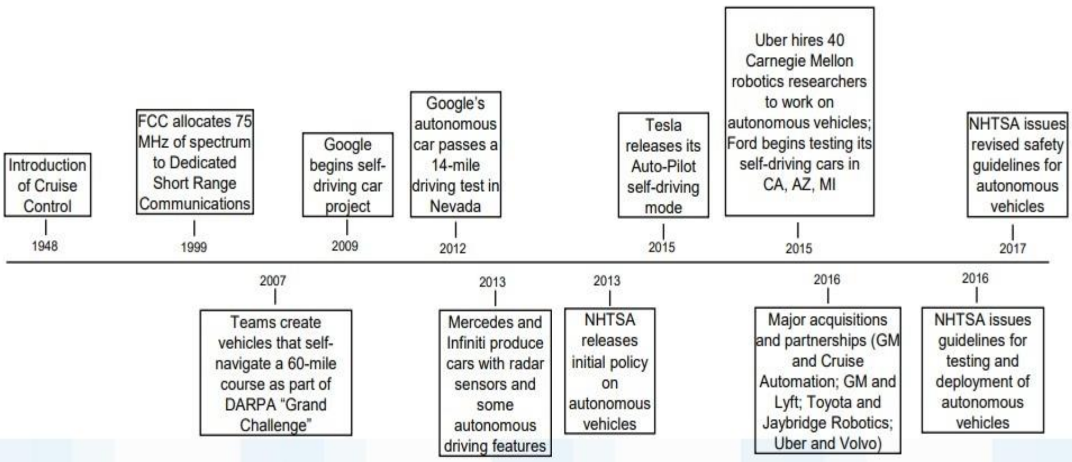


Figure 2.1: History of automation vehicle

- Back in 1948 the cruise control technology saw the life as an under development system. After a decade, it starts to appear shyly in few Chrysler imperial only cars followed by a global production in 1960[20].
- After a log 40 years, lacks of innovations in this domain, a new way of short-range communication in cars were invented. Upon that, United States federal communication commissioning allocated[21] a band of 75 MHz for such applications. This type of technology have not benefited humanities a lot at that time because it have not entered the production vehicles.
- From 2007 and on autonomous driving topic start to gain its popularity in research and development departments and competitions. In less than a decade autonomous driving level two became a production standard for most of German automakers.

2.1.2. Levels of autonomy in self-driving cars

A fully automated driving system is needed for an autonomous vehicle in order to respond to external conditions that a human driver would manage. As shown in Figure 2.2, according to Society of Automotive Engineers, there are six different levels of automation, with the increase in these levels, the independence of external control for the driverless car's increase.

Level zero: automated system has zero control over the vehicle, where the human driver does all the driving.

Level one: the driver is supported by the vehicle's ADAS with either steering or accelerating and braking.

Level two: the automated system has full control over the vehicle in some conditions, although the human driver is required to pay full attention to the surrounding environment throughout the driving.

Level three: all driving tasks can be controlled by the ADS, where the driver can safely turn their attention away, but must still prepared to any intervene with some limited time.

Level four: all driving tasks can be performed by the automated system in some conditions, with no need for human attention.

Level five: the vehicle can perform all tasks in all conditions, and no driving assistance is required at all.

The only level has reached until now is level 3, where the new Audi A8 is the first autonomous vehicle in the world [22].

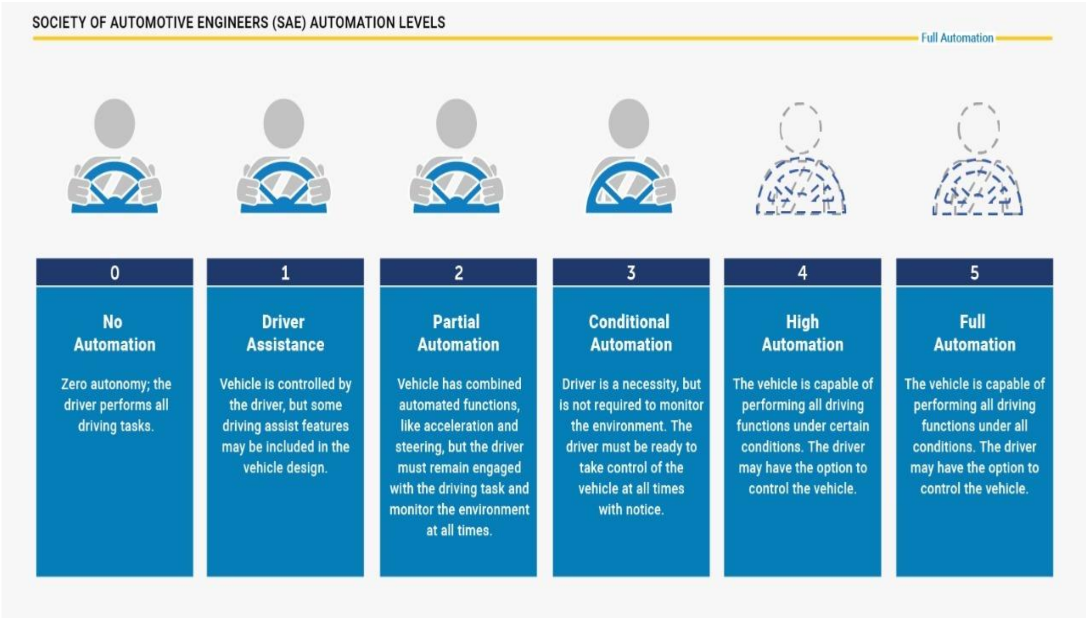


Figure 2.2: Six level of automation

2.1.3. The Evolution of Automated Safety Technologies

Driver help innovations in the present engine vehicles are as of now helping to save lives and prevent injuries.

Some of the present new engine vehicles have innovation that assists drivers from floating into neighboring paths or making hazardous path changes, or that cautions drivers of different vehicles behind them when they are backing up, or that brakes consequently if a vehicle in front of them stops or eases back all of a sudden, in addition to other things.

The proceeding with development of automated technology aims to convey significantly more prominent wellbeing benefits and – at some point- convey Automated Driving Systems that can deal with the entire undertaking of driving when we would prefer not to or cannot do it without anyone’s help.

2.1.3.1. Safety

The security advantages of automated vehicles are fundamental. Automated vehicles' capability to spare lives and decrease wounds is established in one basic and awful actuality: 94% of genuine accidents are because of human mistake. Automated vehicles a possible expel human mistake from the accident condition, which will help ensure drivers and travelers, just as bicyclists and people on foot. At the point when you consider in excess of 37,133 individuals passed in motor vehicle-related crashes in the U.S. in 2017 [23], you start to get a handle on the lifesaving advantages of driver help advancements.

2.1.3.2. Economic and Social Benefits

Automated vehicles could convey extra financial and extra cultural advantages. A NHTSA study demonstrated engine crashes in 2010 expense $242 billion in monetary movement, incorporating $57.6 billion in lost working environment efficiency, and $594 billion because of death and decreased quality of life due to injuries [23].Wiping out by far most of engine vehicle accidents could erase these costs.

2.1.3.3. Efficiency and Convenience

Streets loaded up with autonomous vehicles could likewise participate to smooth traffic stream and decrease traffic blockage. Americans spent an expected 6.9 billion hours in traffic delays in 2014, cutting into time at work or with family, expanding fuel expenses and vehicle outflow [23]. With automated vehicles, the time and cash spent driving could be put to all more likely use. A recent study stated that automated vehicles could free up as much as 50 minutes every day that had recently been devoted to driving.

2.1.3.4. Mobility

While its full cultural advantages are hard to extend, the transformative capability of autonomous vehicles and the driver help highlights can likewise be comprehend by evaluating U.S. demographics and the communities these technologies could help to support.

For instance, automated vehicles may likewise give new versatility alternatives to millions additional Americans. Today there are 49 million Americans over age 65 and 53 million individuals have some type of incapacity [23].

2.2. SIMULATING AUTONOMOUS VEHICLES

For the companies who needs to construct an autonomous vehicle, the most significant part for the autonomous vehicle is the ability of driving flawlessly in the real world environment without any accident. So the first question may be asked, how safe are the autonomous vehicles? One proposition to test the percentage of safety is driving autonomous vehicles in real traffic, watch their performance, and make statistical comparison to the human driver performance. However, can the logical approach be practical? To say it is practical and have a clear proof of autonomous vehicle safety, the number of miles that should be driven must be calculated.

According to a research by (Karla, Paddock), autonomous vehicles would need to be driven countless miles and some of the time several billions of miles to demonstrate their safety in terms of fatalities and injuries [25]. Under even forceful testing assumptions, existing fleets would take tens and at times several years to travel these miles – which means that it is an impossible proposition to demonstrate performance before releasing them for consumer use.

Table 1 provides analysis from RAND research. The three numbered lines show test results for every one of our three factual inquiries concerning the miles to demonstrate safety. Test results are appeared for every one of three benchmark failures rates noted in the lettered columns. These relate to human-driven (A) fatality rates, (B) reported injury rates, and (C) reported crash rates. The outcomes show in brackets the quantity of years it would take to travel those miles with a fleet of 100 autonomous cars driving 24 hours per day, 365 days every year, at a normal speed of 25 miles for each hour. For instance, one can ask, “What number of miles (years) would autonomous cars must be driven (row 2) to exhibit with 95% certainty their failure rate within 20% of the true rate (column A) 1.09 fatalities per 100 million miles?” the appropriate response is 8.8 billion miles, which would take 400 years with such a fleet.

Table 2.1: Reliability of Autonomous Cars

		Benchmark Failure Rate		
Statistical Question	**How many miles (years[a]) would autonomous vehicles have to be driven...**	**(A) 1.09 fatalities per 100 million miles?**	**(B) 77 reported injuries per 100 million miles?**	**(C) 190 reported crashes per 100 million miles?**
	(1) without failure to demonstrate with 95% confidence that their failure rate is at most...	275 million miles (12.5 years)	3.9 million miles (2 months)	1.6 million miles (1 month)
	(2) to demonstrate with 95% confidence their failure rate to within 20% of the true rate of...	8.8 billion miles (400 years)	125 million miles (5.7 years)	51 million miles (2.3 years)
	(3) to demonstrate with 95% confidence and 80% power that their failure rate is 20% better than the human driver failure rate of...	11 billion miles (500 years)	161 million miles (7.3 years)	65 million miles (3 years)

[a] We assess the time it would take to compete the requisite miles with a fleet of 100 autonomous vehicles (larger than any known existing fleet) driving 24 hours a day, 365 days a year, at an average speed of 25 miles per hour.

In this situation, simulation is the best answer for building a reliable autonomous car. To guarantee that everything is taken into consideration, the simulation should have:

A variety of real world situations, for example, traffic circumstance, driver behavior, time, climate and street condition. Different sensors suites/exhibit, for example, radar, camera and laser light.

2.2.1. OpenADE

OpenADE is an autonomous driving engine that is developed from scratch keeping in mind the physics and environment realism. Developing and testing a model inside this simulator will result on a model that is ready to be diploid to a real life prototype. It supports the data streaming to multiple device in order to distribute the processing power evenly on cluster of computers. This simulator contains different types of vehicles such as truck, SUVs and sport cars and it contains pedestrians. Traffic signs and traffic lights control the flow of cars and persons inside the engine.

CHAPTER 3. PROJECT SPECIFICATIONS

3.1. INTRODUCTION

Aside from the high development cost of real autonomous vehicle prototype and the lack of sensors, devices and tools necessary for developing such systems, mechanical work such as sensors fitting, gears & steering wheels modifications represents a big challenge for small teams. Thus preventing them from focusing on the main goal, which is developing a powerful AI model to drive the vehicle.

In this chapter, we will discuss how we tackled such problems by developing a simulator, and the technical challenges we have solved during the development of our simulator.

3.2. KEY PHYSICAL COMPONENTS OF AUTONOMOUS VEHICLES

It is important for the autonomous vehicles to sense its environment, in order to achieve the goals of avoiding obstacles (pedestrians and other vehicles) and recognize traffic rule information (traffic lights and speed limits). Therefore, many devices such as camera, radar and laser light are required for the autonomous vehicle to detect their surroundings.

- Cameras: Provide ongoing obstruction location to encourage path takeoff and track roadway data like street signs, traffic lights and lanes. In general most of the time, a stereo vision is required. Since cameras are passive sensors, in order to extract distance measurements we need to have two cooperative cameras working simultaneously.

Figure 3.1: Stereo vision.

- Radar – Radio waves recognize short and long-extend profundity. In an autonomous driving car, a various types of radars are placed at different locations of cars body to cover the best angles and ranges. Such a system is running at around 77GHz [26], which provides a high resolution.

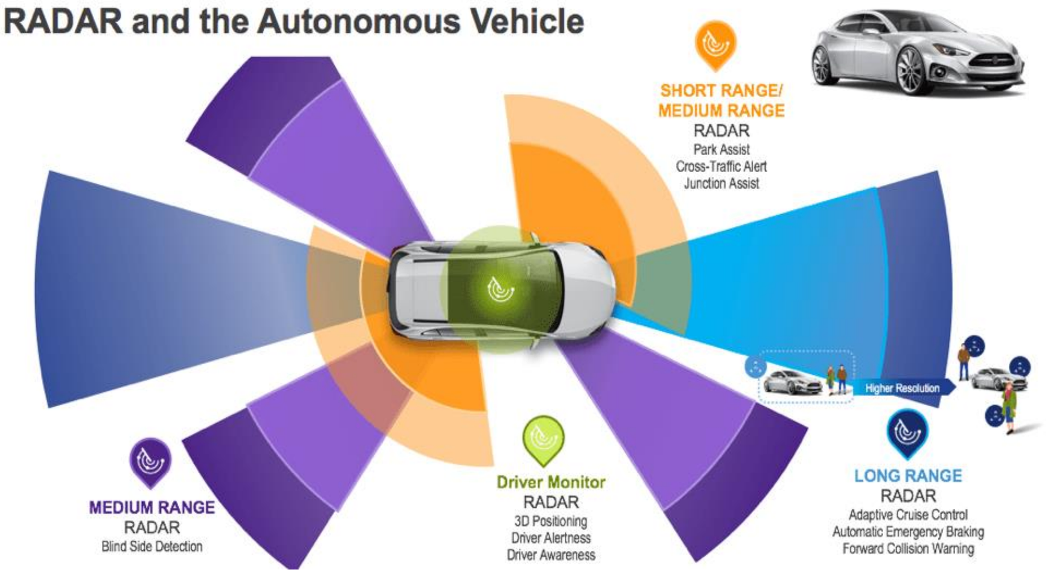


Figure 3.2: Radar distribution in a car.

- LIDAR – Measures separation by enlightening objective with beat laser light and estimating reflected heartbeats with sensors to make 3-D guide of zone. This system considered more reliable compared to radars where some materials can absorb the signal or degrade it. The biggest disadvantage of this system is its size, which force the developers of the vehicle to place it on the roof of the car. Usually it covers a distance from few meters to more than 200m.

Figure 3.3: Car equipped with LIDAR.

- GPS – Triangulates position of vehicle utilizing satellites. Current GPS innovation is constrained to a specific separation. Propelled GPS is being developed.
- Central Computer – "Cerebrum" of the vehicle. Gets data from different parts and sensors in the vehicle. Such type of procession units tends to have a powerful GPU that is used in machine learning and computer vision procession. Typically, every car brand has its own central computer.
- DRSC - Based Receiver – Communications gadget allowing vehicle to speak with different vehicles (V2V) utilizing DSRC, a remote correspondence standard that empowers dependable information transmission in dynamic security applications. NHTSA has advanced the utilization of DSRC [24].

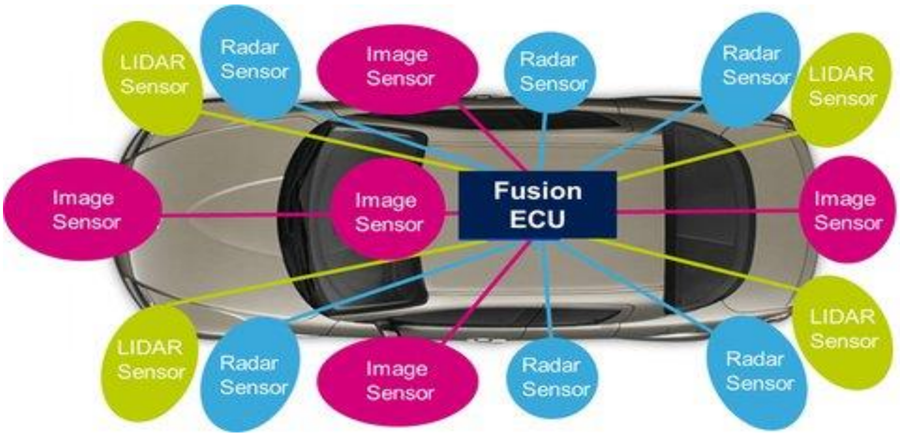


Figure 3.4: Sensors on the autonomous vehicle.

3.3. OPENADE DEVELOPMENT

During the development of OpenADE we have used multiple programming languages and APIs, each of them used to solve a certain challenge when it comes to the performance and realism tradeoff.

Real time rendering is a powerful feature that is offered by many 3D engines, basically it is the ability of an engine to convert a 3D scene into 2d buffered image. Retaining the collision and the biggest amount of details. When it comes to realism and physics the engine should be chosen wisely. Each engine offers a set of libraries that helps developing a games like simulators but what if our intension is to develop a reliable autonomous driving engine? Unreal engine 4 considered one of the most realistic engines that is used for architect, game development and even for vehicle simulations.

3.3.1. Vehicle movement API

Considering the high diversity of the cars, it is of a high importance to give the manufacturer the ability to simulate it specific car with its mechanical specifications. Our engine offers a high number of variable that can be used by the manufacturer to represent its car.

3.3.1.1. Car Differential

The differential is a part that helps distributing the motor power on the wheels, thus improving the stability of the car on the extreme conditions. Our engine offers six types of differentials that can describe how the motor power is going to be handled during the simulation.

Figure 3.5: Customizable differential

The motor torque can be distributed to 4 wheels simultaneously or to 2 of the wheels at once. Among the 2 wheels setup the power can be distributed on either the frontal wheels or the rear ones. Putting the motor torque on the frontal wheels will help decreasing the understeer while oversteering will still occurs, while moving the torque to the rear wheel will result by high understeering and less chances for oversteering. 4WD represents the most efficient way of torque distributing, where precise torque vectoring can help maintain the car stability. Open differential will let each wheel spin freely while LSD will help moving the torque from the wheel that lost the friction to the other one.

3.3.1.2. Torque curve

Each internal fuel combustion engine have a RPM versus torque characteristics curve, which describes the amount of torque, produced at a certain RPM. This curve can be adjusted on OpenADE to represent the manufacturer engine.

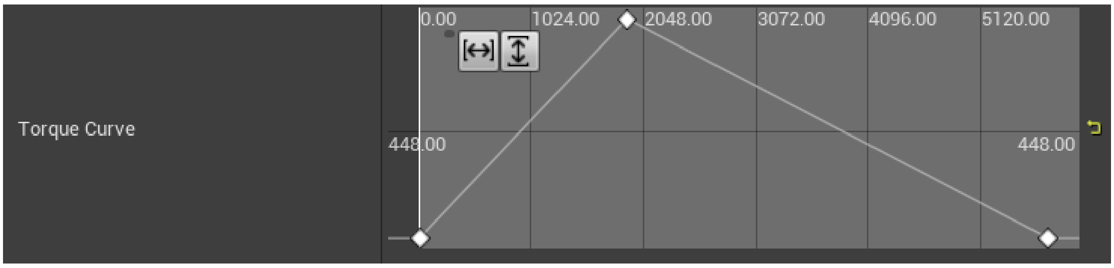


Figure 3.6: Torque (y-axis) versus rpm curve

3.3.1.3. Steering curve

The steering capabilities of any car changes based on its weight, wheelbase, wheel size, motor placement and more. Each car have a different steering behavior that can be plotted as function of speed. After that those points can be used to draw the steering cure inside OpenADE in order to characterize the car movement.

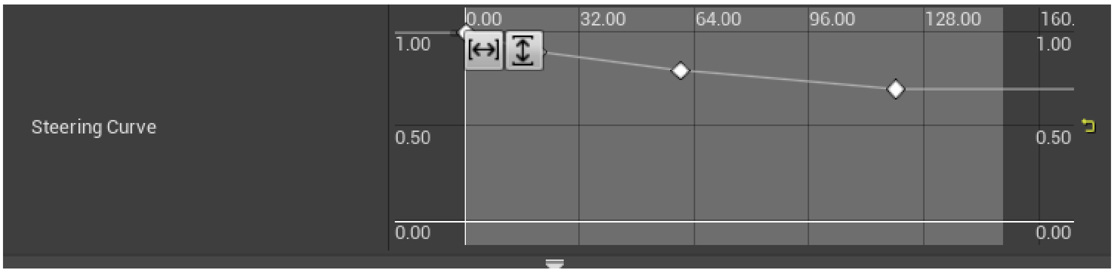


Figure 3.7: Car steering value(y-axis) versus steering angle curve

3.3.1.4. Car dimensions & brakes

The car dimensions braking power wheels characteristics & weights can affect the physical behavior of the car during the car movement and the car collision and can be configured easily using a set of variables.

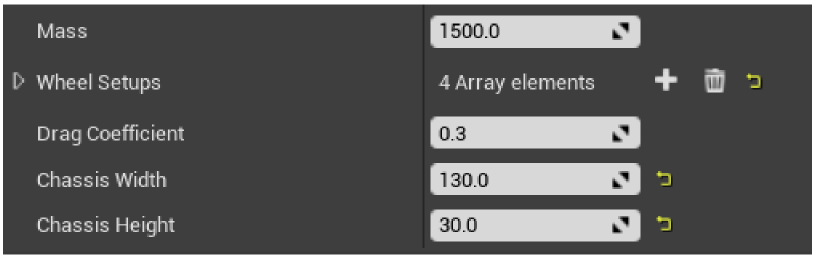


Figure 3.8: Mechanical characteristics

Figure 3.9: Braking characteristics

Figure 3.10: Wheels characteristics

3.3.2. WEBRTC

WebRTC enables peer to peer video, audio, and data communication between different types of web browsers. Such as chrome, firefox, edge which already can be found on different devices such as Android, IOS ,MacOSX ,Windows and linux. This allows for video calling, video chat, and peer to peer file sharing entirely in the web browser, using JAVAScript.

Such API allows us to be able to stream the simulation from different types of devices over the same network. Thus being able to process the different aspects of the simulation by many engineers at once in real time.

Figure 3.11: Cross-platform simulation viewing

In order for a client to be able to stream the simulation, authentication should be done using signaling server. At this stage authentication user and password could be requested. The signaling server is running at port 8888 for data coming from OpenADE and sending data coming from the clients to the engine. At the same time it is listening for clients on port 80.

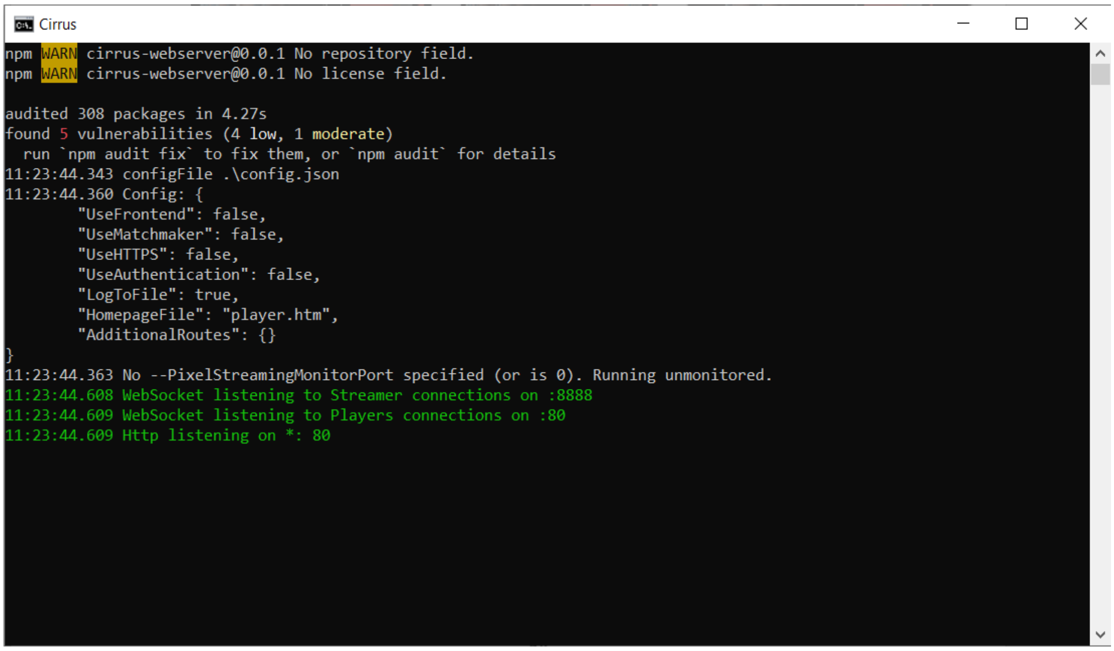


Figure 3.12: Signaling server

3.3.3. Clustering process

Since the simulation itself and the image processing algorithms that required to drive the car are all running on the GPU, thus a massive GPU bandwidth and power are required to handle such load. Usually such type of GPUs can cost up to 5k$ and has VRAM up to 24GB which is highly unaffordable by the most of the teams. The best solution is to split the processing power on multiple low-end devices in which one can run the simulator, other one can run the object detection algorithm, and we can run the lane detection algorithm on the other. In this way the processing power are evenly distributed on multiple machines and can interact with each other with a developed from scratch application called OPENADE controller.

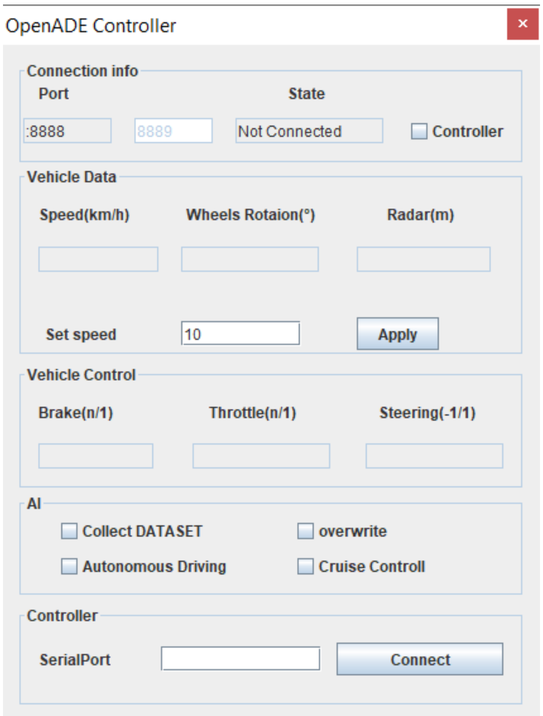


Figure 3.13: OpenADE controller

All the machines can communicate over the port 8889 & 8890, on the other hand the simulator is accessible over the port 8888. This application in cooperation with the signaling server allow all the computers to stream the simulator data process them and control the car in real time.

3.3.4. Virtual sensors

Each car on the engine contains a set of virtual sensors that helps to drive it autonomously. Those sensors are inspired from real life autonomous driving car:

- Cameras: the car contains two different cameras with different views that helps cover the most part of what a driver can see during the car driving. The cameras data are used in image processing to detect the different objects on the scene, the lane and the traffic lights & signs.

- Odometer: help in estimating the car speed and gear in order to precisely control the wheels and the throttle. Those data also could be used to determine whether the car is slipping or in a good dragging conditions.
- Radar: the radar are placed on the front of the car and can measure distances up to 800 meters. This sensor can help estimating the distance to the objects in the front of the car in the absence of stereo vision camera.
- Positioning sensor (Virtual GPS): the sensor can localize the car on the city and can help in simultaneous localization and mapping, path planning and other important algorithms that could be applied in real time navigation.

Figure 3.14: Car cameras and sensors

The car manufacturer itself can introduce other types of sensors. In order to cover every aspect of its car.

3.3.5. Engine realism

In order for a model to work on the real life situation, the engine should have a high level of realism when it comes to level of details, lighting and road conditions.

3.3.5.1. Day time

Image processing algorithms are highly affected by the time of the day conditions, thus introducing variable time is of a high importance to assess our algorithms.

OpenADE supports automatic variable day time, in which the day time will change automatically during the simulation. On the other hand it also supports manual tweaking of the time. During the variation of the time different factors are affected such as the intensity and the direction of the shadows, the lighting conditions, and the reflections. All these factors are rendered in real time inside the engine.

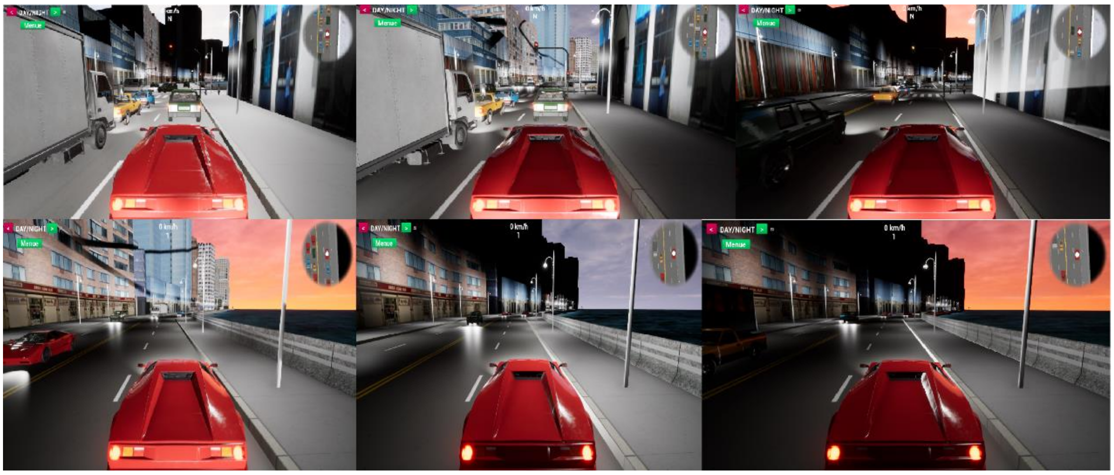


Figure 3.15: Day time

3.3.5.2. Weather and road conditions

OpenADE support two types of weathers, the dry street sunny day where the friction conditions are perfect and the snow condition where the car can be pushed to the limits.

During those two conditions the street are covered/Uncovered by snow which might affect the image processing algorithm and at the same time the friction coefficients are adjusted to simulate a slippery condition.

Figure 3.16: Weather conditions

3.4. AUTONOMOUS DRIVING SIMULATIONS

In order to verify the usability of our engine, several autonomous driving simulations where attempted. In each autonomous driving the trained AI and closed loop controllers are supposed to adjust the throttle, braking and steering in order to keep the car on the lane and avoid obstacles. In order to tackle this issue several levels of AI, image processing and closed loop controllers were implemented. Each frame is processed by several algorithms to take the final decision.

3.4.1. Object detection

The objects in each frame are detected and localized with frequency of up to 15 FPS. In order to do so, a real time Convolutional neural network are processing the images. The objects then are classified.

Figure 3.17: Image to be processed

The image is being processed without any downscaling or segmentation since every part of the scene might contains a relevant object.

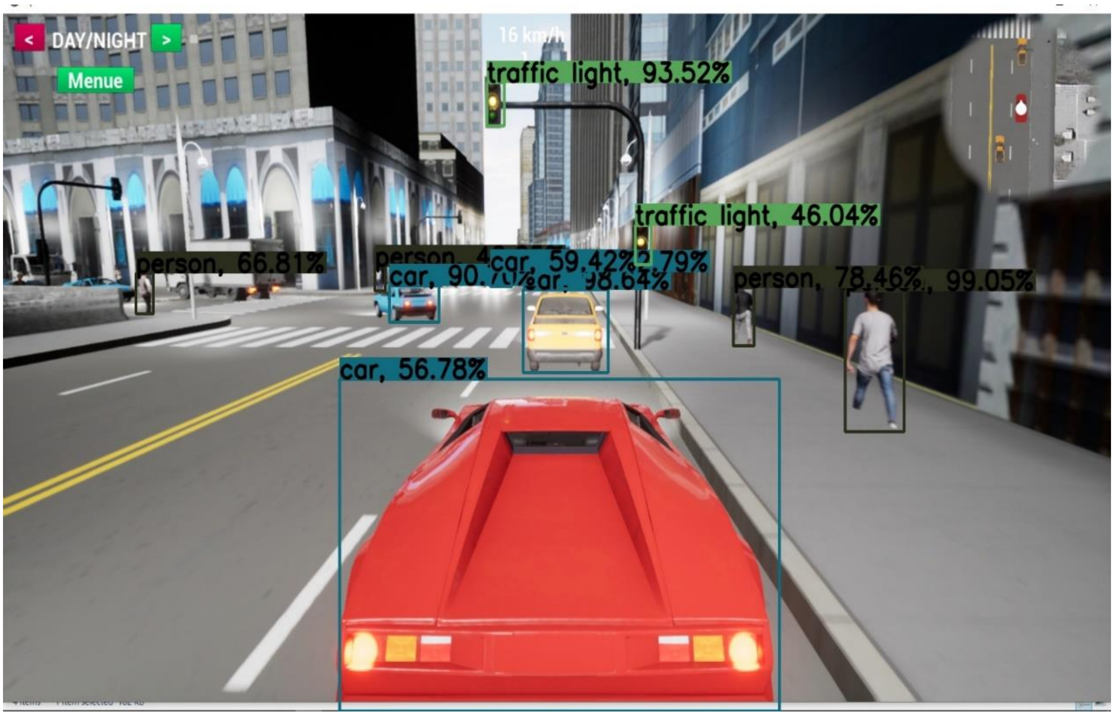


Figure 3.18: classified object

Each object are bounded with a ting box any named according to its class. The percentage value indicates the confidence level in which higher is better. In such single camera single image processing distance estimation requires special neural network that can estimate the distance based on the object class and dimensions. This type of network requires huge amount of data set, which prevented us from implementing it, because of our limited training hardware performance.

3.4.2. Lane detection

In order for a car to be able to steer, the frames should be processed in order to be able to detect the lane. This step requires a high processing power because of its complicate pipeline.

Figure 3.19: Lane detection

After being able to detect the lane, these data is going to be used in order to take steering decisions in real time. The implemented algorithm is capable of detecting curved lanes in a high precision which helps improving the steering accuracy of the neural network.

CHAPTER 4. DESIGN

4.1. AUTONOMOUS DRIVING PIPELINE

The process starts by taking a frame for process. The lane detection and objects detection algorithms are applied simultaneously followed by data fusion. The fused data is feed to a neural network, which take the decision for steering. The speed data and the frontal radar measurement data are used in a PID controller in order to activate the throttle or brakes with a certain level. Those actions are running continuously in order to provide a real time autonomous driving.

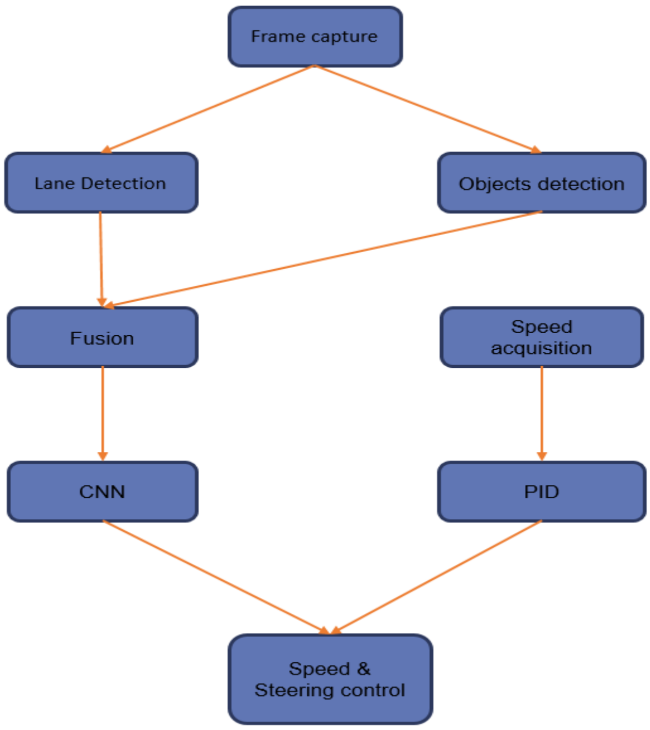


Figure 4.1: Autonomous driving pipeline

4.2. LANE DETECTION PIPLINE

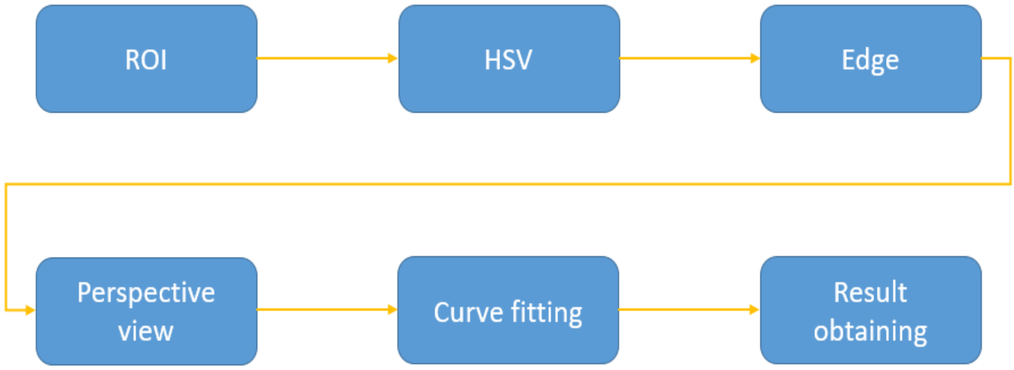


Figure 4.2: Lane detection pipeline

In order to make the processing cheaper on the CPU, we will start by defining the region of interest. Outside this region, the scene is not expected to contain any lane data. Thus, it is going to be masked.

An HSV filter is going to be applied on the masked image. This filter aims to extract the white & yellow lines data from the image. This image is going to be fused with extracted edges using CANY EDGES algorithm. At this point we have a set of lines and contours that represents the boundaries of the objects and the lines in the scene.

In order to be able to filter out the lane data we are going to transform the image into a perspective view using eagled-eye algorithm. Using curve fitting we will be able to match the small lane bounding boxes which then transformed to a polygon and fused with the original image in order to form the final results.

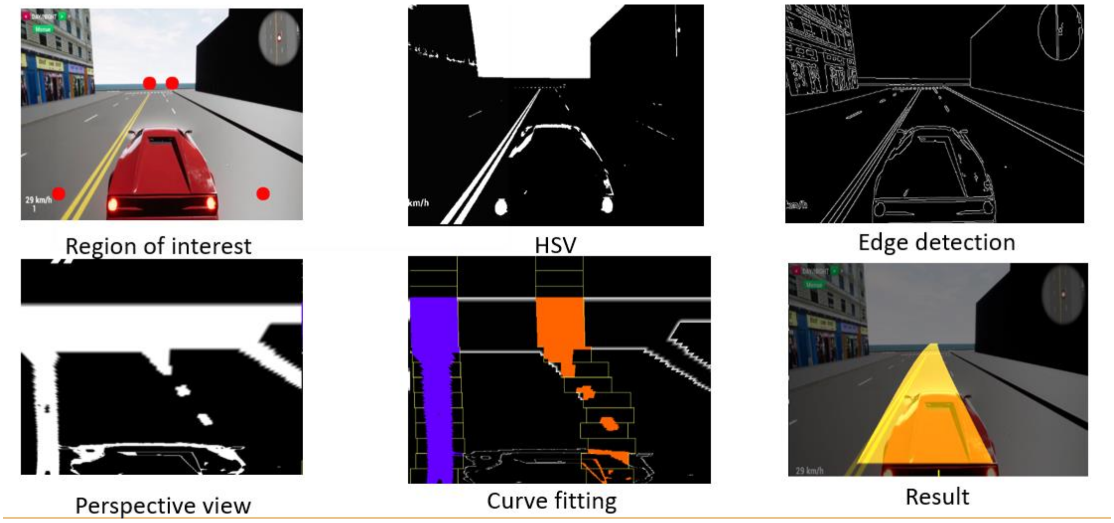


Figure 4.3: Lane detection samples

4.3. OBJECTS DETECTION

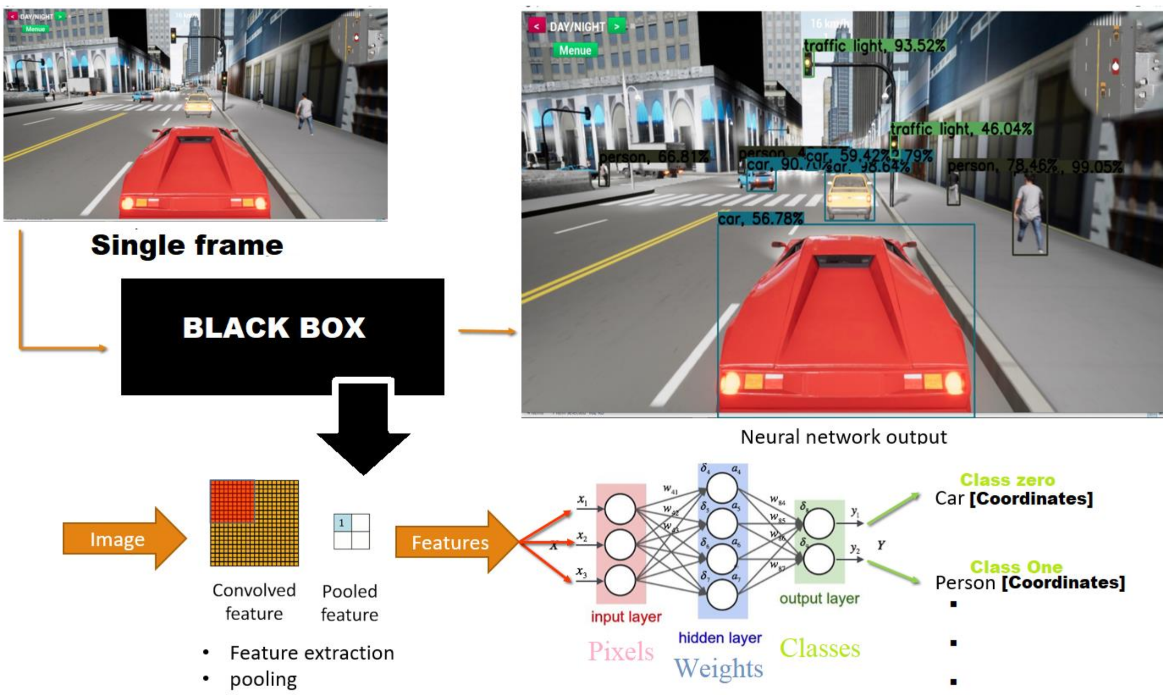


Figure 4.4: Objects detection pipeline

Each sampled frame is going to path through this black box. The black box is going to apply convolution & max pooling in order to minimize the image size keeping the important features only. The features are serialized into the input layer as a form of normalized pixels between zero and one. The normalization is done by dividing the pixels by the maximum value, which is 255, corresponds to 8-bits unsigned integer. The values is going to multiplied with the weights (W0…Wn) and summed up at each neuron. This step will be repeated until reaching the output layer. The values are passed into an activation function, which will bound the output of the neural network. The output is going to be an integer representation for each objects with a bounding coordinates.

4.4. CRUISE CONTROL

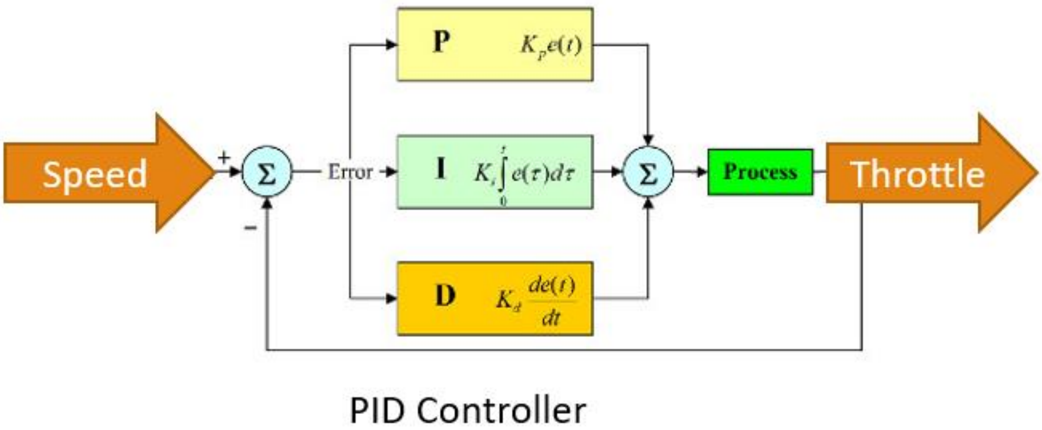


Figure 4.5: PID Controller

The speed of the care is monitored continuously using odometer built inside the engine, which is used to calculate the throttle/brake values that should be applied in order to keep going at the set speed.

The integral, which is represented by (Ki) factor guarantee reaching zero error by keep summing up the error value multiplied by the factor. Whereas derivative plays the role of future prediction thus preventing the overshoot that might happen due to a sharp error correction, but slowing down the system at the same time. The last factor which is the proportional factor (Kp) speed up the whole system by multiplying each iteration error by the scaler factor (Kp).

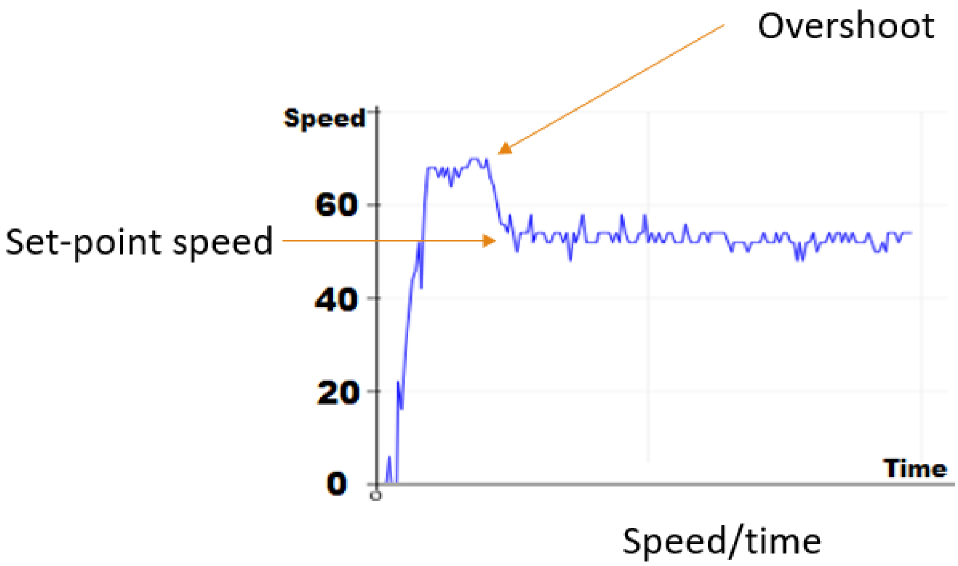


Figure 4.6: Speed versus time

In case of pushing hard in order to minimize a large error, an overshoot might appears which represents a rising above the set point. Followed by a stable and smooth speed at the set point

4.5. AUTONOMOUS STEERING

Autonomous driving simulation is divided into two parts. The first part is the training which it is done and repeated until getting the required precision, and the simulation process which is done using the trained model

4.5.1. Training process

This process is done throughout multiple stages and we have created a controller to be used in the process. the result is a trained CNN.

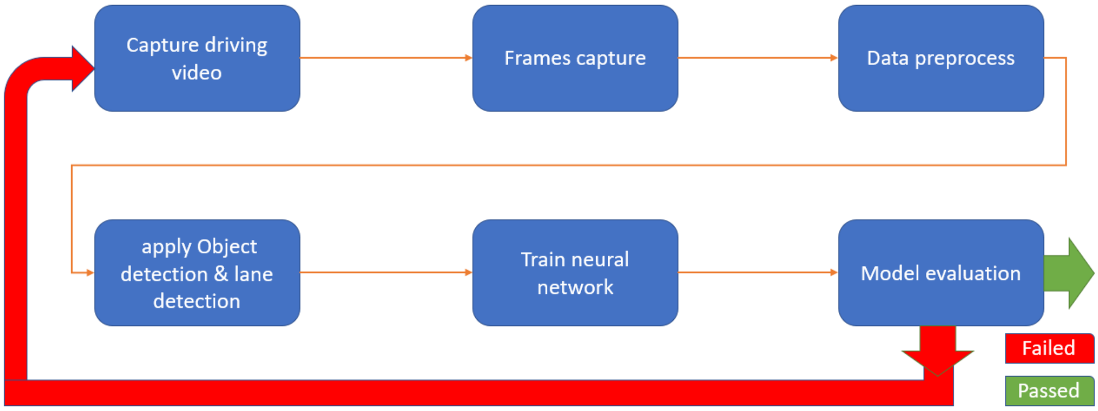


Figure 4.7: Training process

- Capture driving video: During this stage, a human should use the controller in order to drive the car inside the simulator. Driving video is recorded with the steering data from the controller.
- Frame capture: during this process the video is processed into individual frames each frame named with the steering data.
- Data preprocess: before being able to fit the data to the neural network, the data should be downscaled, cropped. The redundant data should be remove

manually in order to prevent model overfitting thus getting poor performance in real simulation.

- Apply object detection & lane detection algorithm: in order for a neural network to be trained, we need to tag the important features in the image. Those features are the objects inside the scene and the lane
- Training the network: this process is just a calculation process and should be done on a powerful computer, which we don’t have thus leaving us waiting for a long time in each training iteration to get the model.
- Model evaluation: in this stage we have a trained model and we need to evaluate its performance in real driving situation. If the accuracy is not good enough, we are going to start over except using a transfer learning to improve the current model. In case the result was good we have an HDF5 model which is ready to be used in autonomous driving simulation.

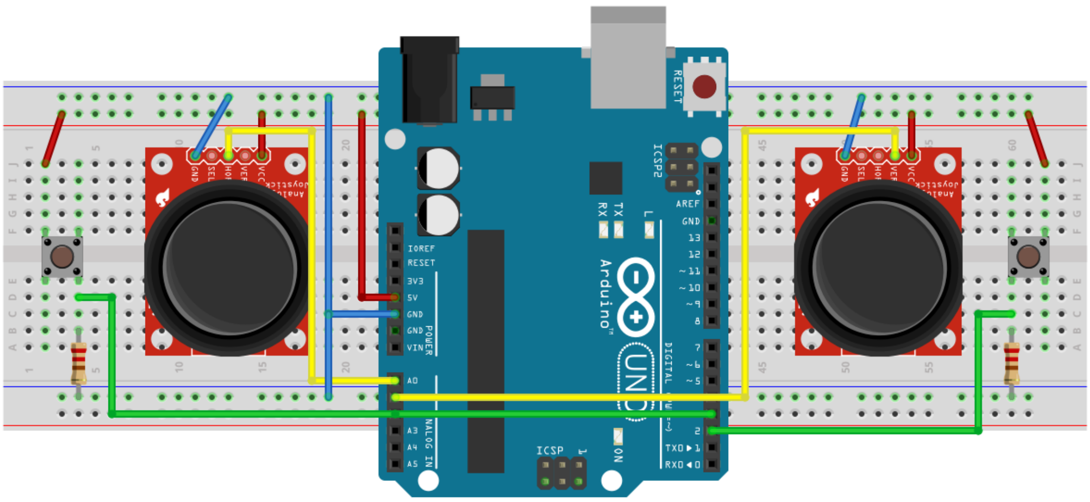


Figure 4.8: Engine controller

The engine controller is made up of two joysticks and two push buttons. The left joystick is capable of controlling the throttle of the car. At each time the left push button can be pressed to Enable/Disable the cruise control. The right joystick is capable of controlling the car steering and at each instance the right push button can be used to Activate/Deactivate the autonomous steering.

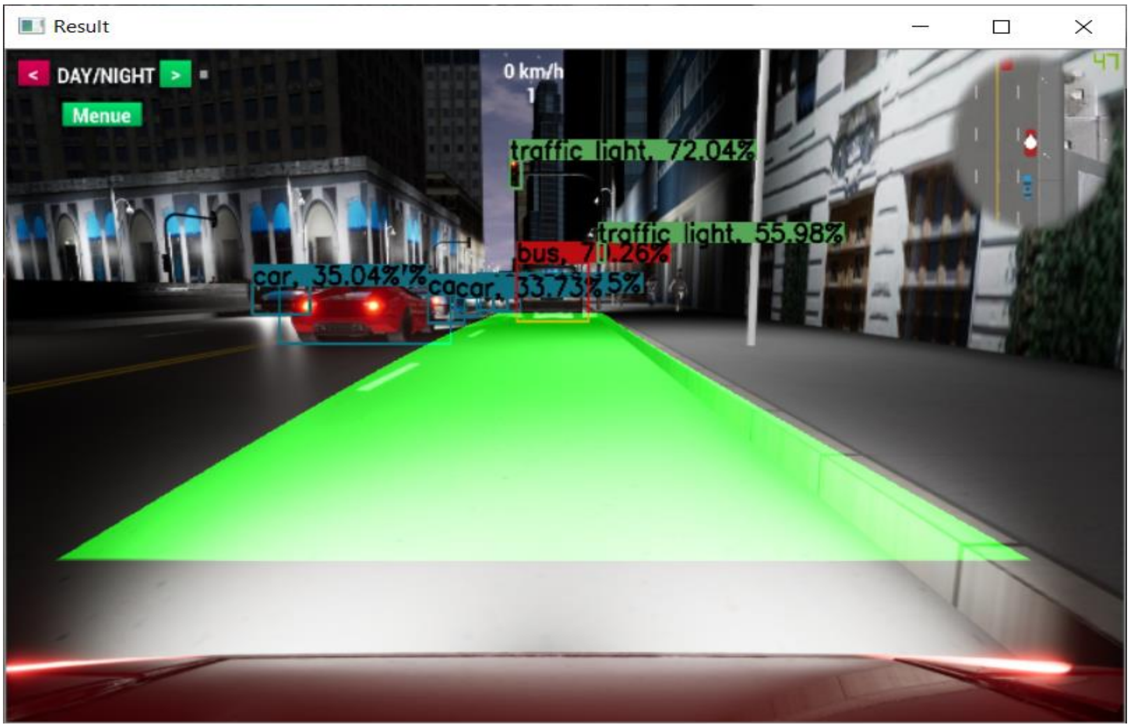
CHAPTER 5. RESULTS

5.1. INTRODUCTION

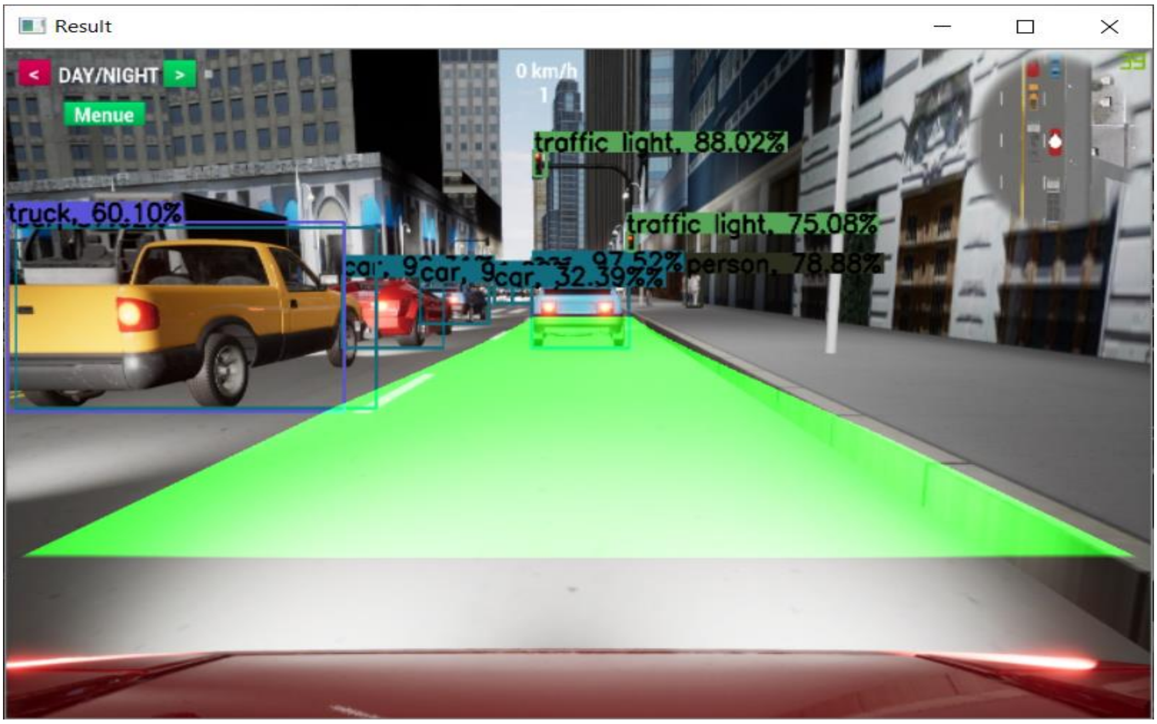
In an attempt to verify that OpenADE is reliable when it comes to the training and testing autonomous driving vehicles, we have done autonomous driving simulation level three. Also, we have done and test each part of the project separately, we were unable to integrate them together due to the fact we have no powerful computer and we have not got the enough support.

5.2. SIMULATION RESULTS

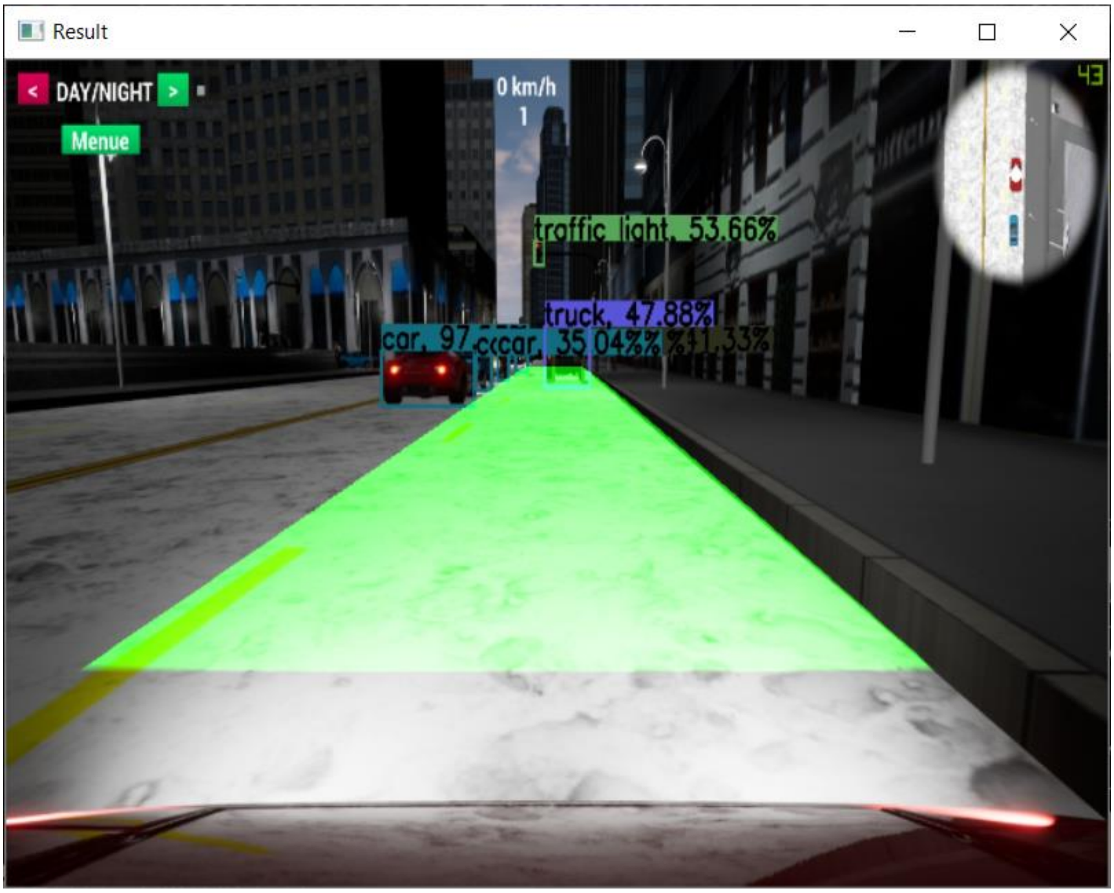
We have done simulations in the different modes that OpenADE supports, such as different weathers & different day time which can considerably affects our autonomous driving algorithms. The results of the image processing algorithms show a robustness in the different conditions which qualifies them to be used in real life testing. The lane detection algorithm still able to extract the important features that defines the lane and was able to detect the lane even on the worst road conditions where snow covers every inch of it. On the other hand, the ability of object detection and localization in different lighting conditions was stable and noticeably accurate. Speaking about the simulator performance a massive rework results in a stable FPS at an average of 47 frame per second which is enough for such type of simulations where 20 decisions per second should be taken. At the same time the cruise control was well behaving even in worst condition starting from zero or making full emergency stop.



5.1: Image processing algorithms results in the dry night mode.



5.2: Image processing algorithms results in the dry day time



5.3: Image processing algorithms results in the snow night mode

CHAPTER 6. CONCLUSION

During one year of work we were able to achieve all the expected millstones and the output is a stable autonomous driving engine that is going to be open sourced. Also, we have tackled a lot of technical challenges like realism, robust image processing algorithms and real-time high-performance simulator, there is still few non-technical issues such as the hardware limitations where a beefy machine can be unaffordable for some of the small teams. On the other side a well-documented API should be done because the tunable cars part of the project still can't be considered as user friendly. Thus, it might take some time for the car companies to get used into it.

As a futuristic plan, OpenADE should be integrated to some sort of cloud computer services. Doing such a big step will convert OpenADE from a simulator software to a software as a service (SAAS) which lower the minimum hardware required to run a real time autonomous driving simulation. Thus, making it more affordable to the small research teams.

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