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Autonomous driving with LIDAR

Bachelor Thesis

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2020-2021

Declaration of Authorship

I hereby declare that I have completed the thesis titled, Autonomous Driving with Lidar, independently and with consultations from my supervisor and other faculty staff. Also, I have made sure to highlight the sources and references where it is required. A list of references and citations is included at the end.

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"All knowledge which ends in words will die as quickly as it came to life, with the exception of the written word: which is its mechanical part."

- Leonardo Da Vinci

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1)Review sensors suitable for a small autonomous car model
2)Prepare software for data processing of data from LIDAR. The software will run on an Arduino ad control the car movement.
3)Design at least 2 test tracks for algorithm testing
4) Show experimentally on the test tracks that the car is able to avoid obstacles and navigate autonomously

Bibliography / sources:

[1] Paul F. McManamon: LiDAR Technologies and Systems, ISBN: 9781510625396, 2019
[2] Pinliang Dong, Qi Chen: LiDAR Remote Sensing and Applications, CRC Press, 2018, ISBN 9781138747241
[3] Sensing and Control for Autonomous Vehicles: Applications to Land, Water and Air Vehicles (Lecture Notes in Control and Information Sciences) ,Springer; 1st ed. 2017 edition (December 2, 2017), ISBN-13: 978-3319553719

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Abstract

By Sunkesula Mohammed Anas Hathif

This bachelor thesis is about the autonomous driving of a car model with the help of a lidar sensor device. It can produce multiple data in least amount of time which is mainly the detection of obstacles' distances around this sensor. It is one of the useful sensors for autonomous driving as it can be implemented for cost effective and for good precision purposes. Initially the lidar is connected to the PC, by using the application RealTerm, we cross check if the Lidar gives response to the characters sent via this application using the correct baud rate (i.e. 115200). Once we check that the lidar is working properly, we mount the lidar on a car model and write the necessary commands in the Arduino language to coordinate the lidar readings and the directions of the car model in order to maneuver its motion. The simple idea is to make sure that the car avoids collision to its surrounding. This will be tested in the lab using certain obstacle course to check whether the lidar does help in avoiding the car from collision. Using this concept, we can also develop in the field of autonomous driving for the future purposes immensely.

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1. Chapter 1

1.1 Introduction

Autonomous driving is the developing concept in today's world. It removes the dependency on a human driver. It is a concept where a vehicle moves on its own with the help of sensors, which is a guiding tool for the autonomous vehicle. Sensors are devices that are basically detecting the changes around it and simultaneously sending this data to the connected appliances. Based on the changes of the output of a sensor when there is an input, the sensitivity of the sensor can be determined. Sometimes the sensor will have effect on what is being measured, this means for example (here in referred to as e.g.) if we have a thermometer and we are checking the temperature of some hot liquid, as the thermometer is inserted into the liquid, the heat from the liquid will be reduced as it is transferred to the thermometer which gives us the almost precise reading of how hot the liquid is. Usually the change is always less when any sort of sensor is absorbing the data to provide us with information. Also, when the sensor is smaller in size, this helps us to counter this problem and it has many more advantages (Yan, 2014)[1].

The different sensors that are usually used in the autonomous driving are cameras, lidar, radar, sonar, a global positioning system (GPS), an inertial measurement unit (IMU), and wheel odometry (Kocić, 2018)[2].

This paper will mainly focus on the field of autonomous driving with the help of mainly a lidar sensor. It will give the readers a sense of understanding what the lidar is capable of, in what conditions can it be used, how reliable it is. The Frontal Object perception (FOP) and Moving Object Classification (MOC) module can be seen in Figure 1 Multiple sensor perception system [2]. This module is a unified one due to Simultaneous Localization And Mapping (SLAM) and Detection And Tracking of Moving Objects (DATMO) simultaneously. This module enables detection, tracking and classification of objects simultaneously. The following sensors provide the input data: camera, radar and lidar sensors (Kocić, 2018)[2].

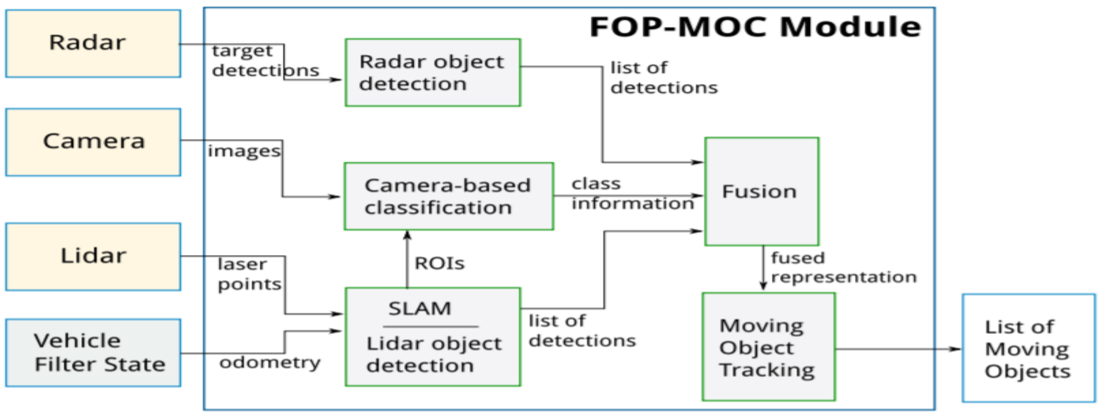

Figure 1 Multiple sensor perception system (Kocić, 2018)[2]

1.1.1. Sensors

A sensor is device that detects any changes around it and sends the respective data to the connected appliance mainly a computer processor.

In this section we will talk about the various sensors that can be used for the autonomous driving

1.1.2. Cameras

3-dimentional (Herein referred to as 3D) Cameras make it possible for the car to read its surrounding in a 360 view with the possibility of detecting any sort of obstacles in its path. With the modern technology developing in today's world, the 3D camera can make the difference in the obstruction being caused by some human or if it is just an object.

Accurate coordination of maneuvers is only possible if the cameras are of the best quality and that can send in data at a faster rate, to avoid any collision at any second.

Stereo cameras with two or more lenses consist of film frame. This allows the camera to produce human binocular vision, which makes it possible to capture three-dimensional images, a process known as stereo photography. Stereo cameras can be used for range imaging which can be useful for autonomous driving. The distance between the lenses in a typical stereo camera (the intra-axial distance) is about the distance between one's eyes (known as the intra-ocular distance) and is about 6.35 centimeter (herein referred to as cm). A longer base line (greater inter-camera distance) produces more extreme 3-dimensionality. Stereo camera provides more precise depth information. It achieves depth accuracy for objects with non-trivial disparities. The perception range of the stereo camera depends on the focal length and the baseline. Hence stereo cameras can provide larger-range perception by combining different stereo modules with different focal length and baselines (Li, 2019)[3].

Time of flight (herein referred to as TOF) cameras measure the speed of light, which determines the distance based on transit time of the individual light points. It can achieve centimeter precision. TOF is highly effective of obtaining depth data and measuring distances. The TOF provides two types of information on each pixel, the intensity value- known as the grey value and the distance of the object from the camera known as the depth of field. TOF cameras are equipped with an image chip with several thousand receiving elements. This implies that when an image is captured, it is done so with high details. There are two types of TOF sensors:

a) pulsed light- These sensors measure the round-trip time of a light pulse. They are known to perform under harsh conditions, they can measure long distances from a few meters to several kilometers. They are based on single photon avalanche diodes (SPAD) which means that they can capture the incoming photons with a high time of arrival resolution, approximately 10 picoseconds (10^{-11} seconds).
b) Continuous wave- These sensors measure the phase differences between an emitted continuous sinusoidal light-wave signal and the backscattered signal received by each photodetector. These sensors generally operate in an indoor atmosphere and they can measure from a few cm to several meters. One challenge that this sensor faces is phase-wrapping ambiguity (Horaud, 2016)[4].

Combination of cameras is another way which can be used in the concept of autonomous driving. Use of 3D cameras can face a challenge in varying lighting conditions as they are hindered by large pixels and therefore have lower resolution. To overcome this situation, the 3D cameras can be combined with higher resolution 2-dimensional (herein referred to as 2D) cameras. In this way a high-resolution detail will be captured which can help in a great way for the maneuvering of the autonomous car. With such high descriptive details, the camera sensor can identify the human and objects separately without having any confusion.

1.1.3. Lidar

Lidar stands for LIght Detection And Ranging. It consists of two main parts; one is laser emitter and the other one is a receiving sensor. The laser emitted from the lidar hits on the objects surrounding it and then reflects on the receiving sensor of the lidar.

The time between the transmitted pulse and the receiving pulse is considered for the measurement of distances of the object.

A small history about lidar, it first came into application in the field of meteorology, where the National Center for atmospheric research used it to measure the clouds and pollution (Goyer, 1963)[5].

But the lidar only came to light when the public became enlightened about the Apollo 15 mission, where the laser technology was used to map the surface of the moon [6].

Lidar uses ultraviolet, visible or near infrared light to image objects. It can target a wide range of materials and can map physical features with high resolutions. So these light sources when they detect any obstacle in its path, they retrace back to the lidar where the receiving sensor picks up these reflections and then the time taken for this light source to reflect is considered along with the speed of light to formulate the calculation of the distance of the object from the lidar.

According to the description, the formula is as follows:

$$D=\frac{CT}{2} \quad \textit{Equation 1}$$

Where “D” is the distance of the object from the lidar, “C” is the speed of light and “T” is the time of flight of the light source. The distance is measured in a 3D environment, which is useful for the autonomous car to navigate by avoiding any obstacles in its path.

Compared to stereo cameras and radars (which we will talk about it in below section), lidar sensors can provide high resolution and highly accurate 3D measurements under varying weather conditions (Laux, 2014)[7].

The two main factors of lidar are maximum range and resolution of the system: short and long range lidar systems.

The short range lidar system has the capability of detection distance less than 50 meters (herein referred to as m) with a narrow angle for forward collision warning and blind spot detection (Thakur, 2016)[8].

Short range lidars cost less due to simple set-up and due to relatively large angle of the light dispersed by the transmitter of the lidar. This type is also limited for the sake of eye-safety (Toth, 2009)[9].

The other type, scanning lidar sensors focus light on a very small area, which provides high resolution imaging and can measure longer distances.

The rotating scanner is even more preferred in the commercial industry because it provides straight and parallel scan lines with a uniform scanning speed over a wide field of view. Furthermore, the mirror surface experiences less stress and low vibrations (Ullrich, 2013)[10]. Drawbacks of this type of sensor is that it is bulky and less scalable (Stutz, 2016)[11].

An exact model of the Lidar this research paper is about can be seen in

Figure 2 RPLIDAR A1 M8 360° 2D LiDAR Laser Scanner.

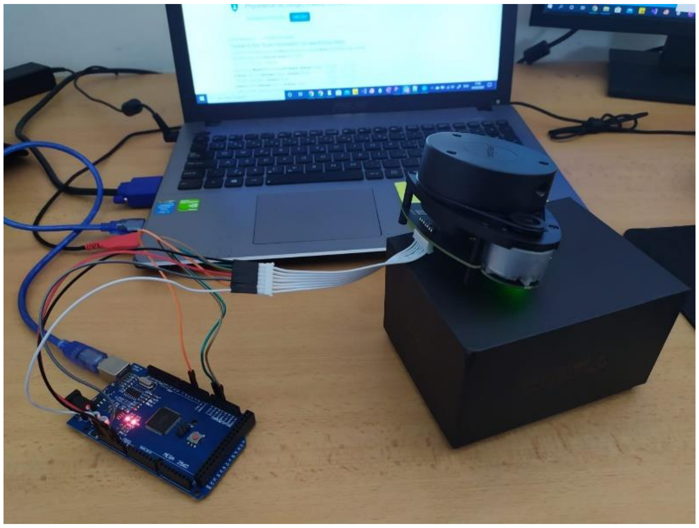

Figure 2 RPLIDAR A1 M8 360° 2D LiDAR Laser Scanner.

1.1.4. Radar

Radar stands for radio detection and ranging. It is a detection system that uses radio waves to determine the range, angle, or velocity of objects. It can be used to detect aircrafts, ships, missiles. A radar system comprises of a transmitter producing electromagnetic waves, a transmitting antenna, a receiving antenna, a receiver, and a processor to determine the properties of the object. Radio waves (pulsed or continuous) from the transmitter reflect off the object and return to the receiver, giving information about the object's location and speed. Radar is capable of virtually looking through the vehicles (Trans vision Effect). It has been improved in terms of its performance where it needs to detect any obstacle, in blind spot monitoring or cruise control systems smart environment applications, semi-autonomous evasion and braking function [12]. The introduction of semi-autonomous emergency braking and pre-crash systems was only possible by huge improvement in radar technology and its network architecture. The main area of improvement is multimodality covering long (250m) and short-range distances (0.5-80m) and azimuth angles from ± 10° to ± 70° in one sensor-package

(Dickmann J. J.-L., 2016)[13]. Some of the challenges the radar could possibly face is that shrinking time scales in terms of observation- and time to react horizons as well as huge larger number of static and dynamic object- and motion types and collision mitigation functions (Dickmann J. J., 2015)[14]. Some of the things the radar can be praised for are settling time of filters, dynamic parameters like relative speed will be faster, more mature and robust (Dickmann J. J.-L., 2016)[13]. Radar grids is a graphical way of representation of multiple data starting from the same point. This method was initially implemented on the in-door mobile robot. It was mainly used for obtaining a detailed 3D representation by using low resolution ultrasonic sensors (Thrun, 1996)[15]. Radars are preferred for their good reliability under bad weather conditions such as in rain, snow, fog and under poor lighting conditions. Due to the trans vision effect, the tracking of extended dynamic objects is more reliable and robust (Dickmann J. J.-L., 2016)[13]. It's still a developing product and needs to be focused in the areas of speed, stand-still imaging performance, short range detections (almost to zero cm), for higher resolutions. The aviation industry widely uses radars. In Figure 3 Radar sensor you can see how a radar looks like.

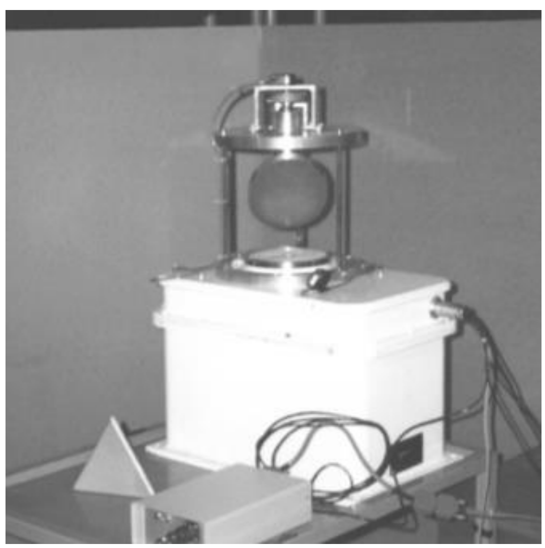

Figure 3 Radar sensor (Clark, 1998)[16]

1.1.5. Sonar

Sonar stands for sound navigation and ranging. It is a system that detects surrounding objects with the help of sound propagation, mainly in underwater activities, such as in submarine. Detections in submarine are mainly from sonar sensors which enable the submarine to detect nearby obstacles or other submarines within range and for communication purposes as well.

Although sonar has been in use for a very long time by some of the animals such as dolphins and bats for the purpose of communication and object detection. Sonar's ideology for human need was only derived in 1490 by the inventor Leonardo Da Vinci. He was experimenting to hear some noise around the water-filled tube, Eventually he could hear the nearby vessels by placing the ear close to the tube (Fahy, 2003)[17].

The term 'Sonar' was given by the Frederick Hunt (American Engineer) to the sound waves that were generated underwater by the sound-detection technology in 1930s [18].

Sonar sensor is known as a timed analog sensor, it sends in a ping of high-pitched sound and it echoes after hitting the first surface it meets. The speed of sound wave pulse is about 1.125 feet per millisecond. The distance from the sonar sensor and the object ahead of is calculated by time of flight method. The sound wave (ping) sent by the sonar sensor and the reflected sound wave (echo) and the speed of sound, using these two parameters the distance to the nearby obstacles from the sonar sensor can be calculated. Some of the important parameters of the sonar sensors are range, which is about 3cm to 3m, field of view is about +22.5° to -22.5° around the center axis of the sonar sensor. As every other sensor, sonar sensors have its drawbacks too, they fall short in its range and the size of the object that the sensor can detect. At times of measurement there can be an error by the sensor which could lead to wrong measurements of the distances of the object from the sensor. This problem can occur when the sound wave gets reflected by multiple obstacles ahead of it due to which there can be multiple variations in the readings, The only way to counter this would be to take average reading of several readings (Dinh, 2009)[19].

The SRF04 sonar radar is shown in the Figure 4 SRF04 Sonar Sensor [19]

Figure 4 SRF04 Sonar Sensor (Dinh, 2009)[19]

1.1.6. Global Positioning System (GPS)

The GPS is a constellation of satellites that locates the exact position of the GPS held device in the real time. This type of navigation was founded by the United states government and operated by the United States Space Force. It is one of the global navigation satellite systems (GNSS) that provides geolocation and time information to the GPS receiver provided there are no blocks of line of sight from the group of satellites to the GPS receiver, example of blocks include mountains and underground tunnels, these create poor signals for the GPS receiver and the satellite connectivity.

A GPS based autonomous navigation comprises of GPS receiver that receives a signal from the group of satellites. The receiver is then able to locate its position on the earth and then certain programming will help the GPS system to detect any obstacles ahead and its distances from the sensor, which can then according to the program, can avoid the obstacles in order to avoid collision. Hence the autonomous driving concept can be implemented. One of the advantages of using GPS for autonomous driving is that the data being read does not have influence from the previous set of data gained, and therefore, timely errors do not build up on the program. But there is a set of disadvantages as well to this type of system, the accuracy, precision and reliability on the satellites (Rahiman, 2013)[20]. The satellites play a crucial role in helping the GPS based device receive the coordinates about its Geolocation. In case of any hurdles on the connectivity, there can be a huge problem for the autonomous driving.

The GPS module is a main component in the autonomous system. Basically, this module is responsible for transmitting the data to the car in bytes comprising of longitude, latitude and other parameters but the two initially mentioned parameters are the most important ones which will be used in the implementation of the autonomous driving. The first application of GPS was in military but later it was made access to public and hence it was used in banking, mobile phone operations.

An example of a real-time kinematics differential global positioning system (RTK-DGPS) composed of a receiver, an antenna and a radio modem is shown in Figure 5 GPS device, whose sample rate is 10Hz and the position precision is 2cm (Wu B.-F. T.-T.-H.-J.-N.-Y.-W., 2007)[21].

Figure 5 GPS device (Wu B.-F. T.-T.-H.-J.-N.-Y.-W., 2007)[21]

1.1.7. Inertial Measurement Unit (IMU)

IMU is an electronic device that measures three linear acceleration components and three rotational rate components (6-DOF) of a vehicle. An IMU does not require any external connections to function. There are external software packages that provide data directly to the IMU for localization, perception, and control. IMU is responsible for current direction of the vehicle in real time. Failure Mode Effects

Analysis (FMEA) is a criteria to assess risk factors, unlike other sensors such as lidar, radar which is a utter failure under unfavorable conditions; IMU can determine full position and altitude for a short while till the vehicle can slow down and come to a complete halt, which is a much more sensible approach for safety purposes when the IMU device fails. The IMU can keep a good check on the dynamic attitude and position changes accurately. In terms of lane checks the IMU yet does a pretty decent job, it distances approximately 30cm from the parallel lines of the lanes, also, during the turns it maintains proper lanes which is very much important for not causing confusion among the rest of the drivers. It can maintain the lanes up to 10 seconds after the device goes off [22].

As for any other sensor, the IMU also has its own disadvantages. There is an accumulated error, as the system determines velocity and position by acceleration due to gravity with respect to change in time, the error also rises. So, there is a miscalculation of the location where the device thinks it is located and the actual position of it. As a result of integration of acceleration, the errors in velocity, position and altitude rises (Siciliano, 2016)[23].

IMU are used to maneuver aircrafts (altitude), unmanned aerial vehicles (UAVs) and spacecrafts. The recent developments of IMU is that it is being combined with GPS which is reliable for location information at all time which helps in calculation of steering control angle, and IMU specializing in the orientation control angle of the vehicle in real time. Both the devices go hand in hand and will greatly benefit the autonomous driving.

The IMU setup is shown in the Figure 6 IMU sensor along with GPS [24] (Wu N. Y., 2012)[24].

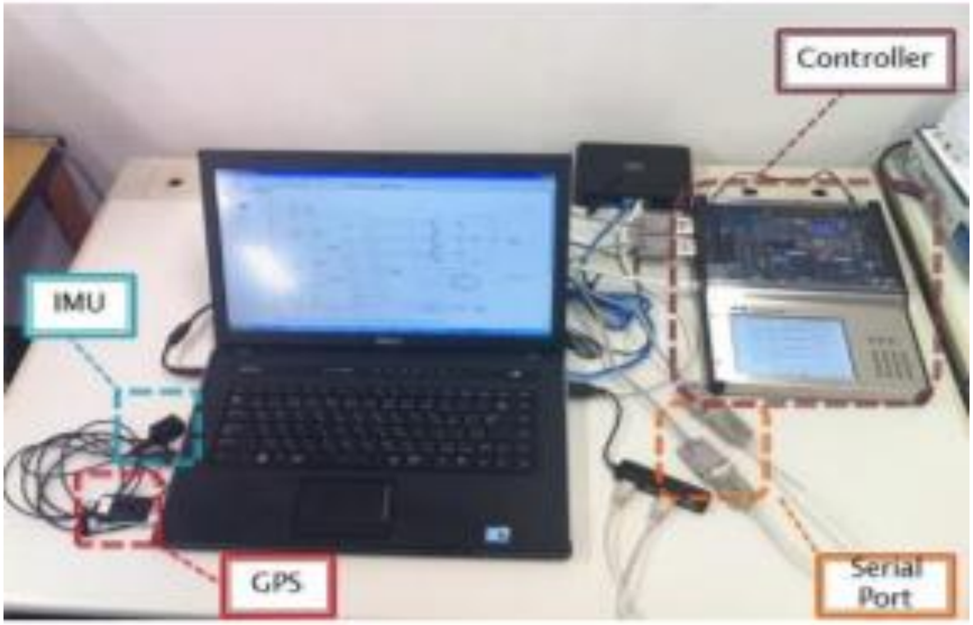

Figure 6 IMU sensor along with GPS (Wu N. Y., 2012)[24]

1.2. Summary

In this chapter we discussed about the various possible sensors that could be used for an autonomous driving. Our focus will be on lidar sensor, which has a very good accuracy compared to all the other sensors listed above. The lasers can accurately map out the vehicle's trajectory. The lidar is smart enough to recognize whether the obstacle is a person or an object, this is possible as the lidar provides accurate data and the details are provided in 3D environment which makes the processing of the data in a detailed manner, these features are possible using the slamtec technology which as mentioned creates a 3D map of the surrounding of the lidar, but in this thesis only the 2D aspect of the lidar will be discussed since it will be used for only linear measurement of the obstacles around the lidar . As always, every sensor has its own drawbacks, so as the lidar sensor. The lidar falls short when it comes to deteriorating environment (such as rain, fog, or snow) or poor lighting condition. It faces a challenge when sun angle is high, as the laser pulses from the lidar works on the principle of reflection. In the next chapter, the information on the lidar sensor that this article is about will be discussed, the components, software and the devices used to make the lidar successfully work.

2. Chapter 2

2.1 Equipment and components

In this chapter, The necessary components used in this project will be discussed. To make the lidar device work, the other important parts for its working will be mentioned here. Such parts are jumper wires, breadboard, microcontroller (Teensy 3.2), power supply unit, electric motor, servo motor, H-bridge. The connections given to the components to be compatible with the lidar device and other useful technical side of resources will be highlighted.

2.1.1 Lidar Sensor

Lidar sensor is the main equipment of this project. It is the device that will help in navigating the route for the lidar controlled car. This device can make 360° rotations to scan for any obstacle around it. In order to avoid it from collision, it measures the distance of the obstacle from the sensor, and then by programming it accordingly, Wherever the sensor detects more space or more distance, the logic is such that the route selected will be in that open space to avoid the collision. The lidar supports USB interface which will enable it for easy access to the PC. It also supports UART interface for embedded board. The lidar used in this project is a RPLIDAR A1 M8. The LIDAR works based on the triangulation method.

The specifications of the lidar sensor is as follows:

Item	Unit	Typical Value
Distance range	Meter(s)	0.15-12
Angular range	Degrees	0-360
Measurement resolution	Millimeter (mm)	<0.5 / <1% of actual distance
Angular resolution	Degrees	<= 1
Time for single measurement	Milliseconds (ms)	0.5

Measurement Frequency	Hertz (Hz)	>=4000
Scan frequency	Hertz (Hz)	5.5
Band rate	Baud per sec (Bps)	115200
Weight	Gram(g)	190

Table 1 Measurement Performance of lidar [25]

The lidar has two sections. These sections have various connecting pins which are highlighted in the following two tables:

Interface	Signal name	Type	Description	Typical value
Motor Interface	VMOTO	Power	Power for RPLIDAR A1	5V
	MOTOCTL	Input	Enable signal for RPLIDAR A1 motor/PWM control signal	-
	GND	Power	GND for RPLIDAR A1 motor	0V
Core Interference	VCC_5	Power	Power for RPLIDAR A1 range scanner core	5V
	TX	Output	Serial output for range scanner core	-
	RX	Input	Serial input for range scanner core	-
	GND	Power	GND for RPLIDAR A1 range scanner core	0V

Table 2 RPLIDAR A1 external interface specifications [26]

Item	Unit	Typical Value	Comments
Scanner system voltage	Volt (V)	5	It the voltage exceeds the max i.e. 5.5V value, it may damage the core
Scanner system voltage ripple	Millivolt (mV)	20	High cripple may cause the core working failure
Scanner system start current	Milliampere (mA)	500	Underpower may cause the startup failure
Scanner system current	Milliampere (mA)	80/300	Sleep mode, 5V input/ Work mode, 5V input
Motor system voltage	Volt (5)	5	Adjust voltage according to speed
Motor system current	Milliampere (mA)	100	5V input

Table 3 RPLIDAR A1 power supply specifications [26]

This sensor is mounted on the top of the car where a single holder is placed to support this lidar sensor. Lidar is capable of sensing in a 360° format so it can scan the entire environment around the car to get the information of the various distances from the obstacles. So, using this data analysis the lidar is programmed to avoid obstacle collision. Hence, a single lidar can fulfill the goal of obstacle avoidance rather than using multiple sensors to record the data like in the other sensors for e.g. An ultrasonic sensor. The position of the mount and the lidar placed on it should be such that the sensor is not interfered with the connecting wires or other material of the car to get the accurate distance of the obstacles from the sensor. The RPLIDAR used for this project can be seen in Figure 2 RPLIDAR A1 M8 360° 2D LiDAR Laser Scanner.

2.1.2 Jumper Wires

Jumper wire is an electrical wire that contains a pin or a connector at each end. It is used to make connections in various electrical peripherals such as breadboard, which is a most common used peripheral, other components without the need to solder these wires [27].

The jumper wires used in this project are solid pins type jumper wires with combinations of a male and a female connector, with a few being male connectors on both the sides and a few being female connectors on both the sides.

The colors in the jumper wires do not have any special function to it. All the jumper wires of different colors hold the same value, but these colors could be used to differentiate when it is used in a project. Such as to highlight a special function such as generally a ground connection is represented by a black color jumper wire and a power source is represented by a red jumper wire and similarly the various colors of the jumper wires will gain its meaning after the connection has been established. It's just for the sake of ease of management of these connections and for the user to be aware of these connections.

Figure 7 Male to Male Jumper wires [28]

Figure 8 Male to Female jumper wires [29]

Figure 9 Female to Female jumper wires [30]

2.1.3 Breadboard

A breadboard is an electronic connecting base where it acts as a junction for all the necessary connections between a device and a source. As the breadboard is a solderless, plug in type tool, therefore many experiments could make use of this tiny tool for testing of the circuits. It consists of perforated block of plastic with numerous tin-plated phosphorus bronze or nickel silver alloy spring clips under the perforations. These pins are known as contact pins. The spacing allotted between the clips (lead pitch) is typically 0.1 inches (2.54mm). There are specific holes for the interconnecting of wires and leads of discrete components (such as capacitors, resistors, and inductors). Here where theses connections are made, there the ICs are not used. The spring clips are rated as follows, the 1 ampere is rated at 5 volts and 0.333 amperes at 15 volts (5 watts). At the end of the boards there are male and female dovetail notches to connect multiple breadboards. Terminal strips is the area on the breadboard where most of the electrical components are connected. There is a notch in the middle of the terminal strip, which provides airflow to the ICs. The clips on the right and left are connected radially. The five holes on each side are connected. The column holes are marked as A,B,C,D and E whereas the rows are numbered from 1 to the number of the rows the breadboard contains. Typically, there are 17,30 and 64 numbered rows on the mini, half, and full breadboard types respectively. In this thesis, the mini breadboard consisting of 17 rows has been used.

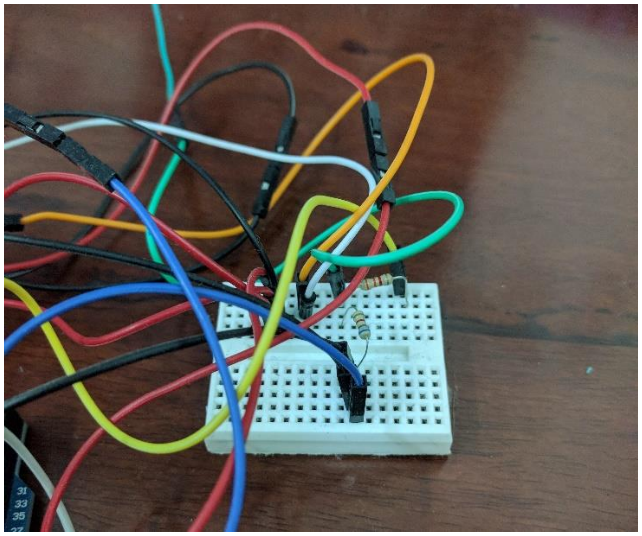

Figure 10 Mini Breadboard connected to jumper wires and resistors

2.1.4 Microcontroller

A microcontroller can be considered as a compact integrated circuit. It is used in embedded systems as a brain of the operation. Typically, a microcontroller includes a processor, memory, and input/output (I/O) peripherals on a single chip.

In this thesis, Teensy 3.2 is chosen. Since the project involves results almost in real time, therefore, if the performance is considered, the Teensy 3.2 can achieve clock rate of 72 MHz which is the rated speed, it can be overclocked to 96Mhz . The I/O pins also matters a lot, The Teensy 3.2 features a 34-digital input/output pins, of which there are 12 pins that provide PWM output. There is a possibility for the digital i/o pins to support serial communication for e.g. I2C and SPI. This microcontroller board also features 21 analog inputs.

The teensy boards are compatible with the Arduino IDE software just like the Arduino boards. Talking about the programming environment, the Arduino IDE is an open source software which eases a lot of complications of coding in cost-free environment. It is user friendly. Most of the required common libraries are present. As the Arduino IDE community is large, there is a lot of space to discuss the coding at the development stage, where a lot of ideas can be shared among the community and useful and effective codes can be made. Since it is user friendly access to more creative coding ideas are easily available. The microcontroller used in this project can be seen in the Figure 11

Figure 11 Teensy 3.2 [31]

2.1.5 Power Supply Unit

To power up the car model and start running the lidar, A power source is required. This power supply voltage regulator is a good way to know how much voltage is being supplied to the electrical components. To protect the electrical components from burning out, the details of how much voltage it can withstand is taken note of and accordingly the voltage is supplied from the Power Supply voltage regulator unit. The regulated power supply converts the unregulated AC (Alternating Current) into a constant DC (Direct Current) with the help of a rectifier. This enables the power supply unit to provide a stable voltage by reducing the current (regulating it). The power supply unit displays Current (Ampere) readings as well as Voltage (Volts) readings.

Figure 12 Power supply unit

2.1.6 Electric Motor

This electric motor provides power to the motors controlling the wheels of the car model. The electric motor model used in this project is SGM25F-370 DC Geared Motor(12V). This motor is mainly capable of running at 12V power supply but a lower power supply minimum of 6V can also be supplied to operate but at the expense of power of the electric motor. The component that will most likely be compatible with this motor is the H-bridge. This motor has an operating voltage range between 6V and 18V, but the nominal voltage is 12V. It weighs around 82g.

Figure 13 SGM25F-370 DC Geared Motor [32]

2.1.7 Servo Motor

The Servo motor is used when anything dealing with rotary actuator or anything related to angular position control is taking place. It uses a regular motor and by pairing with a sensor, it can get the feedback of the position. It’s a closed loop servomechanism which uses position feedback to control the its motion and the final position. The servo motor used in this project is Hitec HS-311 Servo Motor. The main parts of the servo motor are the motor, the potentiometer, and the control board. The main function of the servo motor is do control the direction of the motion as the potentiometer’s resistance changes. The speed of the rotation of the shaft of the motor is at its peak till it attains its desired set position, once it reaches that point the speed of the motor decreases. Basically, the motor is on and working to accommodate the desired position of the shaft, once that is achieved the motor is shut off. The main purpose of the servo motor is this project is to enable the turning of the front wheels of the car model towards right or left which makes it possible to make turns when necessary. It has a max torque of 5.5Kg/cm and a weight of around 35g. It has an operating voltage of between 4.8V to 6V [33].

Figure 14 Hitec HS-311 Servo Motor [34]

2.1.8 H-Bridge

The H-bridge is an Integrated Circuit (IC) which operated the voltage applied to a load by switching the polarity of that voltage. These motors are used to run the DC motors forwards or backwards. Basically, the DC motor can spin forward or backward depending on the connection of the switches of the H-bridge. There are 4 switches, a VCC, a ground and a motor on the H-bridge. When the switches 1 and 4 are closed, the plus charge is activated on the left side of the H-bridge and minus on the other side, this eventually lets the motor spin on one direction. In the other way around, when switches 2 and 3 are closed, plus charge is activated on the right side of the H-bridge and minus on the other side. The PWM (Pulse Width Modulation) is another important factor that helps in adjusting the average voltage value that is needed by the device, this is accomplished by quickly turning on and off the power at a faster rate. With the PWM from the Arduino and the H-bridge connected to it, the DC motor can be controlled effectively. The H-bridge used in this project is L298N H-bridge. This electrical component has two screw terminal box for a motor A and a motor B, and in addition to that, there is a third terminal box which consists of VCC, GND (ground) and 5V connections which can act as an input or an output. This depends on the amount of voltage connected to the VCC connection. Up to 12V of voltage supply provided to the VCC connection, it enables the 5V connection as the output and the voltage regulator of 5V comes into play by attaching the jumper on to the regulator pin, as the excess voltage is controlled by this regulator. But beyond 12V supply, it is risky to use the jumper and 5V regulator, hence the jumper is removed and the 5V connection becomes an input source which draws power supply from an external power source. Also, to take in note is about the voltage drops of 2V at the motor terminals. The logic control inputs of the H-bridge, namely, Enable A and Enable B pins are used to activate and control the speed of the motor. The ways to control the speed of the motor are by attaching the jumper to these pins enable to keep the motor running at the maximum speed and if the jumper is disengaged and these pins attached to the PWM then the speed of the DC motor can be controlled according to the coding in the Arduino. And finally, there are Input Pins 1,2 and input pins 3,4. These pins help in controlling the rotation of the motor A and motor B respectively (Nedelkovski, 2017) [35].

Figure 15 The L298N H-bridge [36]

2.2 Connections and Assembly

In this section, the connections made to the lidar to be mounted on to the car model will be discussed, also, other necessary connections will be highlighted.

To hold the lidar on top of the car model, a plate as a base and a polystyrene foam to hold the lidar on top of it is used. The foam is placed on top of the plate which consists of holes and this plate is screwed on the plexiglass of the car model in front. On top of the foam is where the lidar is placed to give it a height to avoid the interference with the wires.

The lidar pins as stated in the previous sections, the in-depth connections of these pins will be discussed in this section. The main board to retrieve the readings from the lidar is the Teensy 3.2. Since there are many components to be connected and the lidar must be connected onto this board, therefore, the connections are done via a connecting bridge, a breadboard where there will be a common row containing the pin of voltage, ground, and PWM. The teensy 3.2 can help in accommodating 34 additional I/O digital pins. The DC power adapter used in this thesis has a voltage of 9~12V. This helps in powering the electric components that will help in running the car model. The main components connected on a common row of the breadboard to utilize this 9V are positive terminal of the H-bridge and the input positive terminal of the DC-DC converter. To control the voltage of this power adapter a DC-DC converter is used, since 9~12V is just too risky for the teensy board, and other components to be exposed to, hence this voltage is brought down to 5V with the help of the DC-DC converter. To convert this voltage, the 9V from the power adapter's positive terminal is connected on a row in the breadboard, to this row the input positive terminal of the DC-DC converter is connected, Then from the output of the DC-DC converter we receive the 5V power supply. All the negative terminals of these components are connected to common ground connections. Then on the common row of the breadboard being supplied with this 5V input voltage from the output of the DC-DC positive terminal, the following component's voltage pin (Vcc) are connected, they are, servo motor; the lidar has two Vcc connections, one for the motor interface and one for the core interface, and the teensy 3.2. Then on the next row of the breadboard, there is a common pin for the ground connections of the following components' ground connections (GND), they are, The same components as mentioned for the voltage common connecting pins but only the lidar will have one ground connection. Then the next row will have connections of the PWM controlled pins for the lidar, the Motoctl pin of lidar is connected on a common pin on the breadboard with the pin 6 of the teensy which is PWM controlled. The H-bridge which is connected for the purpose of controlling the forward and backward motion of the car. The connection made on to this motor is by connecting all these Input1 and Input2 (In1, In2) pins' signal pins on to the teensy board's pins' (20 and 19) respectively, the enable pin has jumper on, so it is on all the time during the power up of the components. When there is an external power supply for the H-bridge, the jumper is enabled in order to use this external power supply that provides 9V in this case, else if the jumper is removed then the 5V voltage regulator comes into play in order for the motor to avoid taking excess voltage in which case the H-bridge can be destroyed. Then there is a Servo Motor, which is used for the purpose of rotating the wheels at a certain angle. It can supply the angle from 0-180 degrees. This will be helpful in turning the car right or left. The signal pin is connected to pin 23 of the teensy 3.2 to receive response of turns. The connections of the lidar are RX (receiving signal), TX (transmitting signal) are connected to the 1 and 0 digital I/O pins of the teensy 3.2 respectively as 1 is the TX pin of teensy (so RX of lidar to TX of teensy) and 0 is the RX pin of teensy (TX of lidar to RX of teensy) .

2.3 Ideology and Algorithm

This section focuses on how the programming is done, what logic has been used in the program to implement it for the testing of the autonomous driving with lidar. The progam used for this project is an open source software, called the Arduino software which is also called as IDE (Integerated Development Environment). With the help of this program, the code is developed in this software and in order to test this code, it can directly be uploaded to the microcontroller board which is connected to the PC via a USB cable after verifying the code for any errors. Most of the functions on this program are related to C language, at the same time it has its exclusive set of commands as well. There are also libraries included in this software which are prewritten commands in order to use if for the fuctioning of certain devices. This is really helpful as, it’s a standard set of open source coding which can be accessed by many developers and further develp from thereon to achieve their goals. Similarly for the lidar model that is used in this project, there predefined libraries for its proper compatibility to this software, those libraries will be used in this project and also the libraries for the servo motor will be used as well. In the Arduino program, there are two sections, first one is a set up function which consists of commands that are necessary to run only once, for instance to open up the ports for functioning, to define the pin connections of the devices on the microcontroller board, etc. In this project code, under the set up function, it contains: The lidar serial port is opened, i.e the lidar is connected to the port 1 of the Teensy 3.2 (TX1, RX1). This allows the exchange of data between the lidar and the Teensy board. Then pin connections of the H-bridge is made as output to be able to perform fucntions as per the data entered in the coding and then the servo.attach(pin number) is defined in order to attach the servo motor’s connection to the mentioned pin of the Teensy board. At the end the text to represent the data flowing in the Teensy board is printed as the title text in order to differentiate the incoming data into the serial monitor with the command Serial.print(“\n text of the title”);. The above description is shown below as how it is implemented in the code form:

Serial.begin (115200); //we're going to use arduino serial monitor to monitor the results, so we setup the serial monitor at 115200 baud

lidar.begin(Serial1); // the LIDAR communicated at this baud rate with the Teensy board

// setup the motor control pins

pinMode(EnA, OUTPUT); // defining the Enable pin of the H-bridge as the output

pinMode(In1, OUTPUT); // defining the Input1 pin of the H-bridge as the output

pinMode(In2, OUTPUT); // defining the Input2 pin of the H-bridge as the output

// set pin modes

pinMode(RPLIDAR_MOTOR, OUTPUT); defines the RPLIDAR PWM pin 6 as the output

servo.attach(23); // attaches the servo on to pin 23 of the teensy 3.2

The second funtion in the arduino program is the loop fucntion which allows a set of commands to be repeated unitl the condition is satisfied. Here in the beginning once the condition to check if the lidar is scanning properly is succeded, then the variables responsible to collect the data from the lidar are declared, such as lidar's distance and angle that will be collected. Then there will be a criteria to check if one complete cycle of the lidar is achieved. That is one complete 360 degree turn has taken place. Then there is a set of commands to find the maximum distance that the lidar would have scanned in its one complete cycle. There is a condition to check if the current distance is greater than the maximum distance which initially is taken into account as 0 then that current value will become the latest maximum distance. Then the angle of the lidar at the maximum distance will be taken into account, this angle will be passed on to the function turnSides() to compare which particular angle can the servo motor rotate in order to rotate the wheels of the car, for instance if the angle is between 0-90 degrees this is the scope of the left direction and if the angle is between the 90-180 degrees then this is the scope of the right direction of the servo. After the angle is invoked in the turnSides function there is a calculation of the total angle denoted as "totalAngle". This variable calculates the exact angle that is required by the servo motor to rotate in order to ease the turning of a side by the front wheels. There is an offset by the wheels of about 28 degrees as mentioned earlier. Therefore, the minimum angle, 0 degree will be read as 0-28= -28 degrees and the maximum angle 180 degrees will be read as 180-28= 152 degrees. Also since we are dealing with 2-dimentional axis, we have four quadrants 0-90, 90-180, 180-270 and 270-360 degrees. For the forward motion the degree scope from 0-90 and 270-0 degrees is considered. In this scope the car will be made to move in forward direction. For the backward motion the degree scope from 90-180 and 180-270 degrees is considered, in this scope the car will be made to move in the backward direction. So the part of forward and backward has been mentioned, the next step is for the totalAnlge to be calculated, it will consider the offset angle and the angle to maintain within the scope of 0-180 degree since the servo motor's scope is limited to 0-180 degree and the offset is being considered as the front wheels cannot turn entirely 180degrees for the right oriented turns so the offset of -28 is added which gives us respectively 152 degree maximum in the right turn oriented. For the left turn oriented which is from 0-90 degrees the wheels turn fine so the offset is not considered. The totalAngle will be received with a scope of 0 to 152 degrees and accordingly the turning angle will be provided to the front wheels of the car model. Then the maximum distance, angle of the maximum distance, the servo motor angle.Then the angle of the maximum distance will be stored as the anglerequired to later use it for providing the input angle to the invoked function turnSide .

This was the description of the void setup() and void loop() functions. The other functions which help in setting the angle to the servo motor and deciding whether to move forward or backward has been described in the following flowchart. givenAngle is the angle of the lidar. If the condition is true then there are six commands that will be executed namely totalAngle is the angle after considering the offset and the angle respective to forward or backward motion. Then there is servo.write(totalAngle) which will provide the angle to servo motor in order to turn the front wheels of the car accordingly. Then there is a delay of servo (this value is tested with 3 different values, i.e. 1000 ms, 1000ms and 500ms or 1 second, 1 second and 0.5 second respectively. Then there is goForward()/gobackward function according to the condition which makes the car move in forward/backward motion accordingly. Then there is delay(delayMotor) which delays the lidar from picking up next values instantly so as to complete the required action. This is 1500ms, 2000ms and 3000ms or 1.5 seconds, 2seconds and

3seconds respective delays. This entire description is what shown in the following flowchart.

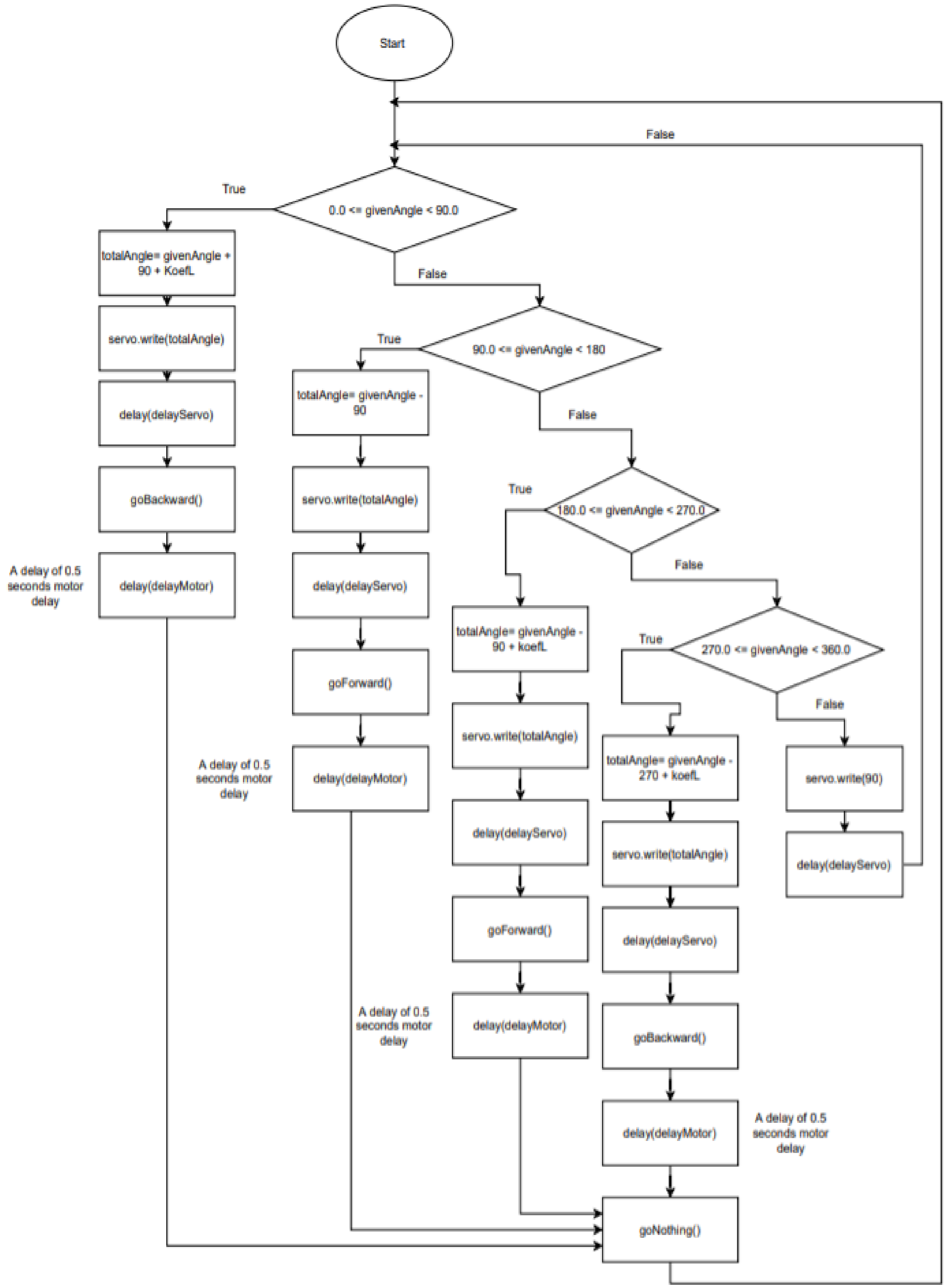

Figure 16 Flowchart representing the idea of the code

3. Chapter 3

3.1 Testing Phase

In this section, first we check the capability of the lidar in capturing all the distances from its surrounding that is while rotating a complete 360 degrees. A small experiment will be conducted where the lidar is positioned around a few cardboard obstacles, and the lidar will be operated to rotate in a 360 degree to measure distances in every degree that it rotates. With this, the data of the distances that is received by the lidar will be generated and eventually this data will be plotted in the serial plotter in Arduino IDE to check the variation in the data captured. For this small experiment, there will be two tests, in both, there is a lidar named LDS-01 and then there will be 4 obstacles. The obstacle 1,2 and 4 will be fixed while the obstacle 3 will be positioned in two different spots to compare if the lidar can consider this difference, hence two tests. In the first test (in Figure 17), the obstacle 3 will be kept close to the lidar at a point, the lidar can detect it and generate the distance from this obstacle. Once the distances are being captured by the lidar, it can be plotted at the same time using the serial plotter in the Arduino IDE software, this provides us instant graphical representation of the data being captured. In the second test (in Figure 18), the obstacle 3 is kept farther from the lidar, same as in the previous test, this incoming data in plotted. Hence from these two tests, we can conclude if the lidar is correctly able to detect the obstacles at various positions and is providing feedback from the actual obstacle detection and not just generating random data from the serial buffer. Below is an illustration of what the two tests look like. From these two tests, the graphs are generated which show the angle measurement i.e. from 0-360-degree range and the distances captured by the lidar from the surrounding obstacles. In these graphs, Only the lines in purple and green will be considered, as the purple represents the angle reading and the green represents the distance reading. In both the tests, the y-axis represents the magnitude for the angle and the distance. And the x-axis representing time in milliseconds. Then the purple being the angle measured has a triangle shape since it has fixed range of the angle that the lidar rotates i.e. from 0-360 degrees and it keeps repeating this sequence, hence a triangle shape. The line spikes in the green color, since green representing the distances from the obstacles to the lidar, are varying since the obstacles are at different locations. In these line spikes, the second and third green line spike will be considered for this experiment, the second spike represents the distance of the lidar from the obstacle 3 and the third green line spike represents the distance of the lidar from the obstacle 4. While the obstacle 1 and 2 are out of score we don't have their reading in the graph. And the first green spike can be picked up by the lidar in the gap through these obstacles which is neglected. The obstacle 4 being fixed for both the tests, we can note that the green spike is fixed and not changing in both the tests, the obstacle 4 being at over 450mm or over 45cm. The graph of first test (in Figure 19) the obstacle 3 is kept at a farther distance from the lidar at a distance of close to 450mm or 45cm, while in the graph of second test (in Figure 20) the obstacle 3 is kept at a close distance from the lidar at a distance of a bit more than 150mm or 15cm. So, this small experiment concludes that the lidar is able to detect obstacles surrounding it, which is very helpful for this thesis, as this lidar can further be programmed to provide logic in order to control the direction of the car model from avoiding collision from any obstacle in its way. In the next section, the test experiments in controlling the car model with this logic is implemented.

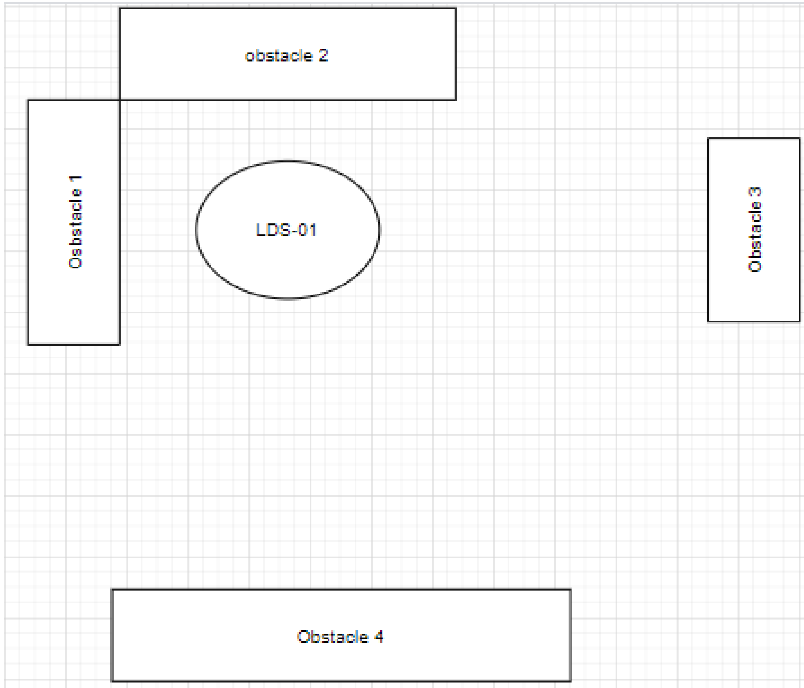

Figure 17 Obstacle detection test 1

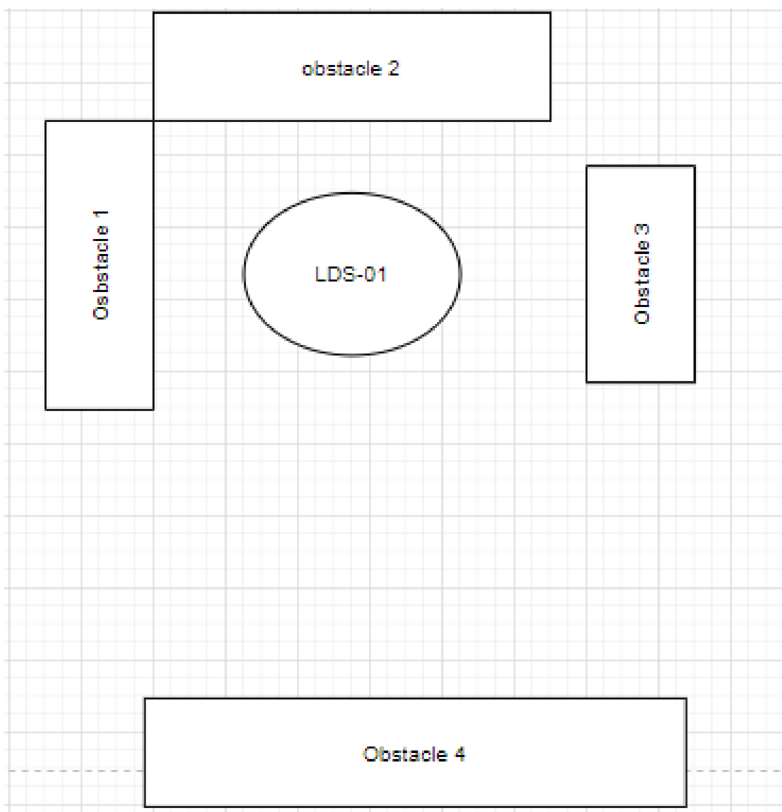

Figure 18 Obstacle detection test 2

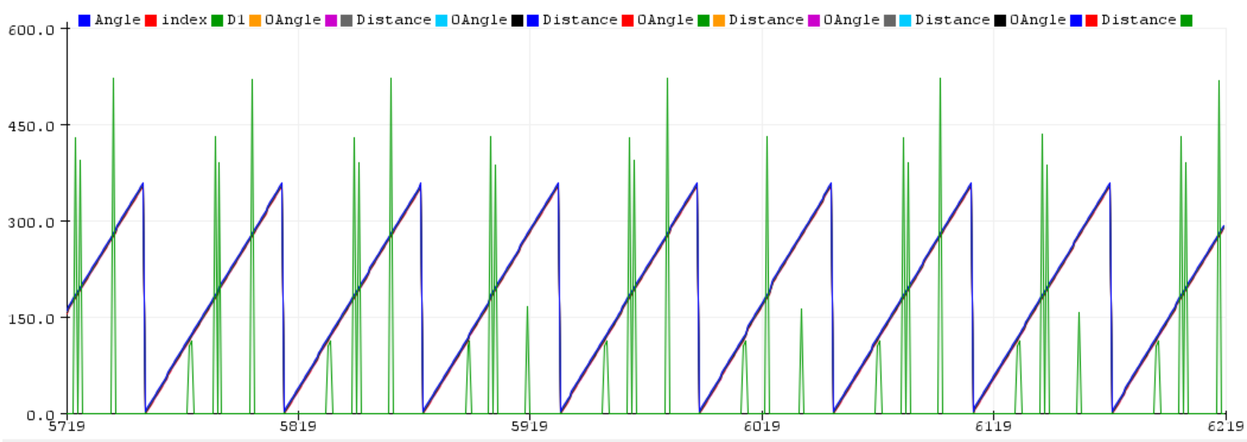

Figure 19 Graphical representation of the data from the lidar in test 1

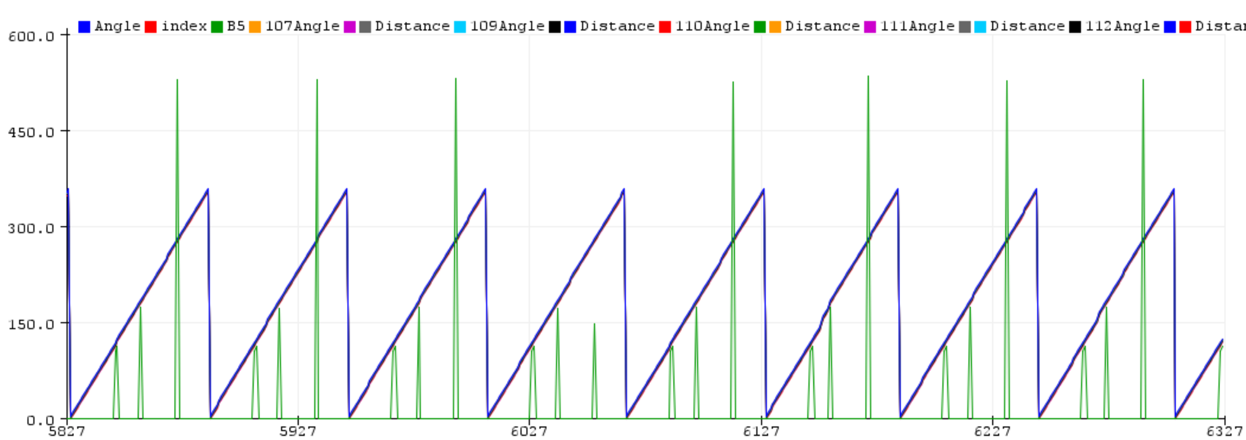

Figure 20 Graphical representation of the data from the lidar in test 2

In this section, the testing of the car model is discussed. The electric connections made on the car model, the uploaded code to the microcontroller board is finally put to test by checking if the car reacts to the code in a way it is meant to, i.e. by avoiding the obstacle on its path, For the testing, there are two test tracks created keeping in mind the dimensions of the car model, mainly the width of the car model, the height of the lidar that is mounted on top of the car model. In each of the test track, the testing is performed thrice by changing the delay of the servo motor and the electric motor inside the program to see by how much delay, the results obtained are the best ones. So, for the two test tracks there will be one test result out of the three chosen for each that provides the optimized result. In the following tests the maximum distance of the lidar which is in 2D and is linearly measured whose range is 10mm to 12000mm. The maximum distance's angle of the lidar whose range is from 0-360 degrees, then the next parameter is the angle of the servo motor whose range is from 0-180 degrees, There is an algorithm that checks the current value and checking the previous value of the angle, if the previous angle value subtracted from the current angle value gives a negative value, that means the lidar has completed one revolution. This implies that a new segment of cylindrical rotation has been started. The time taken for each max distance reading out of the lidar can be calculated by recording it on a stop watch and then dividing the time obtained at the completion of the test track by the total number of data that was generated, and it is taken into account in milliseconds. There are three sets of trial values given for the two test tracks, They are:

1) Delay Servo motor: 1000 milliseconds (in seconds = 1 second) and delay of the electric motor: 1500ms = 1s
2) Delay Servo motor: 1000ms = 1s and delay of the electric motor: 2000ms = 2s
3) Delay Servo motor: 500ms = 0.5s and delay of the electric motor: 3000ms = 3s

Then the data is split into two charts. The first chart is about max distance of the obstacle measured by the lidar vs the time taken to consider that reading. It can also be represented as d=f(t), where d is the distance of the obstacle measured by the lidar and the t is the time taken to get that reading.

The second chart is about the Angles of the lidar motor and the servo motor vs the time taken to make those readings. The time taken here is same as the time in chart one. So, on the x- axis there is time parameter, and, on the y-axis, there are two angles, lidar angle and the servo angle. The car model initially checks the maximum distance away from an obstacle, then it calculates this positions' lidar angle to check if it must turn towards any angle for the car to move under those set conditions. Once the lidar sensor detects the maximum distance of any obstacle, then the logic will tell the car to move in that direction to avoid the nearest obstacle. The idea behind going forward, backward and the turns is by defining the scope of angles for each motion at an angle. For e.g. if the lidar's angle is recorded between [0-90) (0 included and 90 excluded) and [270-360/0) degrees then the car is obliged to go in Forward direction. If the lidar's angle is recorded between the [90-180) and [180-270) then the car is obliged to go Backward direction. The next thing is about turns, the angle taken by the lidar itself is used to describe the servo angle and since the scope of the servo motor angle is only till 0-180 degree, therefore, the lidar's angle is modified to bring its angle within the mentioned range.

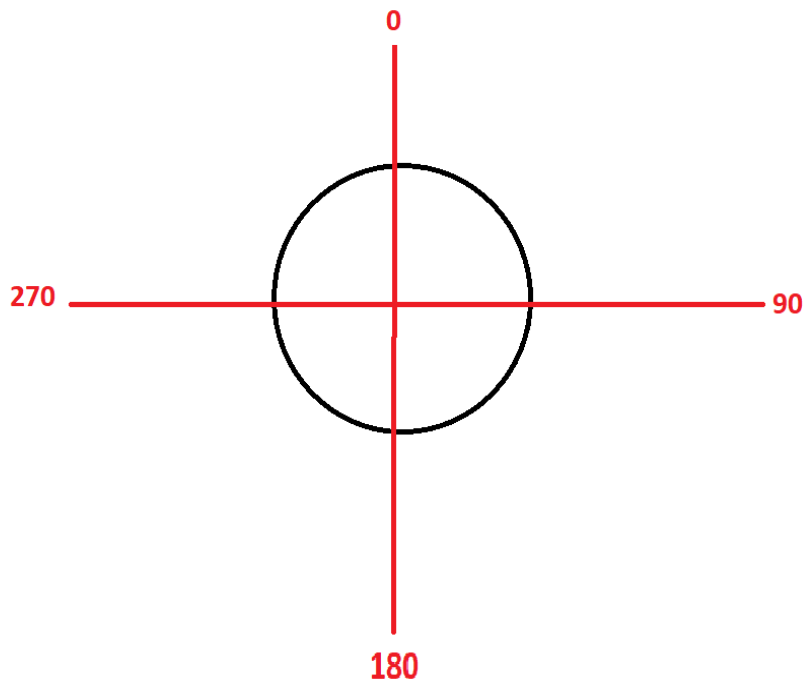

Figure 21 lidar angle definition [90-180) and [180-270) Forward scope and [270-360or0) and [0-90) is backward scope

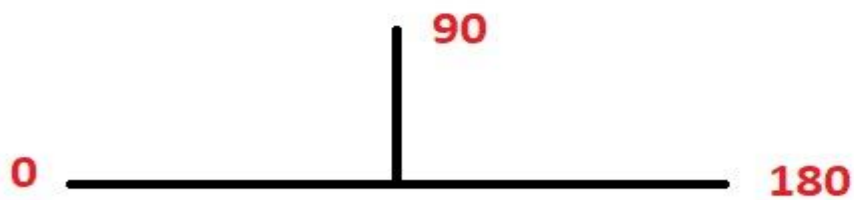

Figure 22 0-90 left scope and 90-180 right scope

For e.g. when considering Forward motion scope of the angle, if the angle is between [0-90) and if 90 degree is added to the given scope of angles then the scope becomes [90-180) degree this scope in the sense of servo motor is RIGHT oriented. So, it describes Forward motion, but the front wheels positioned at angle towards right oriented. The car will start to position itself in that direction. Similarly, for the next Forward motion scope which is [270-360/0) degree and a 270 degree is subtracted from this scope then the new scope is [0-90) degree, this scope in sense of a servo motor is a LEFT turn. So, the motion is described as moving Forward but the front wheels positioned at an angle towards left oriented. The car will position itself accordingly. Similar case is with the scopes of back motion of the car i.e. [90-180) and [180-270) degrees, these scopes will be converted into servo motor scopes and accordingly the car will move. These three tests performed for each test track is to find out which delays give the optimum results for the entire experiment of the autonomous driving of a car with lidar by avoiding the obstacles and completing its course.

In the following testing analysis, the “test 1” refers to test performed on the test track 1 and “test 2” refers to the test performed on the test track 2. On each test track there will be 3 different settings as mentioned before and will also be mentioned again in the following individual testing analysis.

Due to the large data being generated from the void loop() function, the graph is holding the complete data that it took the car to steer out of the test tracks. These tests record data from the RPLIDAR and servo angle. The graphs generated from the following tests are mainly two in each test, they are maximum distance in millimeters vs time in milliseconds, first graph. The second graph is the RPLIDAR and servo angles in degrees vs time in milliseconds. The delays used to make these tests are mainly the servo motor delay and electric motor delay. The servo motor delay is responsible for the delay of the action of the front wheels making a turn to give these wheels enough time to complete the turns. The electric motor delay is responsible for the delay of the action of the rear wheels moving forward or backward. This ensures the car completes a motion from the spot to where the maximum distance has been located.

3.1.1 The First Autonomous Test

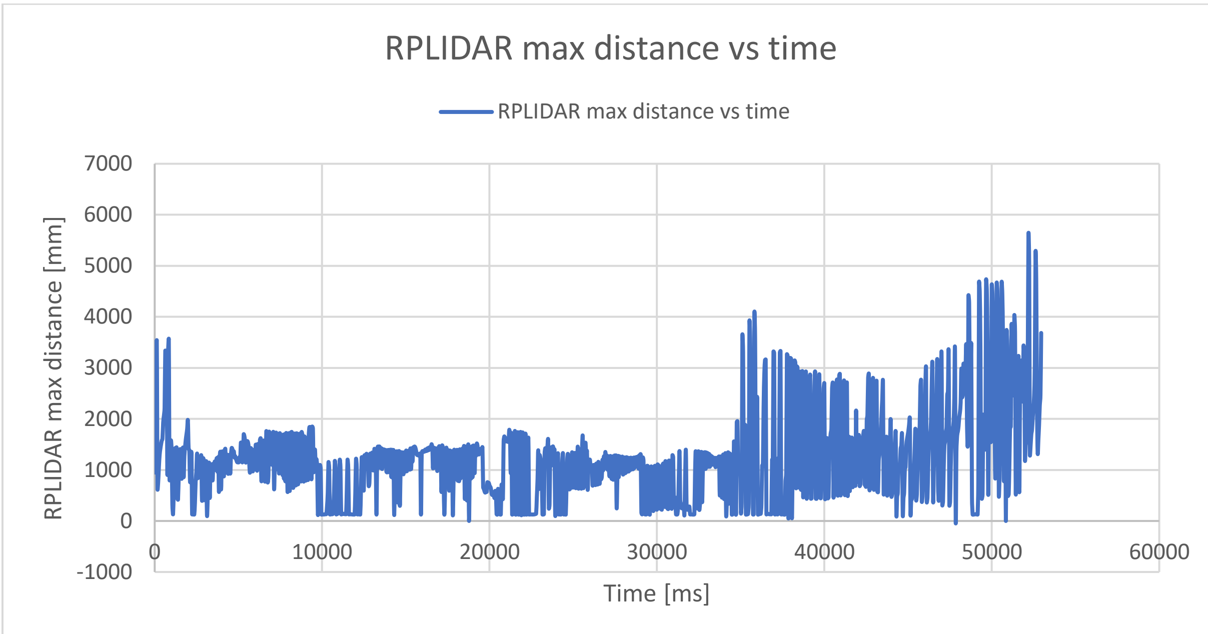

Figure 23 Distances vs time graph for first test

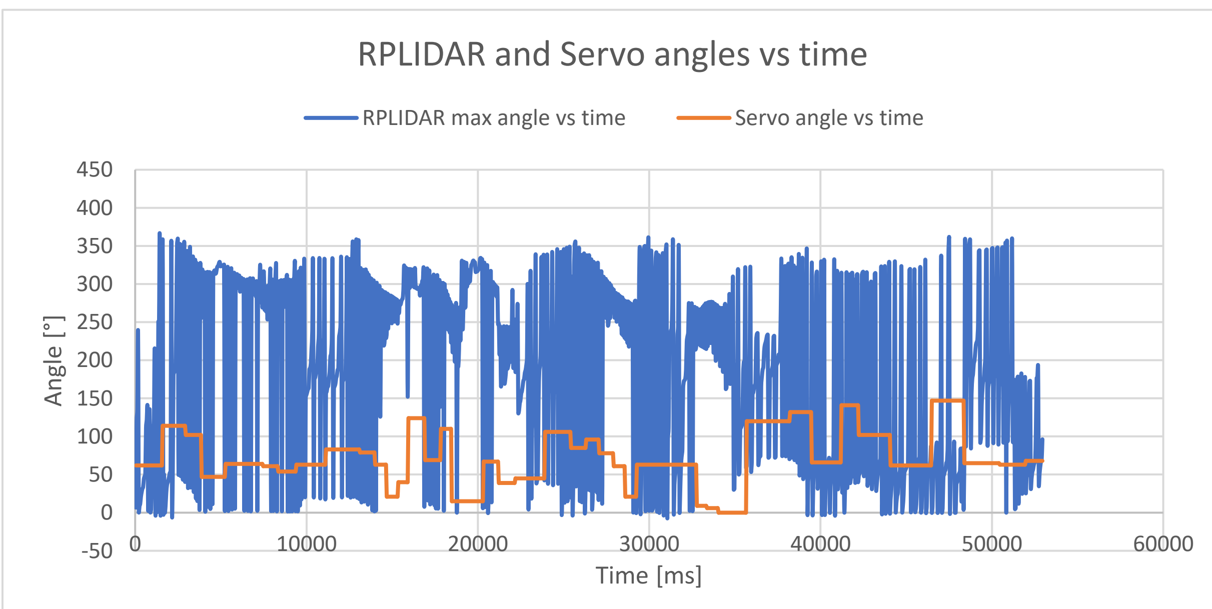

Figure 24 angles vs time graph for first test

In the first autonomous test, it is based on test 1 with settings made as servo motor delay of 1000 millisecond and the electric motor delay of 1500ms. we see the first graph that is the maximum distance vs time graph, the RPLIDAR picks up a few maximum distance of over 2600mm out of the test track from the space where the testing track was set up before entering the test track. Since there is a lot of data, the simple idea behind plotting a graph is to comprehend these large data easily. Since the servo angle is much easier to view on the graph and understand the maneuvering of the vehicle, we will focus more on this servo angle to understand where exactly the car is moving. Initially, the test1 is a U-shaped track. As the car enters the test track the servo angle is 62, which means the front wheels are in a straight orientation without any turns and the car moves straight into the track, Once inside, the car tries to make a right turn which means the servo is trying to get the scope of a right turn (i.e. 90-180 degrees along with an offset coefficient of -28 degrees.). Here onwards the car seems to get too close to the obstacle and as it is trying to find maximum distance to pave its ways out of the test track, it goes forward and then goes backward to move towards more open space. To help this logic work, a support of a sheet is used to help the sensor focus on the more open space in the front rather than back after midway through the test track, this sheet ensures that the path it covered until that current spot has been completed and it needs to keep moving forward where there is maximum space. So, most of the course now, the servo angle is around 60-80 degrees as it is trying to move on a straight path. At some instances the car moves in the right direction and then reverses back as the sheet is a bit further meaning there is more space at the back rather than at front. Eventually starts moving in a forward direction and then taking another right turn which is the last turn of the test track hence the servo angle rises to 149 degrees which is a right scope in terms of the servo motor. Then the servo scope considers an angle of 62 which means the wheel orientation is straight as the car exits the test track. The car takes 53 seconds to complete the test track.

3.1.2 The Second Autonomous Test

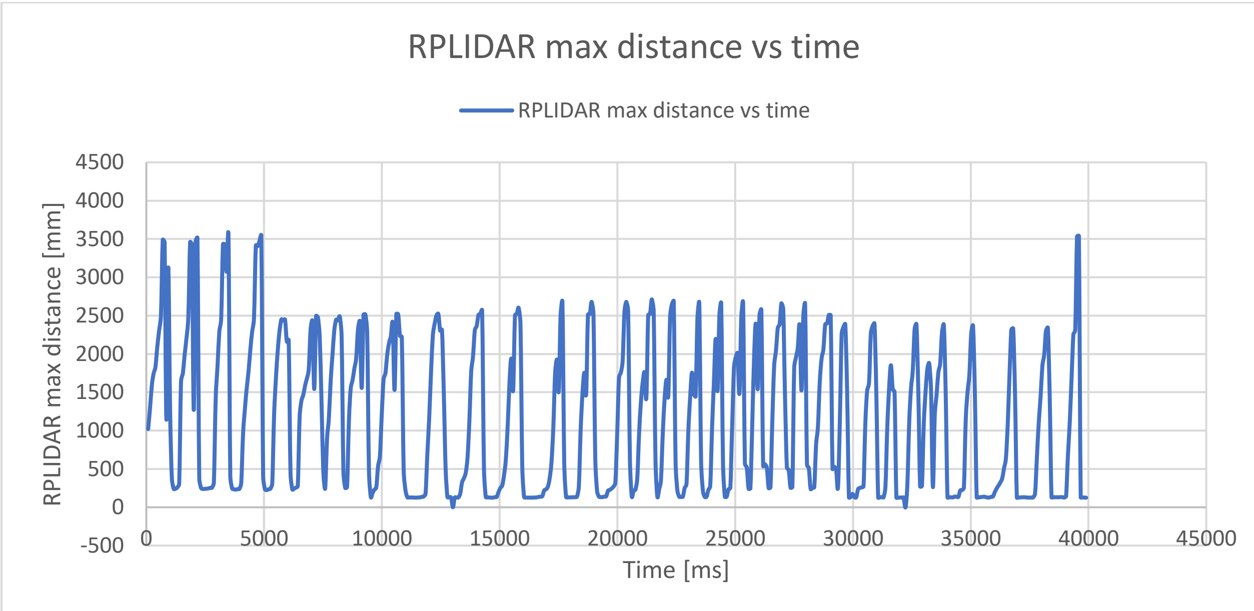

Figure 25 Distance vs time graph for second test

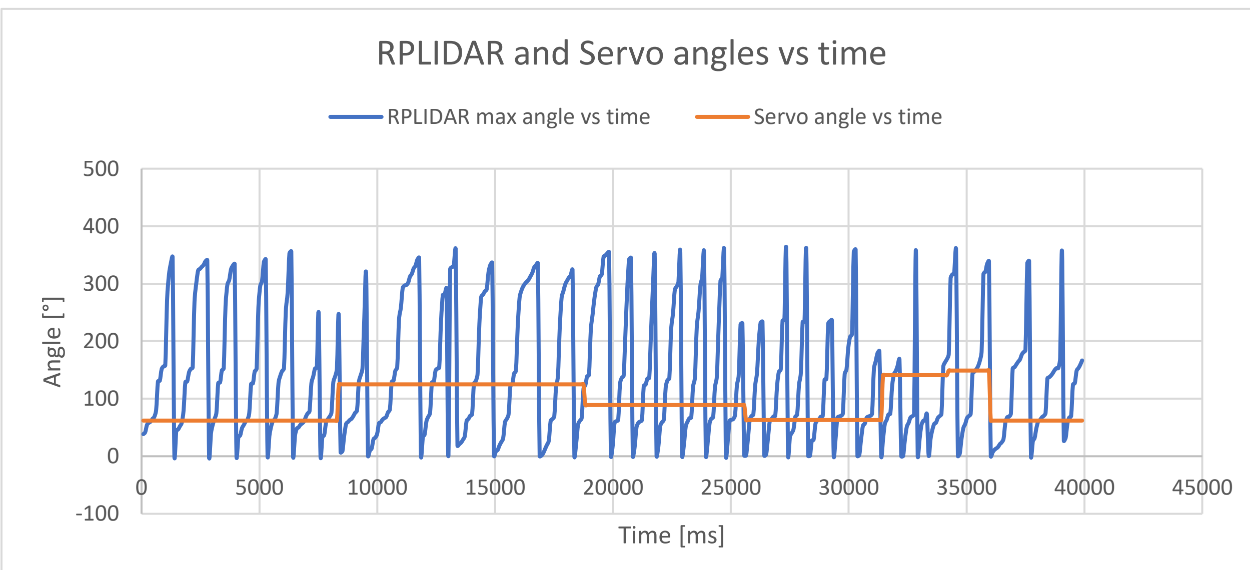

Figure 26 Angles vs time graph for second test

In the second autonomous test, it is also based on test 1 with settings made as servo motor delay of 1000 millisecond and the electric motor delay of 2000ms. we see the first graph that is the maximum distance vs time graph, again the RPLIDAR picks up a few maximum distance of over 2600mm out of the test track from the space where the testing track was set up before entering the test track and also close to exiting the test track. Yet again the servo angle will be considered to understand the maneuvering of the vehicle. This is the test track 1 and it is U-shaped as well, the difference is the delays used in this test. As the car enters the test track, the servo angle is again 62 degrees, this in terms of the servo motor means the front wheels are oriented straight without any turns and the car moves straight into the track. After getting inside the track, the car has to make a right turn, and hence we can see that there is a rise in the angle of the servo motor, to an angle of 125 degrees, this in terms of the servo motor is the right scope and hence the wheels are oriented in the right direction. After taking the turn, the car tries to straighten the wheels, after this action, for most of the time the servo angle is around the 60-degree angle as the car tries to complete the straight path. Then after a while the car takes the final right turn and so does the servo angle rise to 141 degrees which means a right turn. Then the servo angle goes back to around 60-degree angle as the wheels are straighten back yet again. The car completes the test track in 40 seconds.

3.1.3 The Third Autonomous Test

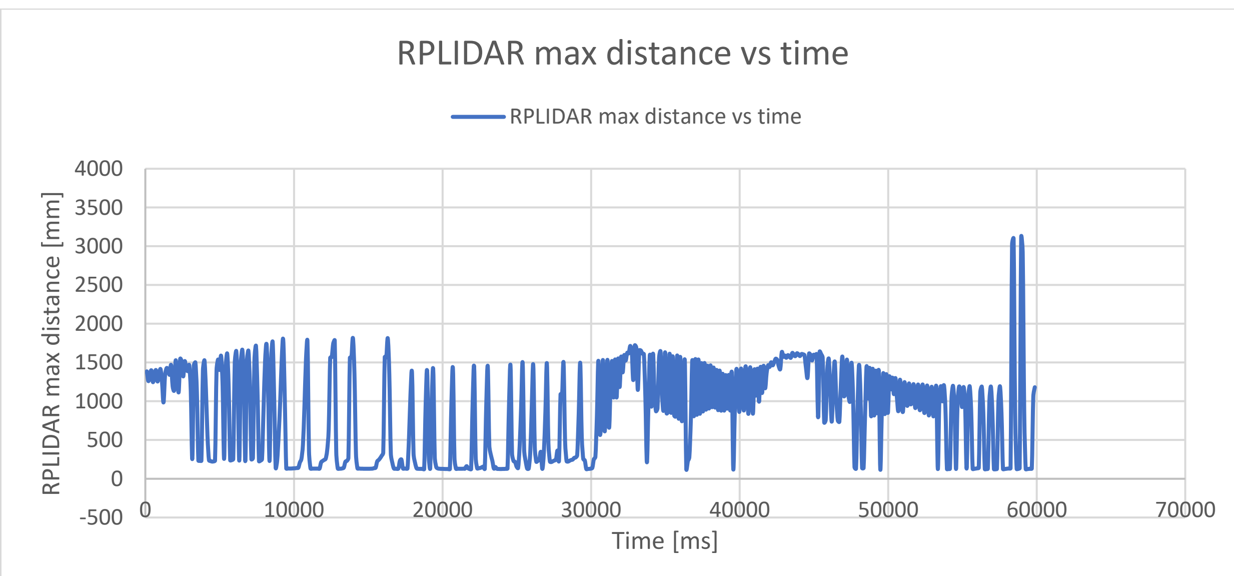

Figure 27 Distance vs time graph for third test

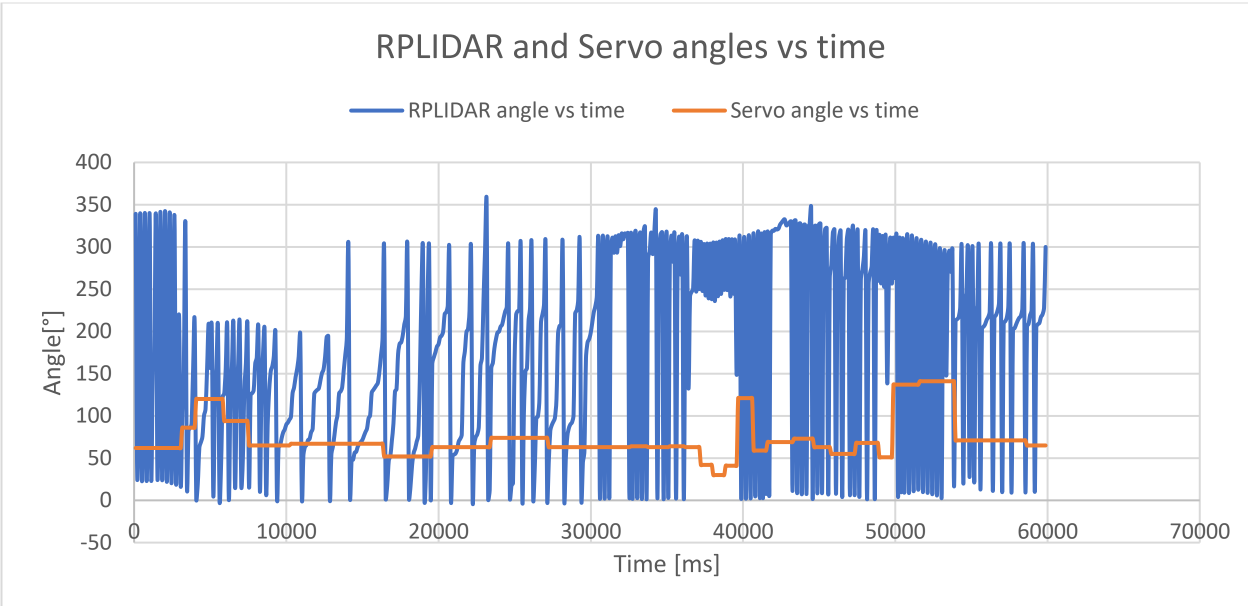

Figure 28 Angles vs time graph for third test

In the third autonomous test, it is also based on test 1 with settings made as servo motor delay of 500 milliseconds and the electric motor delay of 3000ms. In the first graph, there is maximum distance vs time graph. As we can see the servo angle interpretation is the suitable one to know where the car is located on the test track. This is again a test track 1 and it is a U-shaped track, the difference being the delays, of course . The car model enters the test track and has missed a few data earlier as the serial monitor was started a bit later, therefore the car was close enough to the first turn from where the serial data from the serial monitor of Arduino was recorded. Before taking the right turn, the servo angle is around 60 degree, which means the front wheels were oriented straight without any turns. Then immediately there is a rise in the servo angle to about 120 degree, this in the servo scope defines a right turn, the car is starting to take a right turn at this moment, after the right turn has been taken, the wheels realign back to straight and hence for a while the servo angle is around 60 degrees. Here the car seems to take few turns on the right and left before the next right turn arrives due to the positioning of the car but after a few small turns the car realigns itself to take the next big right turn, where the servo angle rises to 141 degrees. After this right turn the car's front wheels are oriented back to straight as the servo angle lowers back to around 60-degree angle. Eventually picking a far-off distance from out of the test track before the reading is stopped. Here since there were a few unnecessary turns the car took, this test track was completed in a 1 minute.

3.1.4 The Fourth Autonomous Test

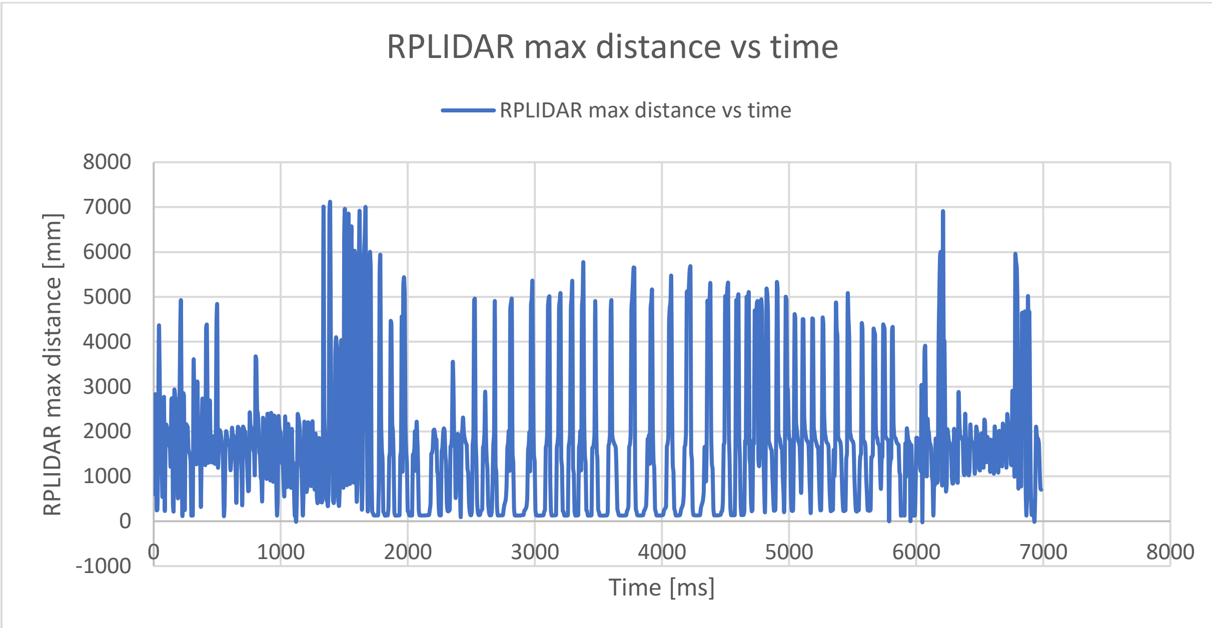

Figure 29 Distance vs time graph for fourth test

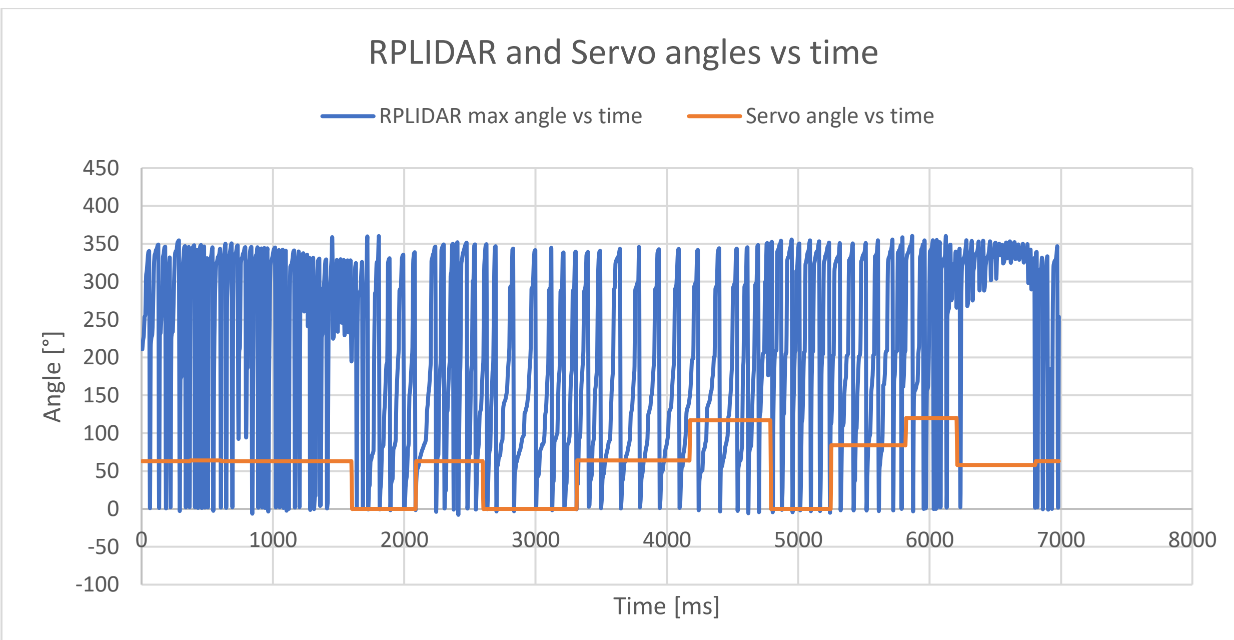

Figure 30 Angles vs time graph for fourth test

In the fourth autonomous test, it is based on test 2 which mean test track 2 with settings made as servo motor delay of 1000 millisecond and the electric motor delay of 1500ms. we see the first graph that is the maximum distance vs time graph, the initial reading and after the one turn is over 2500mm and these readings are from the objects outside the test track, as this track is not so closed, therefore the lidar is able to pick bigger distances which are more than the distances within the test track. Here too as the data is a lot, the data from the servo angle vs time graph will explain better what the car's actions are. This is the track 2 and it is a L-shaped track, the angle as the car is entering the test track is around 60 degree angle which means the front tires are oriented straight without any turns, and as the servo angle drops to 0, it signifies that the car is taking a sharp left turn, as the scope for a left turn in a servo motor is from 0-90 degrees, the offset coefficient can be added but not necessary. So, after the left turn is made, the wheels turn straight. The car seems to take a few left and right turns as seen in the graph and then eventually aligning itself to the course of the track and completing it. The car completes the test track in 76 seconds.

3.1.5 The Fifth Autonomous Test

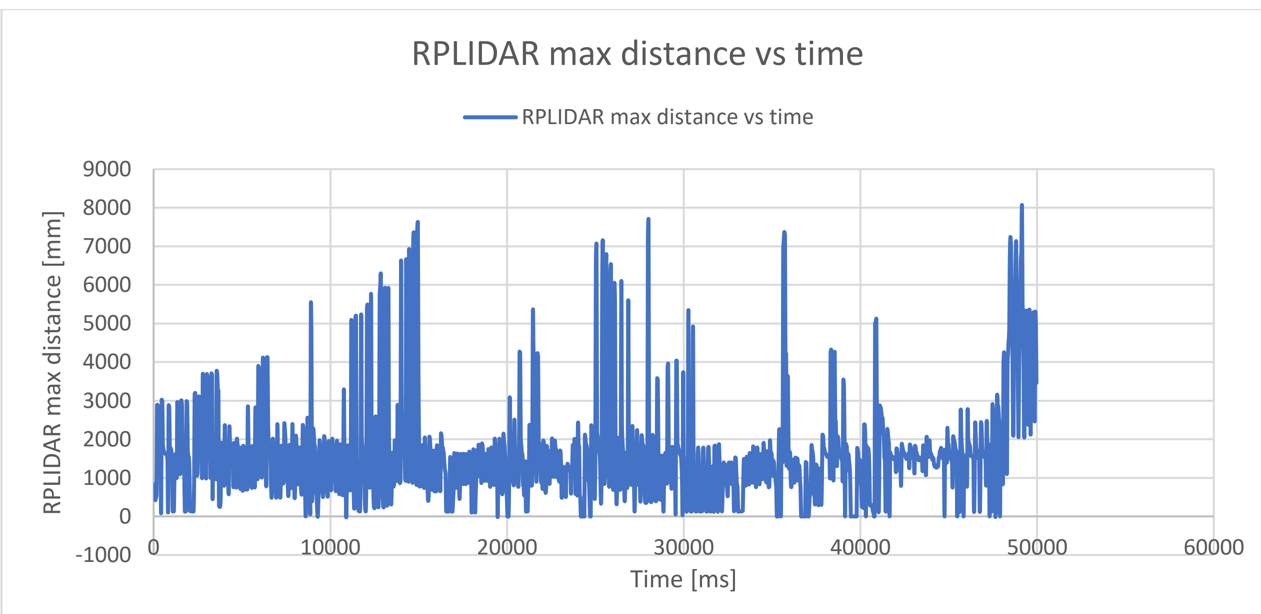

Figure 31 Distance vs time graph for fifth test

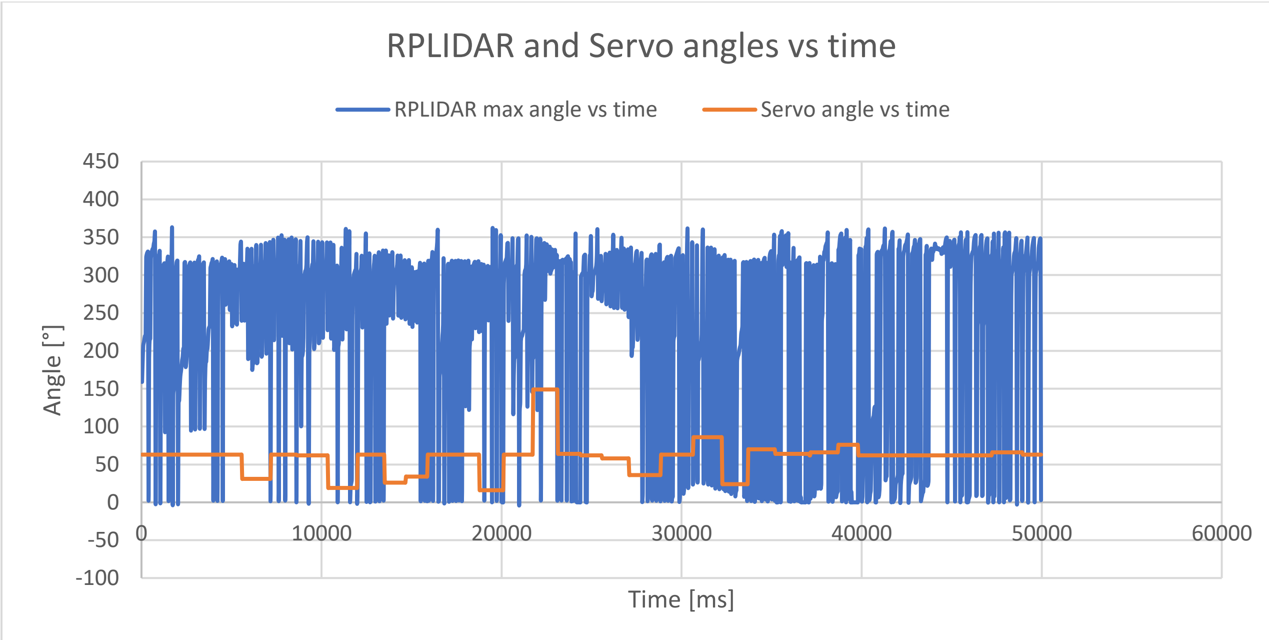

Figure 32 Angles vs time graph for fifth test

In the fifth autonomous test, it is based on test 2 which mean test track 2 with settings made as servo motor delay of 1000 millisecond and the electric motor delay of 2000ms. we see the first graph that is the maximum distance vs time graph, the initial reading and after one turn is over 2500mm and these readings are from the objects outside the test track, as this track is not so closed, therefore the lidar is able to pick a bigger distances which are more than the distances within the test track. Here too as the data is a lot, the data from the servo angle vs time graph will explain better what the car's actions are. This is the track 2 and it is a L-shaped track, the angle as the car is entering the test track is around 60 degree angle which means the front tires are oriented straight without any turns, then there is a small left turn, which makes the servo angle drop to 31 angle. And then the front tires straighten, using these small angled turns the car makes the first left turn. After this, there are a few turns towards left and right, the lidar seems to have caught a maximum distance in these directions. In certain cases, if the lidar is too close to an obstacle, it reverses back and then realigns itself towards the course, at the end of the course of the track the servo angle is around 60 degrees. And the reading from the serial monitor is stopped as the car approaches the end of the track. The car completes the test track in 50 seconds.

3.1.6 The Sixth Autonomous Test

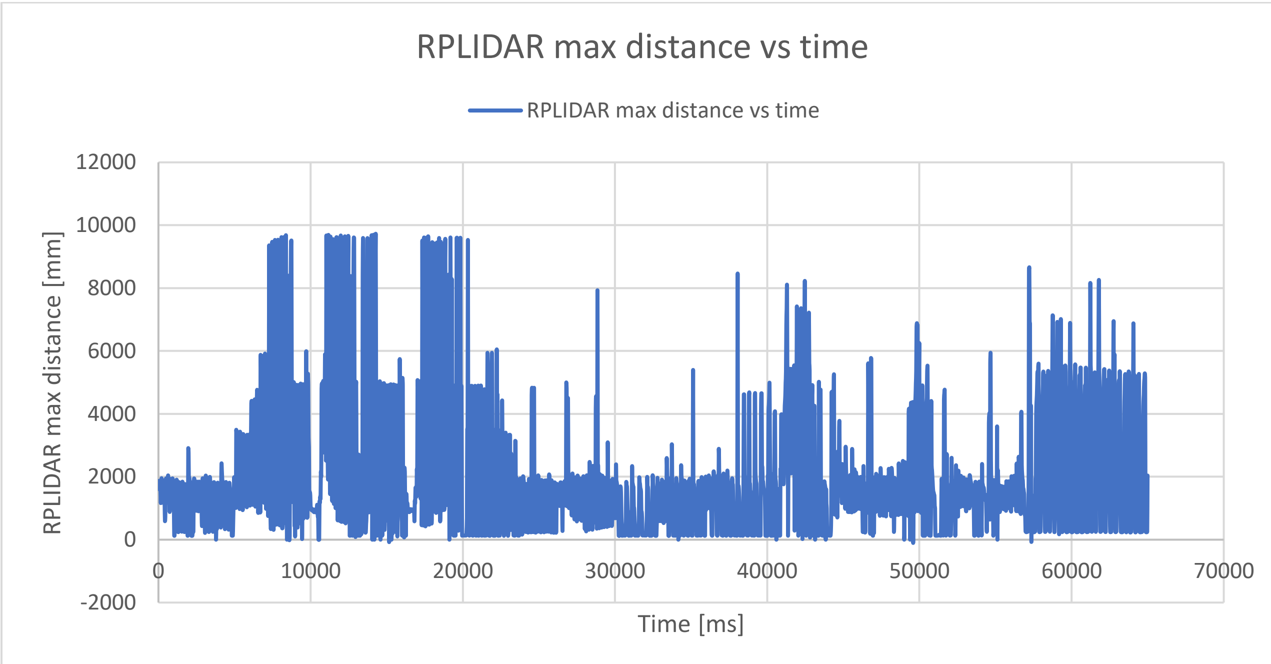

Figure 33 Distance vs time graph for sixth test

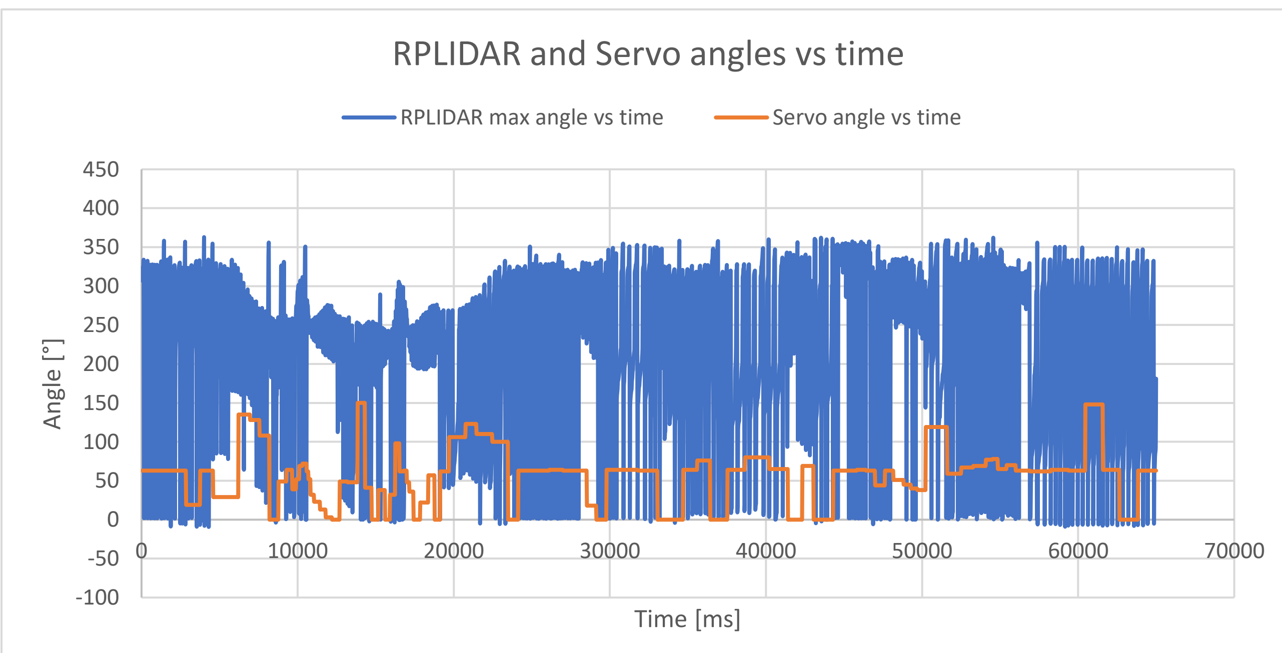

Figure 34 Angles vs time graph for sixth test

In the sixth autonomous test, it is based on test 2 which mean test track 2 with settings made as servo motor delay of 500 millisecond and the electric motor delay of 3000ms. we see the first graph that is the maximum distance vs time graph, a few readings are over 2500mm and this reading is from the objects outside the test track, as this track is not so closed, therefore the lidar is able to pick a bigger distances which are more than the distances within the test track. Here too as the data is a lot, the data from the servo angle vs time graph will explain better what the car's actions are. This is the track 2 and it is a L-shaped track, the servo angle as the car is entering the test track is around 60-degree angle which means the front tires are oriented straight without any turns. Initially it takes a left turn with small angles, hence the angle of the servo being a little more than 15 degrees as it is a scope of the left turn in terms of the servo motor which is from 0-90 degrees. In this test we can see a lot of turns the car is taking, it is having a rough time figuring out to complete the test track as it is taking into account the other unwanted maximum distances, therefore it takes time to realign itself back to the course of the track with a lot of turns and then going backward to realign its self to the course of the track. The car completes the test track in 65 seconds.

3.2 Summary

Here in test track 1, we can note that the second autonomous test was the most optimized and best result, that is the servo motor delay was 1000ms and the electric motor delay was 2000ms. The overall time taken for the car to complete the test track 1 was a remarkable 40 seconds.

And in the test track 2, we can note that the fifth autonomous test was the most optimized and best result, that is the servo motor delay was 1000ms and the electric motor delay was 2000ms. The overall time taken for the car to complete the test track 2 was a remarkable 50 seconds.

We can see in the graphs above how many times the car had to backward and forward due to the car nearing the walls of the test track most of the time. But at the end of the result the car managed to complete its course and exit the test track successfully.

3.3 Limitations

The hanging obstacles above the LIDAR sensor can be a problem and the obstacles lying extremely low out of the LIDAR range on the ground can be a problem as well. If there is a road in front of the car that is cut or is a pit fall then not only the lidar sensor, but other obstacle avoidance sensors too will not be able to detect the cut road and may fall. The local optimal solution to avoid obstacles, the sensor is unable to locate any obstacle if by any chance it happens to be too close to any obstacle. The range of the RPLIDAR A1 M8 which 1cm min and the farthest distance is about 12m or 1200cm. It is a 2d linearly measuring lidar device.

4 Chapter 4

4.1 Conclusion

In this thesis, a lot of electrical knowledge and software knowledge has been implemented. To understand the connections of the LIDAR with the microcontroller, to get the LIDAR running and to get the distances from the objects surrounding it, was the first step to make sure that the device is working perfectly. Then this device was connected to the microcontroller Teensy 3.2, then programming was done to make the LIDAR communicate with the teensy board and eventually display the results in the serial monitor of the Arduino program software. This confirms that there is no problem in getting the data from the LIDAR and the microcontroller. There are other components that are connected in the breadboard, those are servo motor which is responsible in steering the front wheels of the car, then there are is DC geared motor which is responsible for providing the power to the rear wheels of the car to go forward or in backward motion. The next component is the L298n H-bridge which is responsible for controlling the DC geared motor via the Arduino program through the PWM pins. Once all these components are connected to the microcontroller, this entire setup is mounted on a car model when again connections are given. A code is then programmed in the Arduino software to be able to control the car with the input values of the LIDAR distance and angle values as well as by the servo angle of the servo motor. In brief, the LIDAR checks for the maximum distance available and this distance's LIDAR angle is recorded whose range is from [0-359], we have divided the scope in order to give a better command and feasibility for the car to move. The scope between the [90-180) and [180-270) is the backward direction and the scope between the [270-360/0) and [0-90) is the forward scope. So accordingly, the car will be made to go in the backward or forward direction. Then for the turns, the servo angle cannot directly give sharp turn commands, it will be with certain angled turn orientations for smoother turns by the car around the corners. The total scope of the servo motor is from 0-180 degree and the scope from [0-90) is meant for the left oriented turn by the front wheels of the car and the scope from [90-180) is meant for the right oriented turn by the front wheels of the car. Accordingly, the car will receive to make a turn with an angle given by the servo motor. Eventually using the distances and angles of the RPLIDAR and the

Servo motor the car can pave its away around the test track and completes its course. The test track was designed by the boxes available in the lab since the test track had to be tall enough to prove the obstacle avoidance by the lidar, boxes were the perfect object to create the test track with.

The test track was a way to prove experimentally that the car model made with LIDAR mounted on it does the job of obstacle avoidance. It does succeed in this mission; the car was tested with two test tracks and with three conditions of delay for each of the test track thereby collecting six experimental data. The conditions were to change the servo motor delay and the electric motor delay, the combinations used on both the test track were:

1) Delay Servo motor: 1000 milliseconds = 1.5 seconds and delay of the electric motor: 1500ms = 1.5s
2) Delay Servo motor: 1000ms = 1s and delay of the electric motor: 2000ms = 2s
3) Delay Servo motor: 500ms = 0.5s and delay of the electric motor: 3000ms = 3s

During the test as mentioned before, for the test track 1, the second autonomous test was most optimized and the best result as the car took only 40s to complete the course and for the test track 2, the fifth autonomous test was most optimized and the best result as the car took only 50s to complete the course. With this we can prove that the LIDAR does the job of obstacle avoidance.

4.2 Future Work

As highlighted in the limitation section the RPLIDAR is unable to cover up all the scope as it is not a 3D sensor, it is just a 2D sensor which is capable of measuring distances linearly. If the combinations of different sensors could be used, then the autonomous driving could be even more optimized. As the area where the RPLIDAR cannot reach we would need to use an alternate sensor that could help in detecting in these objects in such a situation, for e.g. a radar suits for this purpose to avoid the car crashing into hanging obstacles which the lidar is unable to capture or the extremely low lying objects which are again out of the scope of the RPLIDAR due to which these objects can be crumbled under the car when it runs over them. So, combination of sensors is what perhaps can be a better solution in creating an effecting model of an autonomous driving.

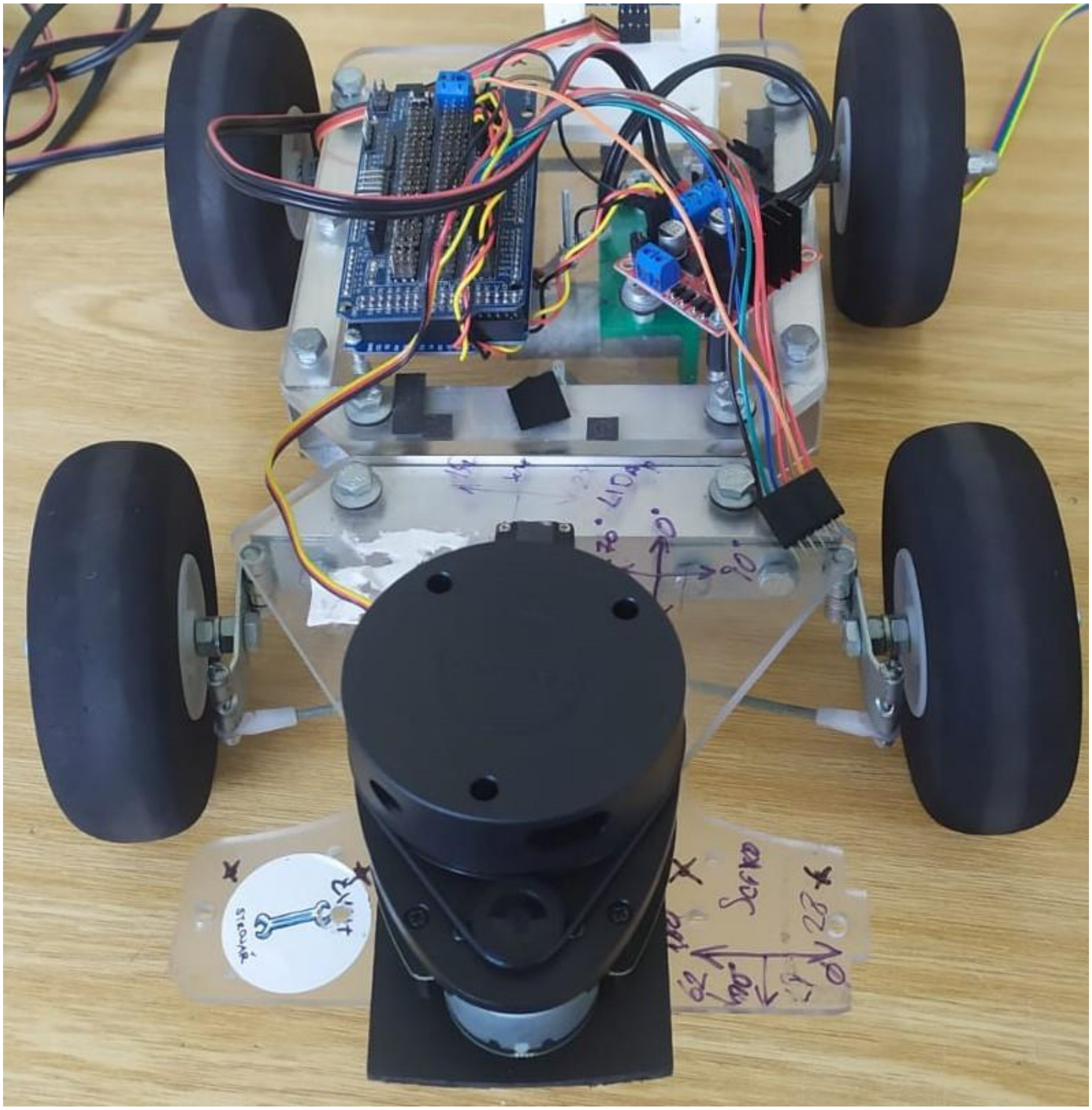

Figure 35 The car model with lidar mounted on it

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