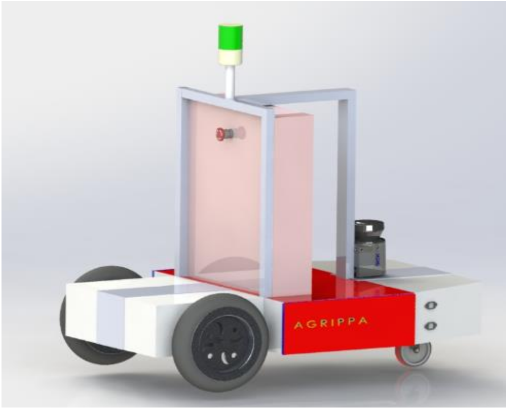
# SRM Institute of Science and Technology,

# Kattankulathur - 603203




## SRM TEAM ODYSSEY

## VEHICLE: MAVERICK

## **PRELIMINARY DESIGN REPORT**

Date submitted: 22 May 2019


| Name | Designation | Domain | Email Id |
|---|---|---|---|
| Rishav Choudhary | Team Leader, Domain Lead | Mechanical | rishavchoudhary_skc@srmuniv.edu.in |
| Anant Shukla | Domain Head | Electronics | anantshukla_arvind@srmuniv.edu.in |
| Arya T R | Member | Mechanical | aryat_bth@srmuniv.edu.in |
| Anand R John | Member | Mechanical | aanandrjohn@gmail.com |
| Aayush Kumar | Member | Mechanical | aayushkumar_rajesh@srmuniv.edu.in |
| Shubham Sampat Dawkhar | Member | Electronics | shubham_sampatdawkhar@srmuniv.edu.in |
| Malavika Prabhuram | Member | Electronics | malavika_prabhujayaraman@srmuniv.edu.in |
| Dikshika Kunwar Asolia Rao | Member | Corporate | dikshikakunwarasoliarao_m@srmuniv.edu.in |
| Mayank Agarwal | Member | Corporate | mayankagarwal_man@srmuniv.edu.in |
| Paritosh Sapre | Member | Electronics | paritoshsapre_himanshu@srmuniv.edu.in |


I hereby certify that the development of vehicle Maverick, as described in this report is equivalent to the work involved in a senior design course. This report has been prepared by the students of Team Odyssey under my guidance.


Barathraj R K
Faculty Advisor
Email id: barathraj.k@ktr.srmuniv.edu.in

# TABLE OF CONTENTS

## 1. Conduct of design process, team identification and team organization

At the start of Maverick's design process, the Robotics Team made a few key assumptions. It is assumed that the course terrain would be relatively smooth with slight elevation changes. The Team equipped Maverick to operate in light rain and other mild weather conditions. Lastly, the Team assumed that the 2018 rules would be like the new ones so that it could start the design process early.

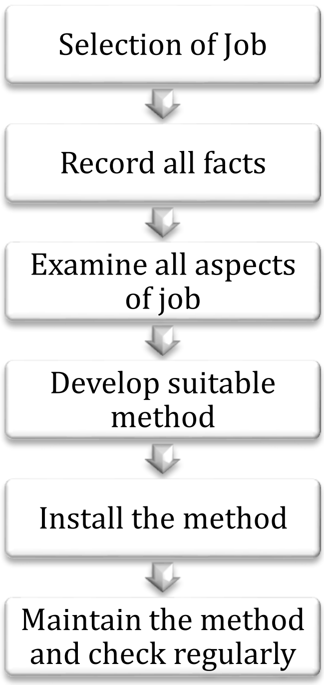



**Figure 1: Design Cycle**

Since Team Odyssey is competing in IGVC 2019 for the first time, a literature survey of design reports of various teams competing over the past few years was done to get a glimpse of the designing methodology, their shortcomings and how they overcame it.

The design problems involved a combination of three areas, mechanical, electrical and software design. To tackle this multi-disciplinary endeavour, our design process seeks to implement a work study process whereby which the job is analysed to find the preferred way of completing it and the time required to do so. It comprises of two areas namely, method study and time study. Method study aims to improve the method of doing work by efficient and economic use of available resources. Time study provides a way to measure the standard time required for the completion of a job.

Specific tasks are allocated to the team members and they are asked to keep a record of all facts related to their task. All aspects of the task are examined critically by brainstorming with other members. A suitable plan is developed by considering the constraints of the system. It is ensured that the method developed is effective, economic and practical in nature. The plan is implemented and integrated in the overall system. The developed solution is checked regularly to ensure that it is working smoothly with other subsystems and producing the required output.

Team Odyssey seeks to apply this process so that we can achieve maximum output at less cost while ensuring quality, and hence achieve high productivity.

## 2. Design Innovations

Teams competing in IGVC have a long running trend of designing large and complex vehicles. Maverick's platform offers a compact and efficiently integrated design capable of performing tasks on par with the previous year's bulky systems.

Notable features include:

- Modular system packages that can be attached directly to the frame.
- Backwards-compatibility from older sensors
- The sensor mast is removable to simply transport alongside the vehicle.
- Quick disassembly for compact storage and easy travel/carrying.
- Use of hinges and L shaped angle brackets which facilitates the flexibility to modify the vehicle according to the future requirements.

## 3. Technical Proposal

### 3.1 Vehicle Layout

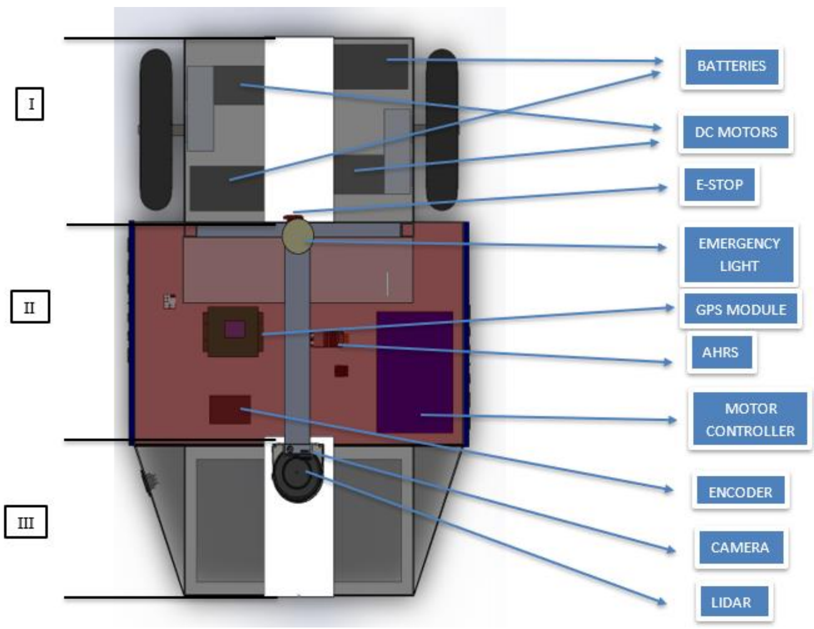



**Figure 2: Maverick Layout**

| | |
|---|---|
| I | Propulsion Compartment |
| II | Central Electronics and Payload Compartment |
| III | Imaging and Charging Compartment |

### 3.2 Mechanical Design

The vehicle has been designed in such a way so as to ensure modularity with efficient use of space and a smooth dismantling/assembly process. The vehicle is made of three parts namely, the base, the electronics compartment attached with a cabin to hold the payload and the mast. The outer dimensions of the vehicle have been selected to be a little over the minimum size requirements. This is done to ensure that the vehicle is able to navigate through the course with maximum manoeuvrability.

To facilitate mechanical motion, the vehicle utilises a three-wheel configuration with two tyres at the rear of the vehicle connected to two DC motors and a spring loaded caster wheel in the front for turning.
Separate compartments have been designated to enclose the electronic components and contain the payload. The mast is on the centre rear of vehicle to ensure minimum vibration. The Aluminium frame provides high strength for holding the Omni-directional camera at a height to have a wide visual range in order to manoeuvre the track.

### 3.3 Material

The vehicle’s body is made of Aluminium frame composed of L and square channel along with polycarbonate sheets to enclose the electronics compartment with PVC covering the top. Two tyres of diameter 10.5” with cross tread design pattern are used as the rear wheels to manoeuvre easily on different types of terrain and are powered by Ampflow DC motors. The front wheel of the vehicle is a spring loaded caster wheel which is in cantilevered configuration to give extra damping and stability to vehicle on turns and uneven path.

### 3.4 Structural Design

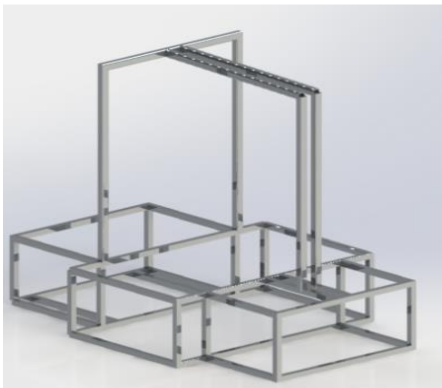


**Figure 3: Structural Frame**

The driver chassis and frame structure of the vehicle is composed primarily of aluminium and is shown in figure. The central compartment houses the steering and the LiDAR. The middle compartment packs most of the electrical hardware including the AC/DC converter and vehicle controller module (including motor driver, both E stop and wireless E stop). Payload storage area is stacked over this cabinet. The rear compartment contains the DC motor, speed reducers, battery and an area to place a mini laptop. The front compartment provides additional space and a base for the suspension system.

To prevent the vehicle from tipping over while navigating through the course, the payload storage space is arranged laterally (perpendicular to the travel direction of our vehicle) instead of placing it longitudinally.

### 3.5 Suspension

The Auto-Nav course is laid out in a grass ground with a relatively smooth surface. For smooth turning, a spring loaded caster is placed in the front of the vehicle. When the vehicle moves across the course, the deformation of spring allow the vehicle to move up and down slightly instead of experiencing a jolting motion. This allows the payload to stay secure in its cabin.

### 3.6 Weather Proofing

Maverick has many features that lend well to its ability to function in different weather conditions. Among these features are the following: white paint with a clear gloss finish; edges are sealed with the silicon sealant; an internal, static pressure fan; and weather stripping. The white PVC sheets and clear gloss finish allow Maverick to operate in hot and sunny environments because these features reflect solar radiation, keeping the internal temperature of the body at acceptable levels. In rain, the oil paint coat allows water to roll off the robot to the ground. This aspect and the positive pressure fan, which blows air around the seams in the weather stripping, allow the vehicle to operate in rain. The combination of these features allows Maverick to work in large variety of weather conditions.

## 4. Power Systems

### 4.1 Power Distribution System

The circuit distributes power from the 6S 22.2V 12000mAh 10C lithium polymer battery to different subsections/branches by using a system of power distribution buses and voltage regulators/converters. The battery is connected to one central power distribution bus that transports its power to the other subsections. One subsystem uses a 5-volt step-down regulator, which distributes its power through a smaller power distribution bus, and distributes the power to the 5V circuit and the mechanical emergency stop circuit. Another subsystem uses a 12-volt step down regulator to distribute power through another small distribution bus and powers the router and the indication light. Finally, the motor controller and the Odroid XU4 and other microcontrollers and communication systems are wired directly to the main power bus.

To improve the stability and reduce noise we have outfitted the circuit with step-down regulators that maintain a constant current and voltage. The 12-volt regulator is chosen due to the fact that a more powerful router is needed to manage all of the extra traffic and communication between the devices.

### 4.2 Battery Life

The total power consumption is calculated to be roughly equal to 700 Watts. Using the specifications of our battery (6S 22.2V 12000mAh 10C), estimations of the battery life for different scenarios have been computed. Assuming that all systems are running simultaneously at their maximum capacity, the run time of the vehicle is estimated to be at around 10 minutes. However, if the vehicle is to stay on Standby, then the battery life would extend to approximately 1.08 hours.

### 4.3 Radio Controlled Mode

Following competition guidelines, the vehicle is equipped with a radio controlled mode allowing the user to fully control the movements of the vehicle. The components included in this module are: RC Controller, RC Receiver, Pololu RC switches, Odroid, Eaglebone, Arduino UNO and the motor controller.

The implementation of the RC mode consists of three main steps: reading the signals from the receiver, sending the signals to motion planning, and executing commands. The receiver is the 2.4GHzmodule. The receiver has 4 analog channels and 4 digital channels. The analog channels are controlled by the left and right knobs on the controller while the digital channels have been mapped to the four back switches on the controller. The multiplexing of the 8 channels is achieved using Pulse Position Modulation. However, each channel has an individual PWM wave with a duty cycle that ranges from 5% to 10%. The controller is configured to facilitate two analog channels for driving and steering. The horizontal motion of the right knob is used to indicate the direction to turn and the vertical left knob is used as the throttle

Two of the digital channels are enabled to indicate the change in modes between autonomous and radio controlled, and the triggering of the emergency stop. To process the radio signals coming from the receiver, two devices that entail different methods are used: An Arduino UNO and a Pololu RC switch. The Arduino uses two pins to read the PWM signals coming from the receiver. The PWM libraries on the Arduino Uno IDE are used to interpret the signals. The Arduino Uno is connected to the Raspberry Pi by a USB Type B cable to establish serial communication.

Two Pololu RC switches are used to obtain a Boolean signal from the channels on the receiver. These devices transform a radio signal into a Boolean HIGH or LOW signal. The voltage level for HIGH can be adjusted, yet the value used is 5 Volts for HIGH. The output of these switches goes to the GPIO pins on the Raspberry Pi for motion planning. The Pi is connected to the motor controller by USB. The Roboclaw is equipped with a firmware capable of receiving and executing USB commands that come from the Eaglebonein order to move the motors in the desired direction and with a controlled speed.

### 4.4 Emergency Stop

Due to competition guidelines, the vehicle is equipped with an emergency stop mechanism that is independent from software. A two level emergency stop mechanism is designed to meet competition guidelines and ensure effectiveness and safety. The first layer is the software soft stop; the second layer consists of a logic circuit and a relay to cut the power to the motors.

### 4.5 Soft Stop

The first layer of the emergency stop is a “Soft stop” conducted by the Eaglebone. When the emergency stop switch has been triggered by the RC controller, the receiver sends an RC signal to the RC switches that is later transformed into a readable Boolean signal by the Eaglebone. When the Eaglebone detects a HIGH coming into its GPIO pin, it immediately sends "STOP commands" via USB to the motor controller. The motor controller then receives these "STOP commands" and ceases to send current to the motors. This stop mechanism is designed to inform the motion planning that an emergency stop has been called to reduce the power entering the motor controller when the crowbarring of the power occurs.

### 4.6 Hard Stop

The second layer of the emergency stop is the crowbarring of the power going into the motors. This ensures that no current will flow to the motors when the mechanism is triggered; thus bringing the vehicle to a stop. It is important to note that this mechanism is independent from the first layer where the "soft stop" occurs and contains no software interfaces or sequences.

The main component in the emergency stop is the D1D1000 solid-state relay. The input loop of this relay is controlled by a digital circuit with the output loop going directly to the motors.

The circuit shown on top consists of the following logic components: an inverter gate, and or gate, a 555 monostable multivibrator, and a positively triggered D-type flip 10 flop. The circuit receives a level signal coming from either the mechanical E stop button or the RC switch. These level signals are passed through an OR gate and the output goes to a Resistor-Capacitor circuit that creates a short pulse from the level signals. This short pulse is enough to trigger the monostable multivibrator. This device creates a delay that will allow the Eaglebone to perform the "soft stop". The delay is also a short square pulse that serves as a trigger to the clock of the D-type flip flop. Once the flip-flop is triggered, it will send a 5V output through its Q pin. This output is used to control an IRLZ34 MOSFET that is being used as a switch. In the presence of a HIGH output, the MOSFET will become saturated, hence behaving as a shot circuit that will ground the input loop of the relay, enabling current to flow through the output loop that feeds the motor controller.

In the absence of an output from the flip-flop, the MOSFET will remain on cut-off mode, hence behaving as an open circuit blocking the path of current in the input loop of the relay and consequently its output to the motor controller. This way the digital circuit is able to decide whether or not the relay will enable current to the motors.

After the emergency system has been triggered upon runtime, and the flip-flop has been activated, the system needs to be brought back up to a known state. To do that the flip-flop has to be reset so that it looks for a trigger again. This is accomplished by a reset button attached to the reset pin on the flip-flop. This reset button is a normally closed button that sends a constant 5V signal to the reset pin in order to ensure proper operation. To reset the flip flop, the reset pin has to be brought low, and then back high again where it will stay that way until it is triggered again and a new reset of the flip flop is required

### 4.7 Obstacle Detection and Avoidance

LIDAR is used to detect obstacles. A threshold distance is set and when the vehicle is closer than the threshold distance, command is given to avoid the obstacle. Exact angle of turn is calculated and a command in terms of vector is given to the motors to turn in a certain direction. A combination of lane and obstacle's position information is required for obstacle avoidance to make sure that the vehicle stays within the lanes while avoiding the obstacles. To avoid obstacles, the position of the lane and the obstacle is noted and then the possible path with maximum gap is followed. For example, in the case where an obstacle is placed in the middle of the lane, the algorithm would measure the pixel distance between lane and obstacle and either side and will choose the larger distance.

## 5. Control Systems

### 5.1 Mathematical Modelling of the Bot

The mathematical modelling of the bot is done to know the dynamics of the bot. Every bot moving in physical environment can be described using equations.

**Resultant Force = Applied Force – Drag Forces**

Here, the resultant force at any point can be determined by the above formula. The drag forces are determined by simulations and tuned to perfection by real life physical testing.

The above equation will help us give the utmost perfect control of the bot. The applied force will be given using the propulsion system which is the motors. The resultant forces are the forces which we need to be applied on the bot.

### 5.2 Model Predictive Control

Model predictive control is used to determine the future state of the bot. By determining the future state of the bot, we can choose the best path to make the bot manoeuvre around a track. The path can be linearized and each segment can be treated as small paths.

By applying the equations of motion,

$$v = u + at$$

$$v^2 = u^2 + 2as$$

$$s = ut + \tfrac{1}{2} at^2$$

We can predict the force values of the bot at the each and every path along the predicted path. This method checks the viability of the multiple paths.

### 5.3 A* algorithm

The following diagram can show how the best path from the start to the end can be determined:

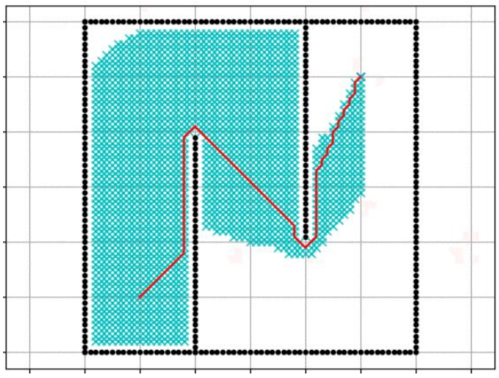


**Figure 4: Optimum path using A* algorithm**

The above is the best path planning algorithm go get from point A to point B. In this the grid starts filling towards the destination and as soon as the destination is found a path is drawn.

### 5.4 Localization

The bot uses multiple input sensor feedback. The following sensors are used for localization:

- Wheel Encoder
- Inertial Measurement Unit
- GPS-RTK
- Lidar

The above sensor using an Unscented Kalman Filter can be used to determine the exact location for the bot in the space around.

### 5.5 SLAM

The Lidar is used to create a map of the surrounding by using the point cloud. The point cloud of the LIDAR is used to determine the probability of an object being present in the open space. As the object is found to be present after multiple scans the probability of that object being there goes above a certain value and thus is established that the given point on the map are occupied. As the object is not found in the subsequent scans, the probability of the object being there decays and thus the object disappears from the map.

This is a graph based SLAM example.

The blue line is ground truth.

The black line is dead reckoning.

The red line is the estimated trajectory with Graph based SLAM.

The black stars are landmarks for graph edge generation.

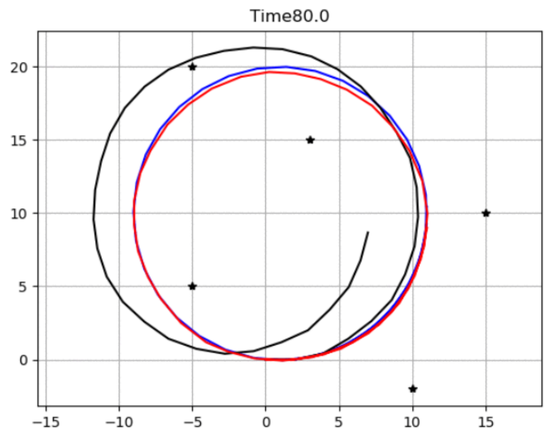



**Figure 5: Mapping the environment using SLAM**

### 5.6 Lane Detection

The lane detection algorithm consists of the following steps:

1. The first step to working with the images is to convert them to grayscale. This is a critical step to using the Canny Edge Detector inside of OpenCV. We collapse 3 channels of pixel value (Red, Green, and Blue) into a single channel.
2. For the detection of our lane lines, which are either yellow or white. Yellow can be a tricky colour to isolate in RGB space, so we convert it to Hue Value Saturation or HSV colour space.
3. Next, apply a mask to the original RGB image to return the pixels we're interested in.
4. We then apply a Gaussian blur. This filter will help to suppress noise in our Canny Edge Detection by averaging out the pixel values in a neighbourhood.
5. Then we use Canny Edge Detection. Canny parses the pixel values according to their directional derivative. What are left over are the edges—or where there is a steep derivative in at least one direction. We will need to supply thresholds for Canny as it computes the gradient.
6. Now, in order to filter the images from distractions, we create another mask called our region of interest (ROI). Everything outside of the ROI will be set to black/zero, so we are only working with the relevant edges.

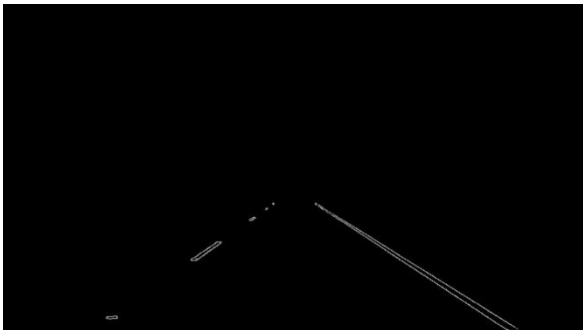


**Figure 6: The ROI for lane detection**

7. We use Hough Transform next to create the final mask. The image contains zero-pixel data from any of the photos we processed to create it. It is strictly black/zeros and the drawn lines. Also, what looks like simply two lines can actually be a multitude. In Hough space, there could have been many, many points of intersection that represented lines in XY. We will want to combine all of these lines into two master averages.

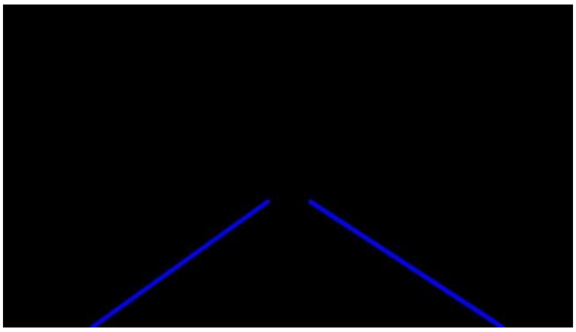


**Figure 7: Lines from Hough transform**

## 6. Failure Point and Resolution

| Failure Modes | Mitigation |
|---|---|
| ESC's may overheat while working or due to excess load | ESC's with a higher rating were chosen to prevent this. Moreover, the control system of the vehicle has a pre-arm only after which the ESC's and Motors will be powered |
| Connection Break between ground station and the bot | The vehicle will stop instantly and resume operations after regaining connection. |
| Vehicle makes unexpected behavior and moves in unexpected manner | The E-Stop helps in stopping the vehicle instantly in case of such situations. The Ground Control Station will also be equipped with a disarm switch. |
| Motor driver malfunction | Replace the motor driver with the spare one |
| Sensor crashes or not working as required | Reboot the component causing the issues. In case that does not solve the problem we recalibrate using the software and if required replace the sensor. We have replacement sensors for GPS, IMU, Lidar and encoders. |
| Control System behaves unexpectedly | If the tuned PID fails, the PID can be re-tuned easily by changing the parameters file. |
| The fasteners may loosen during repeated use | All the fasters are reinforced with a thread locking fluid which makes these fasteners extremely unlikely to open. |
| Wheel Alignment has issues | Two bolts joint are used to maintain the required camber angle |
| Decrement in the spring force of the front wheel | Spare spring loaded wheel is available to cope this. |

## 7. Performance Testing

- Max torque without skidding: 31.77 Nm
- Max Acceleration: 1.962 m/s2
- Average driving force on the bot: 230 N
- Average Motor torque: 25.3 Nm
- Average speed: 1.11m/s or 4 km/hr
- Ramp climbing ability at 30 degrees 1.14 m/s2
- We have made sure that all the mounts of the bot withstand rocky terrain with no loosening.
- The motors are able to meet the minimum speed and incline requirements specified in the rules
- Endurance: We tested our system by running it for 60 minutes on the obstacle course and by the end of it; the entire system was performing as it should have.
- Software Stack: All algorithms were tested for various situations and we have incorporated failsafe mechanisms. Algorithms are: Lane Detection and Mapping, Localization, Lane Driving, Waypoint Navigation and Path Planner.
- Manoeuvres for recovery have been tested in situations: very close to obstacles, very close to lanes and end of path.

- With our current GPS module, we have localization accuracy, between 0.1m to 0.5m.
- Object detection range is close to the maximum range of the RP LIDAR A2M8 which is about 15m.