Intelligent Ground Vehicle Competition 2019
Design Report

Centaur

Delhi Technological University

May 15th 2019

Faculty Advisor Statement: I hereby certify that the development of vehicle, described in this report has been equivalent to the work involved in a senior design course. This report has been prepared by the students of Team Centaur under my guidance.

InduAshok

Dr. S. Indu
Department of Electronics and Communications Engineering, DTU

1. Team Member Details

Team Member	**Email Address**
Apoorv Goel (Captain)	apoorvgoel_bt2K16@dtu.ac.in
Robin K. Singh	robinvishen@gmail.com
Sudhanshu Shekhar Singh	singhsudhanshu204@gmail.com
Arindaam Roy	alpharoy14@gmail.com
Mukesh Yadav	mukesh7541@gmail.com
Sahil Jain	314sahil@gmail.com
Khwaish Kumar Anjum	kka011098@gmail.com
Manish Bhatia	manish4291@gmail.com
Sahil	sahil5051.ss@gmail.con
Parth Dharmarha	pddharmarha@gmail.com
Yashodhan Srivastava	yashodhansrivastava9@gmail.com
Samvandha Dev Pathak	psamvandha@gmail.com
Kshitij Rastogi	kshitij2301rastogi@gmail.com
Yatharth Ahuja	yatharthahuja1999@gmail.com
Nishant Kumar	kn1990kn@gmail.com
Jalan Ishu Kamal	ishujalan123@gmail.com

2. Conduct of Design Process

Introduction

Establishing a design process is one of the most important prerequisites to a project, especially a complex multi-disciplinary project. Therefore, we invested a lot of time to build an effective process. The resulting process is mentioned in the section below.

Organisation

The design process has been organised into iterations where each iteration is more complex and improved than the previous one. An iteration consists of the following phases:

- Conceive - This phase involves formulating the problem to be solved in the iteration, chalking up the requirements and constraints, and building a timeline of events with expected hurdles.
- Design - This phase attempts to solve the formulated problem and is tested in simulation to boost confidence in the solution. If the simulation does not inspire confidence in the solution, we try to another solution or try to find better formulations of the problem.
- Realise - Integrate the solution with the rest of the vehicle after unit/component testing.
- Analyse - Study the failures of the attempt and note down the improvements to be made in the next iteration.

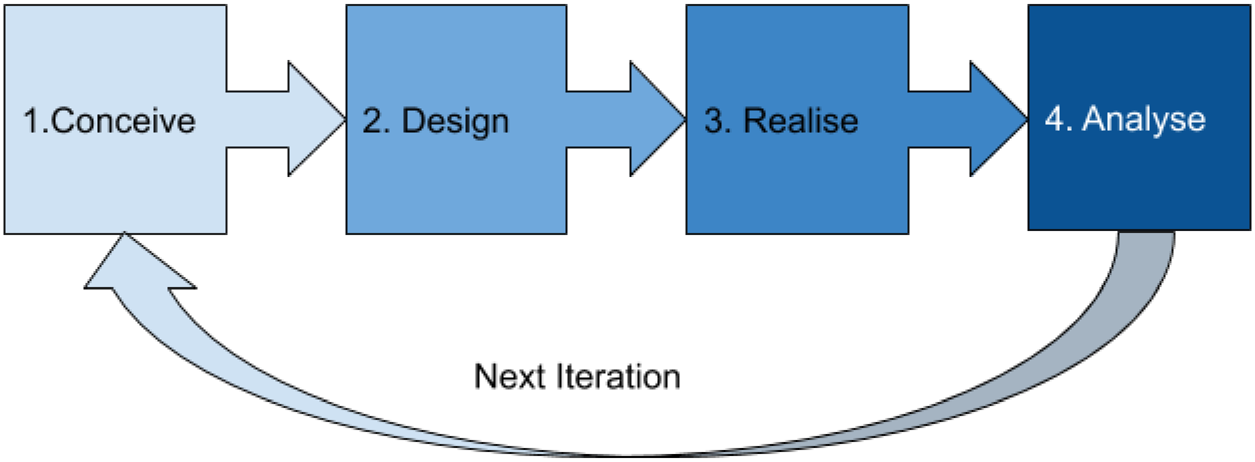


Figure: Flowchart Showing Design Process

3. Innovations

- Bio-inspired contrast enhancement by reducing the number of green shades.
- Parallelising the image processing algorithms on the GPU for increased speed.
- Use of Real-time Kinematic GPS to reduce cost without sacrificing accuracy
- The distance between front wheels and castor can be customized to provide different radii of turn.

4. Description of Mechanical Design

Overview

The body of the vehicle is built such that it portable and easy to transport to the competition venue, it is modular and efficiently manages space while minimizing the adverse heating effect on electronic components.

Frame Description

The vehicle is designed to be teardrop shaped in accordance with aerodynamic analysis to reduce the amount of power required to drive the vehicle.

The chassis uses Aluminium T-slot extruded profiles which are made of 6105-T5 aluminium alloy. They have high strength to weight ratio and slots present on them enables to fasten bolts without drilling the holes. Aluminium Angles (1.5X1) are used for fabricating the welded compartments due to their exceptional strength ease of weld.

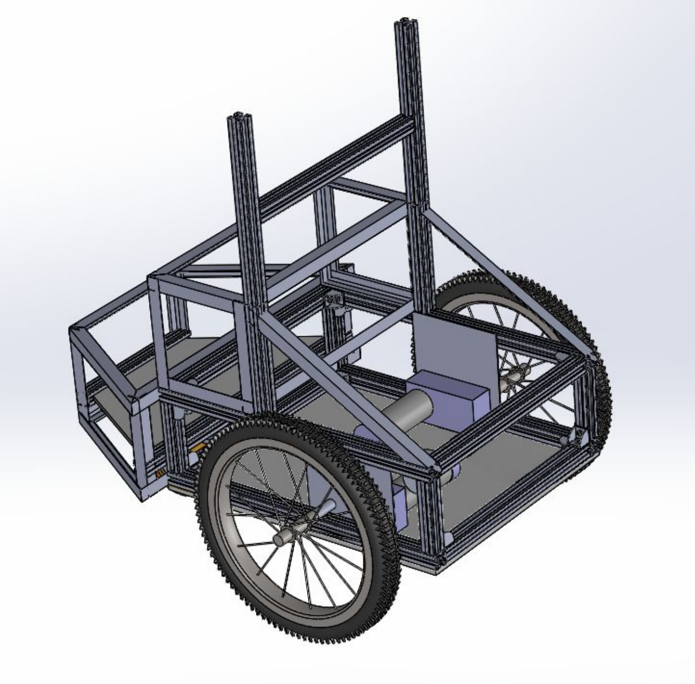


Figure: Solidworks render of the frame

Bakelite sheets are used for covering the outer body. It retains its shape and is resistant to heat, scratches, and destructive solvents. It is also resistant to electricity, and prized for its low heat conductivity. Delrin sheet is used as a base for motors and the sliding base in the electronics drawer. It has excellent machinability, high strength and good stiffness properties. It is the material of choice because of its low coefficient of friction and due to resilient surface. Transparent acrylic sheets are used in the electronic bay for covering. It allows for the controller to see through it for any glitches. Silicon-Germanic rubber is used beneath the motors for increasing friction between base and motors that absorbs the vibrations of the motors.

Mounting platform for LiDAR is fitted with extra rubber sheet to stabilize it while in motion which works as a suspension for it. The castor used has a separate suspension to provide stability to laptop.

Suspension

A dedicated suspension system is not added in Centaur as it was determined that the increase in cost and weight of the design outweighed the foreseeable advantages that would be gained for the slow speed of travel.

The two main drive tires are made of a tough, but impact absorbent rubber polymer. These along with the PU caster wheel which offers the elasticity of rubber wheels combined with the toughness and durability of metal wheels act as the vehicle’s suspension.

The LiDAR platform deals with vibrations of low amplitude and can be dealt with by employing rubber paddings in critical areas. Rubber washers are utilized to dampen vibrations on the mast, platform and the caster wheel.

The camera is mounted to a rugged and sturdy mast to minimize movement and vibrations from the vehicle while it is in motion. Camera software is also designed to filter out vibrations and account for vehicle movement over rough terrain.

Weather Proofing

The vehicle utilizes tight fitted silicone gaskets around all acrylic exterior and access panels. These gaskets ensure that the electronics are not be exposed to seepage into the electronics bay. The GPS antenna has an enclosure rating of IP69 while the LiDAR enclosure is rated IP67.

The laptop is placed inside a fabricated case so as to protect it in case of light rain
The wires for the electronics placed outside of the vehicle such as the camera, GPS antenna, and the emergency stop run through covers to prevent rain from entering the vehicle.

5. Description of Electronic and Power design

Electronics Suite Description

The choice of components used has been as per our technical demand, budget and reliability. Each of the component of electronics suite is described in the following table

S.No.	**Component**	**Specification**
1.	Motor	1. AMPFLOW FAN COOLED 24V A28-400-F24-G 2. 700W and 100 RPM
2.	Motor Driver	1. Dual main channels 160 Amps each 2. Current limiting on both main channels 3. Robust signal processing for smooth, reliable fail-safe operation.

3.	LiPo Battery	1. Voltage output: 22.2 V 2. Power output: 16000 mAh
4.	GPS	1. Accuracy of less than 10cm (can go as precise as 10mm if correctly configured) 2. Voltage: 5V or 3.3V but all logic is 3.3V 3. Receives both L1C/A and L2C bands
5.	LIDAR	detectable range is 20 mm to 4000 mm
6.	Camera	1. Large Screen Wide Angle 2. Ultra HD and Waterproof 3. 14 MP

The components used in the robot have been interfaced in the way as shown in the diagram:

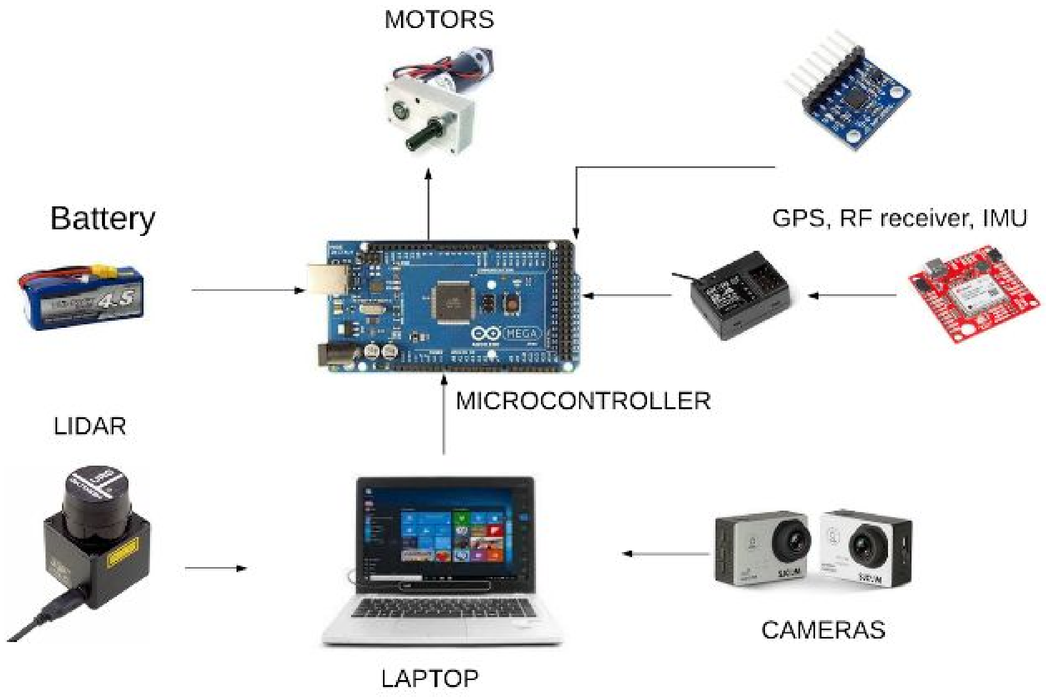


Figure: Electronics Connections

Power Distribution

The main power source for the vehicle is a **22.2 V**, **16000mAh** Lithium-Polymer Battery. It can give great instantaneous discharge current upto **400A**. It weighs just **2120 grams** and is smaller in size compared to alternatives such as NiCd, Ni-MH and Lead acid batteries.

Table : Power requirement of the electrical components

Electrical component	**Max power consumption**	**Operating voltage**	**Source**
GPS Sparkfun GPS-RTK2 module	297mW	3.3V	Li-Po Battery
CAMERA SJCAM SJ5000 WIFI Action Ultra HD Waterproof Underwater Large Screen Wide Angle Sports DV Camcorder, 14MP	10W	10V DC	Li-Po Battery
LIDAR Hokuyo's URG-04LX detectable range is 20 mm to 4000 mm	2.5W	5V	Laptop (via USB)
MOTORS AMPFLOW FAN COOLED 24V A28-400-F24-G	700W	24V	Li-Po Battery
Microcontroller Arduino Mega	0.1W	5V	Laptop (via USB)
Cooling fan(x2) MAA-KU DC12025 4.72” inches 2400rpm (Specs provided per unit)	3.36	12V	Dedicated battery

The run-time is calculated by taking the battery's capacity in amp hours, then divide that into the average amp draw by the vehicle and then multiply it by 60. The total run-time is in minutes.

The final runtime is found to be 32 minutes. However, this value is calculated in full load condition. Thus, Centaur's runtime is around an hour under practical circumstances

6. Software Specification

Overview

The on-board navigation stack is designed as a pipeline comprising of the following four phases:

- Perception: Involves gathering data from the sensors and processing it to extract useful information about the vehicle and its environment.
- Mapping: Constructs a map of the surroundings from the information extracted in the previous phase and places the vehicle in the constructed map.
- Path Planning: Finds the optimal path from the current position to a specified goal avoiding obstacles, lanes and potholes.
- Control: Generates throttle and steering commands to maintain the trajectory from the previous phase

There is little dependency between each of the phases and have been developed fairly independently from each other for strong modularity. Perception phase is mostly built using OpenCV with highly parallelised code running on the GPU using OpenCL. Remaining phases (and parts of the perception phase) are implemented on the ROS platform. ROS is selected as the development platform for the vehicle for two primary reasons. The first of which is the availability of a large number of production-ready modules, which distinguishes it from other platforms. Secondly, ROS implements complex IPC efficiently using Berkeley sockets. This is important as efficient communication between modules enables the navigation stack to achieve real-time performance.

The entire architecture is summarised by the following data flow diagram:

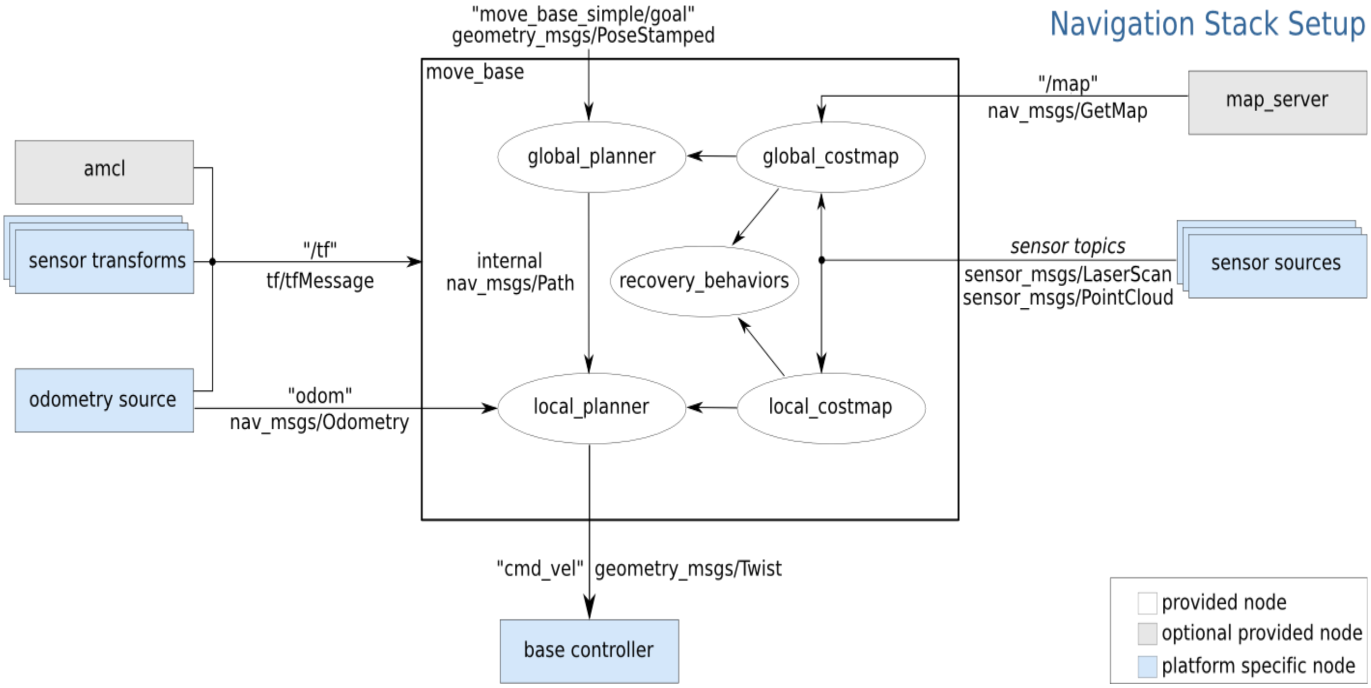


Figure: ROS Navigation stack setup for Centaur

Obstacle Detection And Avoidance

2D Hokuyo LIDAR is used for detecting obstacles. The LIDAR readings are interpreted as point clouds and processed for noise removal. This point cloud is then thresholded by a specified distance, and all points lying at a greater distance are left out. Remaining points are considered as obstacles.

Lanes and potholes are also treated in the same way as obstacles, as a point cloud. The wide FOV camera is used to capture a large part of the environment and image processing pipeline extracts the lane from the image. The image processing steps are shown in the image.

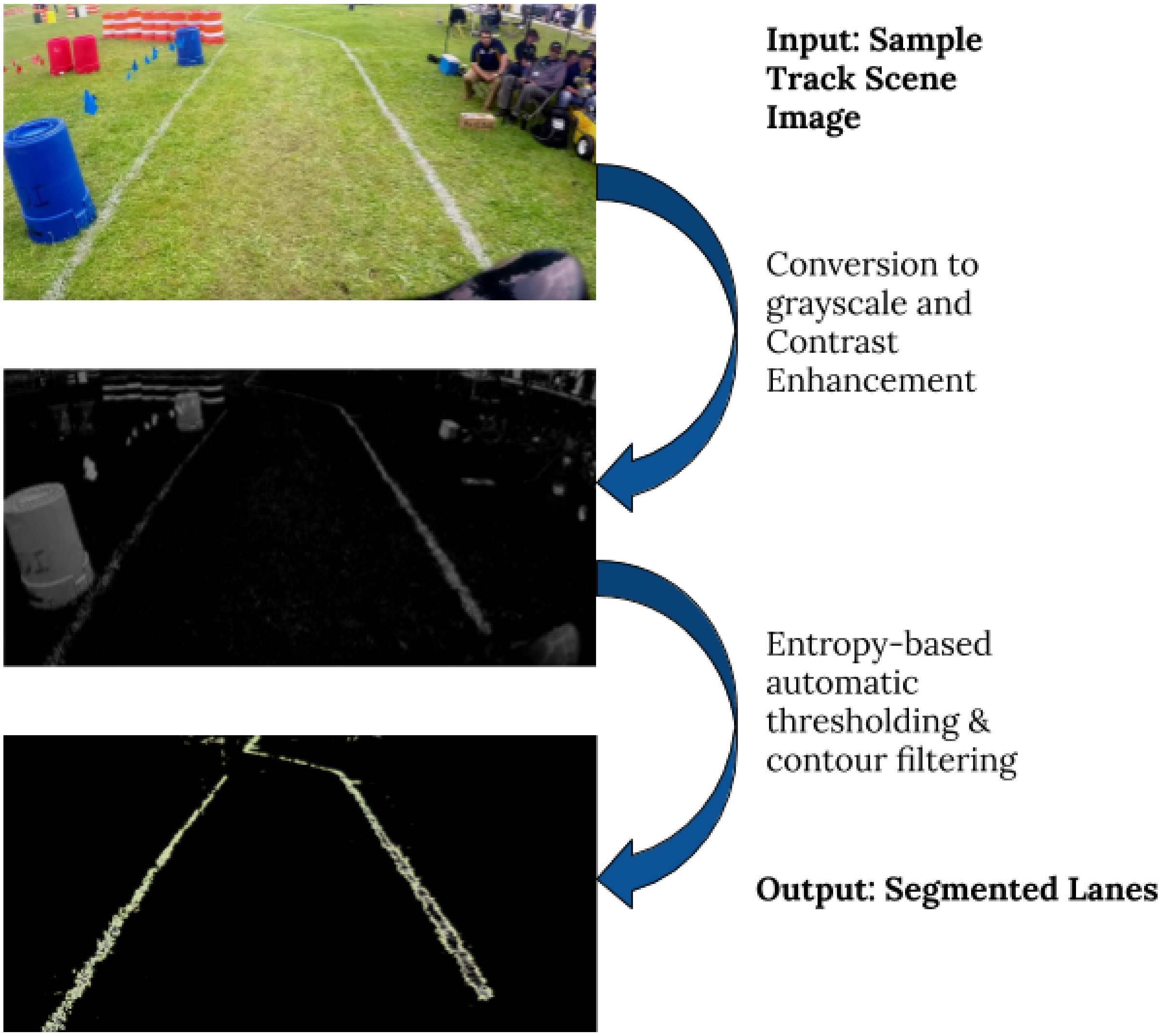


Figure: Main stages in image processing pipeline

Path Planning Strategy

A global map is not available for the course before the run, therefore an initial global path consisting of straight lines joining the specified waypoints is generated. As the map is discovered, a local trajectory is needed to avoid lanes and nearby obstacles. This is generated using Rapidly-exploring Random Trees (RRTs) to generate an optimum trajectory. The algorithm is augmented with a rolling dynamic window approach to make it suitable for real-time operation.

Map Generation

Traditionally, two maps are maintained by a navigation stack. One is a global, static map representing the known knowledge about the terrain and a second is used to represent dynamic obstacles. However, only a single map needs to be maintained for IGVC runs. This is because landmarks are not known prior to the competition and can only be discovered during a run, thereby rendering the maintenance of a global map unnecessary. The local maps are generated using the gmapping SLAM algorithm. Particle-filter based SLAM approach is taken over the traditional Kalman-filtering based SLAMs due to their ability to represent multi-modal probability distributions, which is highly useful for sparse environments.

Controller

A PID controller is used for generating actuation commands. The input consists of linear and angular velocities of the vehicle and output the motor commands. Since PID is a feedback controller, it has self-correcting properties.

Additional Creative Concepts

- Lanes and potholes are treated as a output from a laser-scanner, which allows seamlessly integration with the existing SLAM frontends.

- The action cameras on-board the vehicle are made for viewing the pictures by humans. As human beings are more sensitive to shades to green, the generated image contains more shades than is necessary for lane detection. Once we reduce this information, the image lends itself nicely to entropy-based automatic thresholding.

- Use of polynomial approximation helped in detection of complete lane even when lane was partially blocked due to obstacle.

- Contour analysis is used for filtering out lanes from other objects that might have similar colour.

7. Failure Points and Resolutions

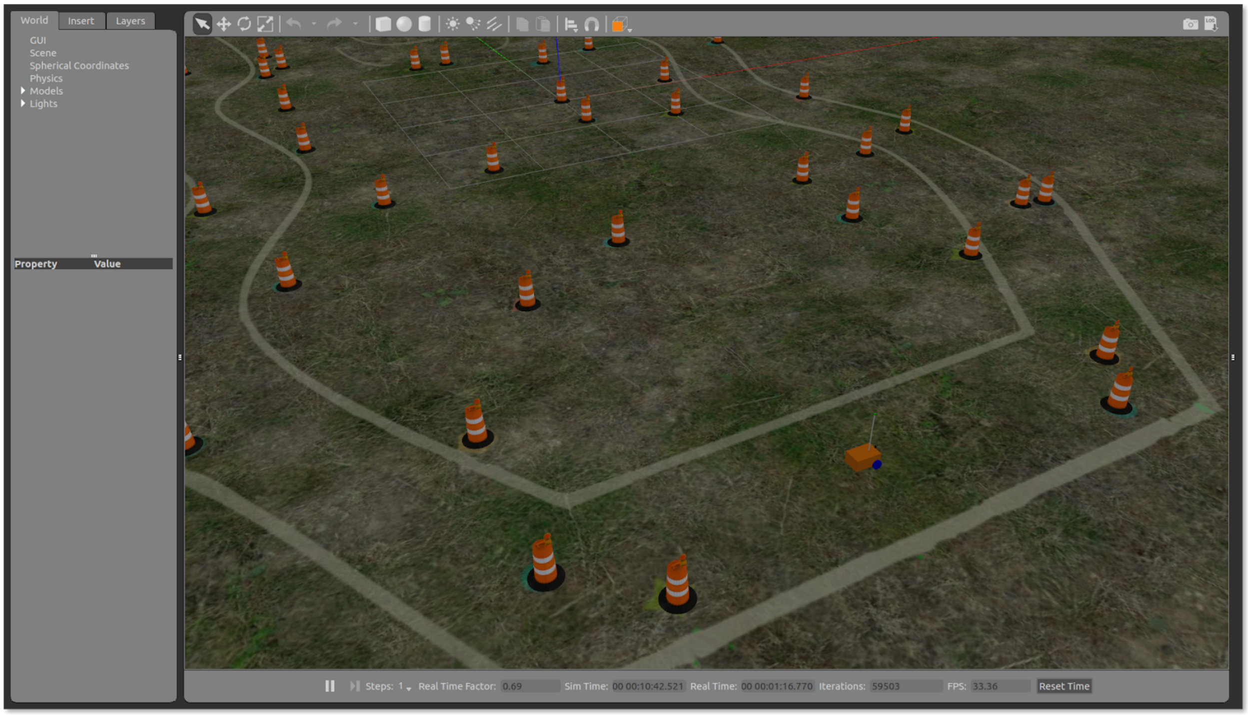
Identified Failure Mode	**Resolution**
The vehicle may take an incorrect path leading to a dead end	When the navigation stack detects that the vehicle has chosen a wrong path and has encountered a dead end, it activates the recovery behaviour of rotating the vehicle until it finds a clearing
Electronic components may perform suboptimally due to heat generated by other components.	Cooling fans are used to draw cooler air into the case from the outside, expel warm air from inside, and move air across a heatsink to cool the electronic components.
LiPo battery has a small risk of exploding when damaged	The battery is wrapped in a special protective casing that restricts the damage
In order to increase portability sliding in of front compartment into the main compartment was used but it led to unnecessary mechanical complexity.	Modularity in design was introduced so as to keep vehicle easily portable while removing moving parts and complications.
Sprocket gear mechanism lead to high amplitude vibrations and chain slipped off sprocket at high RPM	Use of hub motors gave low vibrations and no problems even at high RPM
Delta arrangement required larger correction time while changing direction	Use of Tadpole arrangement gave better maneuverability

Safety Points

The system has two separate E-stop switches: one implemented through hardware and the other through software. The software safety system is through the remote controller without cutting the motor power.

8. Simulations Employed

The entire navigation stack has been simulated on the Gazebo platform on a realistic IGVC track to make sure the image processing and mapping algorithms work as expected.



Steps: 1 Real Time Factor: 0.69 Sim Time: 00 00:10:42.521 Real Time: 00 00:01:16.770 Iterations: 59503 FPS: 33.36

Figure: Screenshot of a simulated run on Gazebo

The mechanical design has been tested for stress and thermal conditions in ANSYS to ensure that design is robust and reliable. A render of the total deformation simulation is shown below.

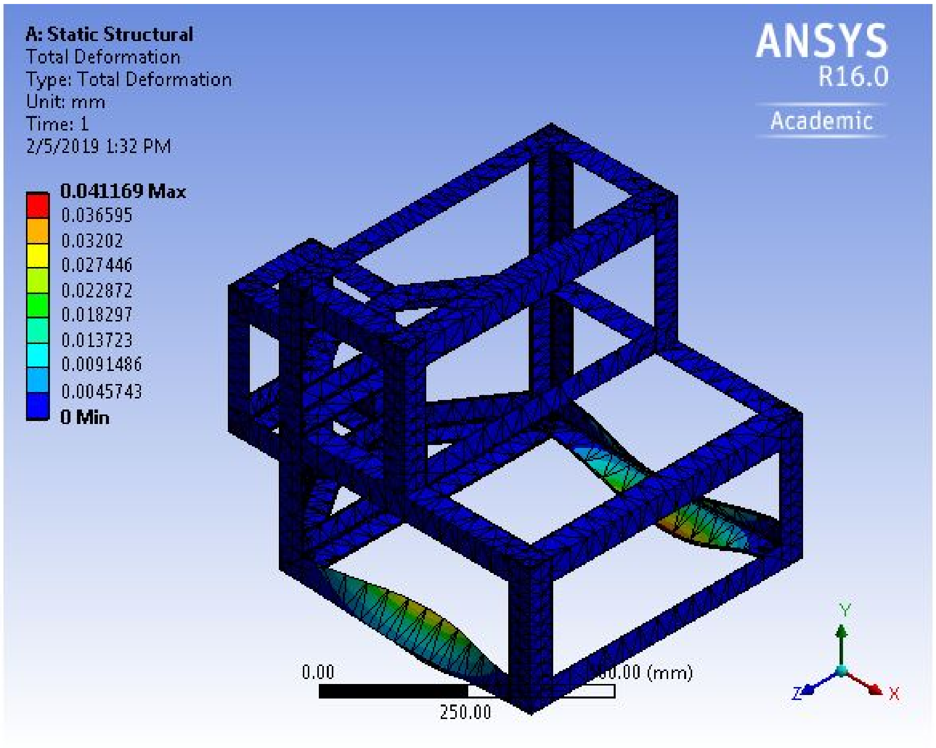


Figure: ANSYS render showing exaggerated deformations for better visibility.

9. Performance Testing

We have successfully performed unit testing separately on all software modules, as well as regression testing on the whole navigation stack. We have also performed component testing on most of the hardware modules and plan on performing system testing as well.