DELHI
TECHNOLOGICAL
UNIVERSITY

KURM

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I hereby certify that the design and development of the vehicle **KURM**, described in this report is significant and equivalent to what might be awarded credit in a senior design course. This is prepared by the student team under my guidance.

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2. Conduct of Design Process, Team Identification, and Team Organization

2.1. Introduction

UGV (Unmanned Ground Vehicle) is a group of highly motivated and enthusiastic students at Delhi Technological University, India whose sole purpose is to develop autonomous ground vehicles for industrial applications like delivery bot, autonomous self driving car. We devote our time to doing research on autonomous technology and passing the knowledge and technical know-how to our juniors so that they can take it forward and make some useful implementation out of it. For the purpose of IGVC 2023, we have developed an autonomous ground vehicle for the Autonav Challenge. The vehicle is named '**KURM**' which is the sanskrit translation of the english word '**Tortoise**' as due to the shape and structure the robot displays.

2.2. Organization

We believe that teamwork is at the heart of any great achievement. Our goal was not just to develop an autonomous vehicle but to build an environment which nurtures team and individual's growth simultaneously.

Name	Major/Year	Software	Mechanical	Electrical	Hours
Lakshay	CSE/2nd	✔			500+
Abdul Basit	SE/2nd	✔			600+
Daksh Gupta	IT/2nd			✔	550+
Rajat Chandra	ME/2nd		✔		650+
Kaushal Kumar	CSE/2nd			✔	500+
Lakshya Sinha	ME/2nd		✔		700+
Harsh Saini	EP/1st.			✔	550+
Aditya Kumar	CSE/1st.	✔			700+
Utkarsh Diwakar	CSE/1st	✔			650+

2.3. Design Assumptions

We participated in the IGVC 2019 before this. From that time till now we have added upon a lot of technology and robustness into the bot. We adopted a pragmatic approach for this year's competition which became the backbone of our design philosophy - aiding us to determine realistic design goals.

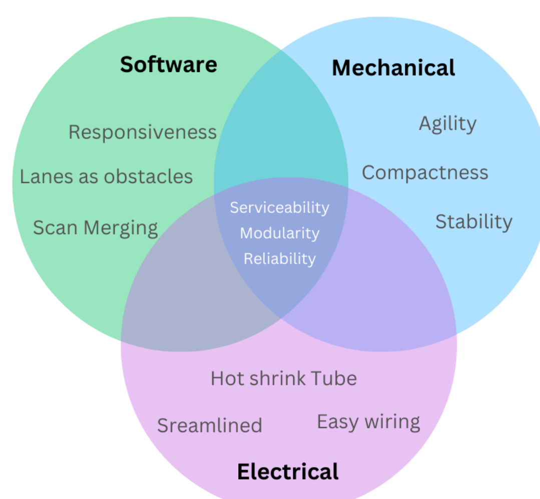


Figure 1 : Design Functionality

2.4. Design Process

Before starting to build the design, It was very crucial for us to decide upon the strategy that we must follow to step by step execute all processes, from building the model to testing it in a real time environment. Thus, we developed a V-design approach that demonstrates relationships between each phase of the development life cycle and its associated phase of testing.

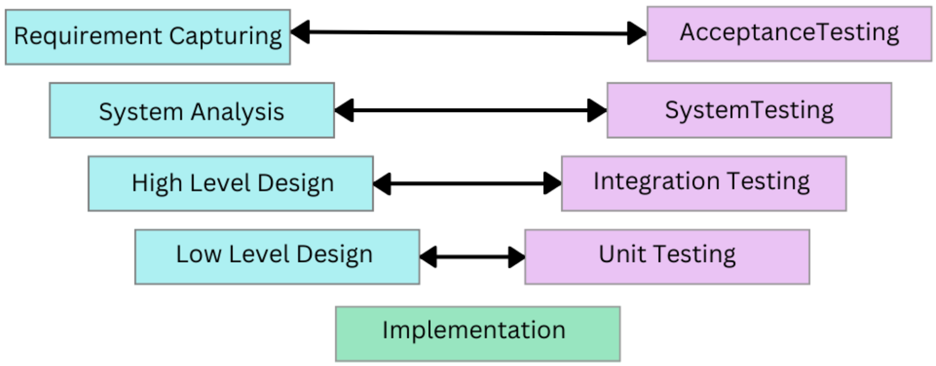


Figure 2 : Design Process

3. Effective Innovations

I. **Isolation**: All the wires are completely isolated by heat shrink tubes. So there's absolutely no chance of short circuit and spark

II. **Easy Wiring**: The connections are easy to understand and one can distinguish which wire goes to which component.

III. **Battery Capacity**: The battery capacity has been increased by combining cells in parallel so that it can operate for a longer duration of time.

IV. **Stability:** The heavy components and the payload are placed at the lower level shifting the center of gravity low and increasing the stability.

V. **Ease of use with electrical components:** A lid is provided in the front of the vehicle which makes it easier to work with the electrical components without disturbing the vehicle assembly. An interior lid is further provided to work with motors and battery.

VI. **Adjustable Camera Mount:** The position of Zed Camera can be altered both vertically and horizontally.

VII. **Vehicle Compactness:** The size of the vehicle is kept approximately equal to the minimum specified size as per the rules of IGVC 2023. This provides extra clearance between the obstacles and lanes allowing the vehicle to run at higher speed.

VIII. **Separate compartments for Battery, Payload and other Electrical Components:** The battery and on-board computer along with electrical components are kept separately so that if any spark is developed in the battery, it does not affect the other components. There is a special compartment for keeping the payload which prevents the falling off of the payload during jerky movements.

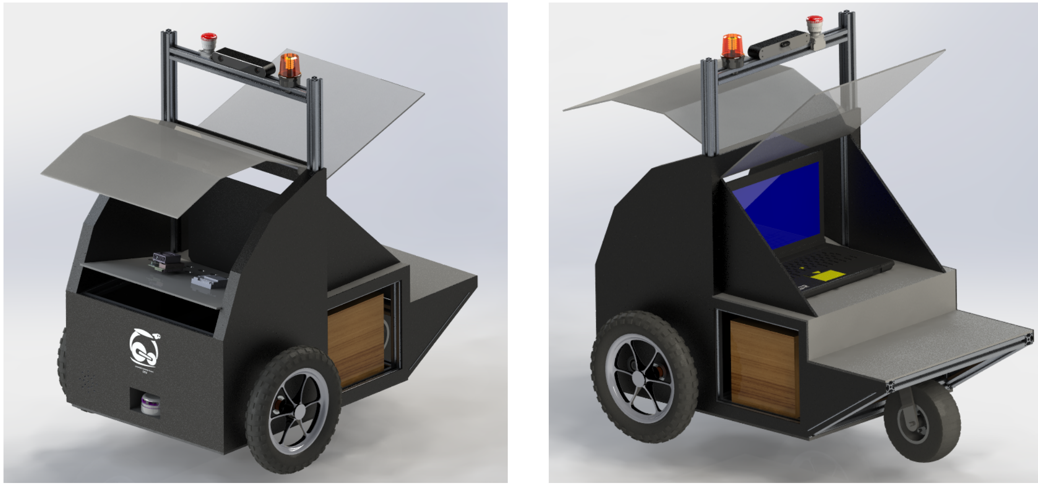


Figure 3: Lid System of Kurm for electrical components and on-board computer

IX. **Scan Merging:** The bot merges the Lidar Scan as well as the scan from Zed camera into a single cost map, generating a precise as well as accurate map of the environment.

X. **Lanes as Obstacles**: We are detecting lanes as obstacles so that they can be plotted on the same cost map thus reducing computational time.

4. Mechanical Design

4.1 Overview

While designing Kurm, the main focus was to make the vehicle lightweight, strong, compact with the advantage of easy assembly and disassembly. Major time was invested on research, material selection, computer aided designing and analysis. The compact design of Kurm allowed the use of only 3-wheels which helps to make sharp turns and hence better obstacle avoidance.
The following things are taken into consideration while designing and manufacturing of the vehicle:

1. Size and Dimensions of the vehicle
2. Material of the Chassis
3. Portability
4. Stability and weight management
5. The positioning of the components and the heat management
6. Vehicle Exterior
7. Weather Proofing

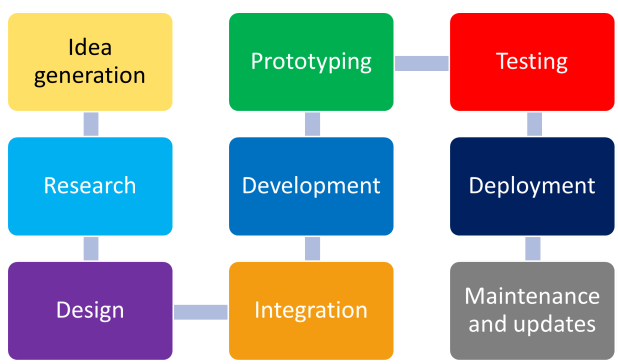


Figure 4: Bot Crafting Blueprint

4.2 Size of the Vehicle

As per the rules of IGVC 2023, the minimum length and width of the vehicle had to be 3 feet and 2 feet respectively. The vehicle is designed as compact as possible exceeding the minimum length and width by 0.6 inches and 1.5 inches only. This allows greater clearance between the obstacles and thus can help the robot to avoid obstacles more efficiently and run at a higher speed.

4.3 Chassis

Kurm's Chassis is made using 3030 Aluminium 6061 t-slot extrusion. This purpose of using this material was due to its high strength to weight ratio thus providing high strength keeping the weight of the vehicle low. Another reason to use this material is that it can be assembled and disassembled easily as it is joined using angle brackets, nuts and screws. The ease of assembly and disassembly provides us the feature to dismantle the vehicle completely and carry it in our luggage avoiding the need of cargo, thus eliminating expensive transportation charges.

Figure 5: Chassis Structure

4.4 Stability and Weight Management

The vehicle is divided into three main compartments, two at the lower level and one at the upper. All the heavy components of the vehicle, which are motors, gearbox, and battery, are kept in the lower first compartment, and the payload at the second lower compartment. Thus, all the significant weight of the vehicle lies at the bottom, keeping the center of gravity low and increasing stability. The other lightweight components, like the motor controller and the onboard computer, are kept in the above vehicle compartment. The sensitive electrical components (motor controller, onboard computer) are kept separately from the battery to avoid any damage if a spark arises in the battery. Additionally, a lid is provided for ease of working with the electrical components.

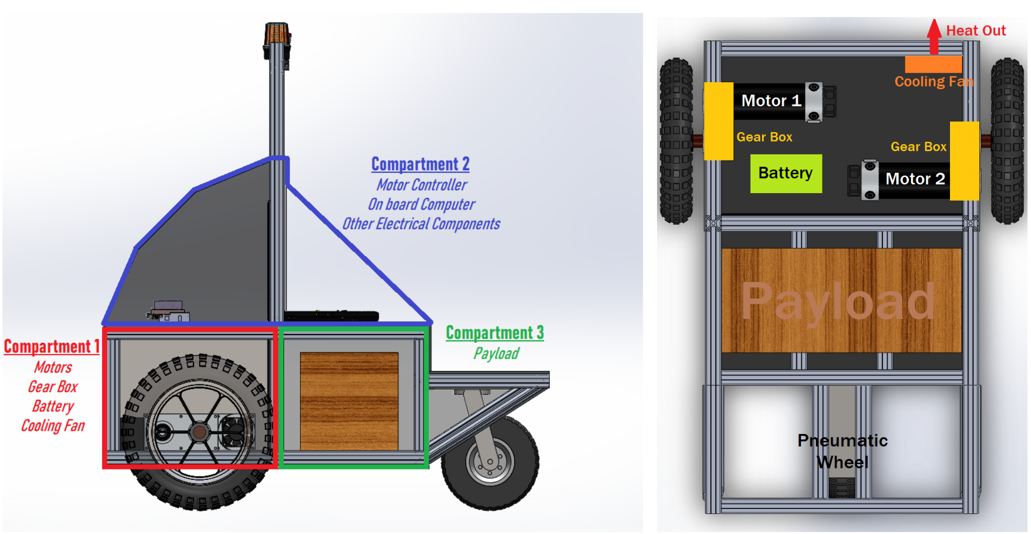


Figure 6: Side View and Top View of Kurm

A dedicated suspension is not provided for the vehicle, as the run will occur on an asphalt path. A suspension would only add extra cost and more complexity to the vehicle. Silicon rubber paddings are provided below the motors, gearbox, Zed Camera, and Lidar sensor to counter the vibrations. Moreover, all three wheels used are pneumatic, and thus, they provide the necessary suspension themselves.

4.5 Heat Management

The fans attached to the motors exhaust the primary heat developed in the motors. The motor placement is non-collinear, and thus fans of the motors do not exhaust the heat to each other. The motor controller and jetson also have exhaust fans attached to them to remove the heat. Now all the heat from different components is created inside the vehicle, and as the vehicle is weatherproof, there is little or no space available for this heat to escape. Hence, a fan is attached at the front of the vehicle to exhaust this developed heat out.

4.6 Weatherproofing

The exterior body of the vehicle is made using acrylic sheets of 4mm thickness. The purpose of using acrylic sheets is that they are lightweight, waterproof, have good machinability, cost effective and can be painted easily. As no vehicle load is acting on the outer body, there was no need to make the outer body any thicker.

The major setback arises from the gaps between the joints of acrylic sheets as moisture can easily enter through these gaps. To counter this problem, the gaps are covered using waterproof rubber tape followed by waterproof acrylic tape which makes the vehicle completely waterproof and protects the interior components.

4.7. Weight Distribution

ITEM	Total Weight (Pounds)	Weight Ratio
Aluminum Extrusion	23.8	22.43
Motors and Gearbox	33	31.10
Wheels	12.1	11.40
Battery	2.9	2.73
Payload	20	18.85
Other Components	3.3	3.11
Outer Body	11	10.38
Total	**106.1**	**100**

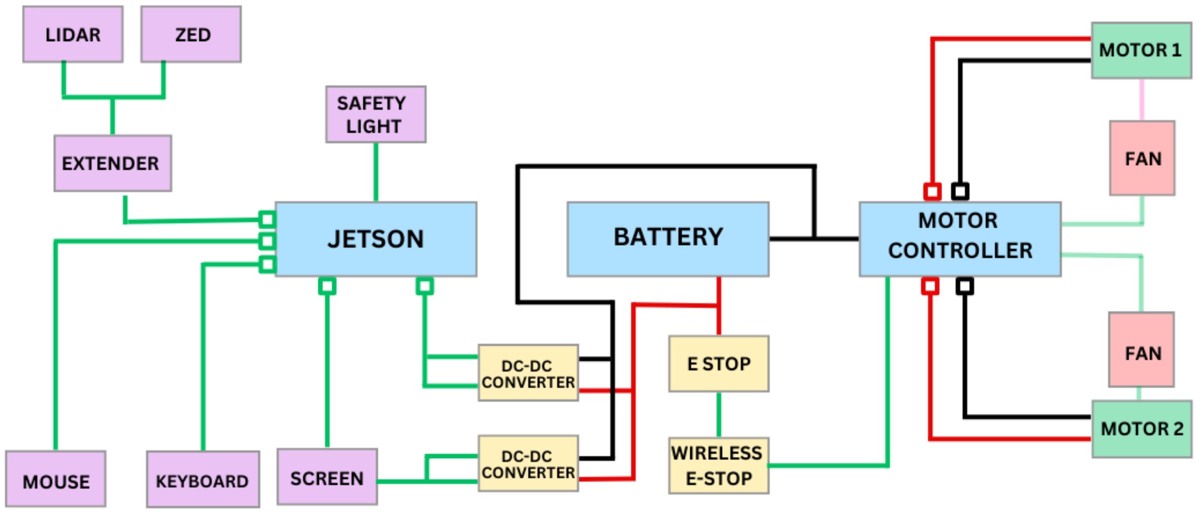
Excluding the weight of Aluminium frame chassis which constitutes 22.43% of the total weight of the vehicle, it can be concluded that around 64% of the total weight lies at the lower part of the vehicle. This lowers the center of gravity of the vehicle which increases the stability of the vehicle.

5. Electronic and Power Design

5.1. Overview

The electrical schematics of KURM have been designed in such a way that it displays safe design, long-working hours and durability along with simplification and intelligence. The Electronic Suite consists of Jetson Xavier NX as the main processing unit (brain of the bot), AF 160 Motor Controller to implement a 2 channel high powered system, two Ampflow motors, LoRa (Long Ranging Modules) for Wireless E-stop and a safety status light. In addition an Arduino microcontroller is used to establish communication links between devices.

5.2. Power Distribution System



Electrical Design Suite

COMPONENTS	POWER CONSUMPTION	OPERATING VOLTAGE
Jetson	20 W	19V
RP Lidar	2.2 W	5 V
SparkFun GNSS receiver	0.5 W	3 V
Zed 2i Camera	1.9 W	5V
Motor Controller	28.8W	24 V
WaveShare Screen	12 W	12 V
TOTAL POWER	**65.4W**	

BATTERY SPECIFICATIONS	MEASURED VALUE
Battery Capacity	10000mAh
Operating Voltage	24V DC
Power Supplied (Ideally)	66.66 W

Power Supplied (Actually)	65.4 W
Battery Life	1Hr.
Recharge Rate	45 min.

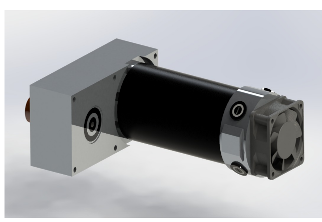
5.3. Electronics Suite Description

5.3.1 Jetson Xavier NX

The Jetson Xavier NX is a powerful embedded computing device that offers high performance and capabilities in a compact form factor.It features an NVIDIA Xavier processor with 6 core CPU, 384-core GPU, and 48 Tensor Cores, delivering upto 21 TOPS of computer power. It stores the python scripts to move the robot. It runs Ubuntu 20.04 and operates on 19 volts DC.

5.3.2 Motor Controller AND Motors

The AF-160 Motor Controller is a compact and cost effective solution for driving 3 phase brushless DC motors with upto a 160A of continuous current. It has built in protection features such as over-current, over-temperature and under voltage protection. It uses an RS-232 communication interface for programming and configuration.



5.3.3 RP Lidar

We are using RP AM31 2D scanning Lidar. It has a range of upto 25 meters and a scanning angle of 360 Degrees and a scanning frequency of 10Hz.Its compact size, low power consumption and high speed scanning makes it an ideal sensor for a wide range of applications.

5.3.4 Zed 2i Camera

It has a maximum range of 40 meters and a field view of 120 degrees. It has a resolution of 2.8 megapixels and can capture images at 100 frames per second. It also has a built-in NVIDIA Jetson TX2i processing unit that allows for real time image processing and analysis. Its

high accuracy and real time processing capabilities make it an ideal sensor for a wide range of applications.

5.3.5 GPS

We are using the SparkFun UBlox F9P RTK2 GNSS receiver module. The module is built around the UBlox F9P chipset, which provides us with an accuracy of 1-2 centimeters. It is reliable and well suited for applications that require precise and accurate positioning. The antenna has a range of 1.6GHz and a baud rate of 115200 bps.


5.4 Safety Devices

5.4.1 Emergency-Stop

KURM incorporates both hardware and software solutions to stop the bot.

- The mechanical E-STOP is mast on the top and can be stopped by pressing the button.
- The electrical E-STOP is made using Arduino boards, a relay and two LoRa communication sensors. The first LoRa module is used for transmission and other as a receiver.

In electrical E-STOP the button is held by the user while the receiver module is placed on the robot. With one push of the button, even if the bot is 1KM away, it can be STOPPED.

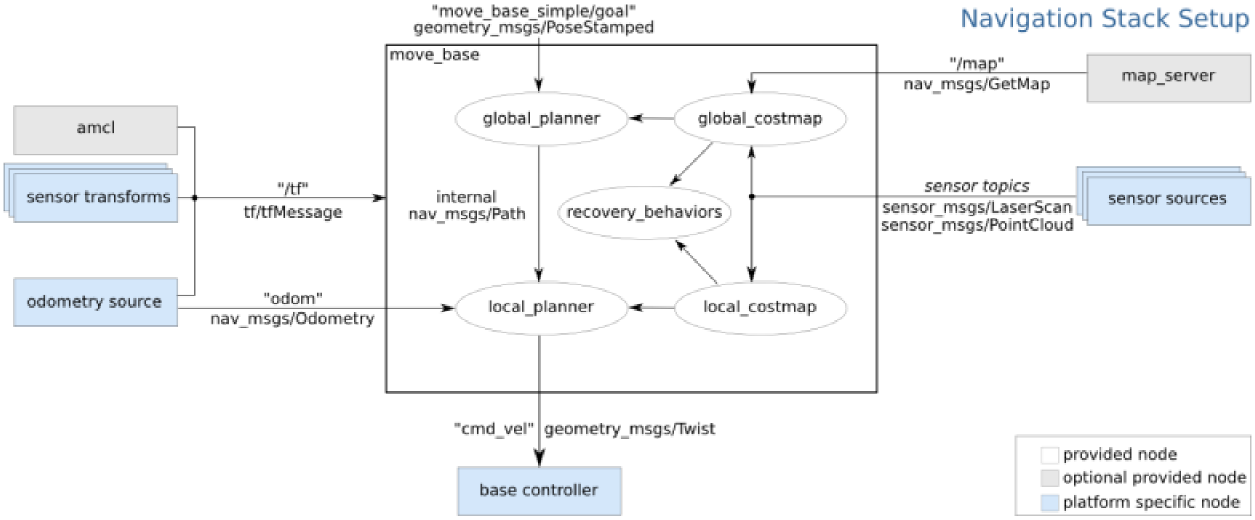
5.4.2 Safety Light

KURM includes a safety light that works as a status light for KURM. We are using an LED strip that becomes solid when the robot is powered on and keeps blinking while the robot is in autonomous mode as an indicator for its surrounding entities.

6. Software Strategy and Mapping Techniques

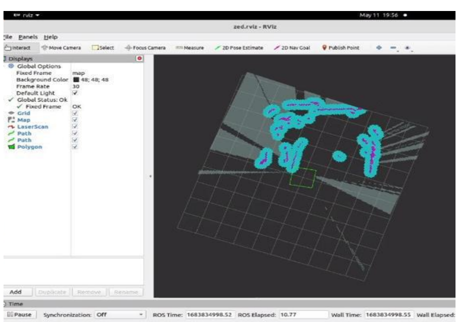
6.1 Overview

The on-board navigation stack for autonomous vehicles enables perception, mapping, path planning, and control. This report outlines a modular navigation stack designed as a pipeline comparing four distinct phases, each handling a specific aspect of the vehicle's autonomous navigation capabilities. The proposed architecture ensures minimal dependencies between phases, facilitating strong modularity and maintainability.



6.2 Obstacle detection and avoidance

The detection and avoidance of obstacles is achieved through the RPLiDAR A3M1. The LiDar operates by emitting laser beams and measuring the time taken for the light to return after reflecting off objects, thereby gauging the distance of various objects from the vehicle. It then generates a 2D point cloud that represents a detailed 'map' of the surroundings at a given point in time. This point cloud is valuable for detecting obstacles, creating cost maps for path planning, and enhancing the accuracy of the vehicle's environmental perception.



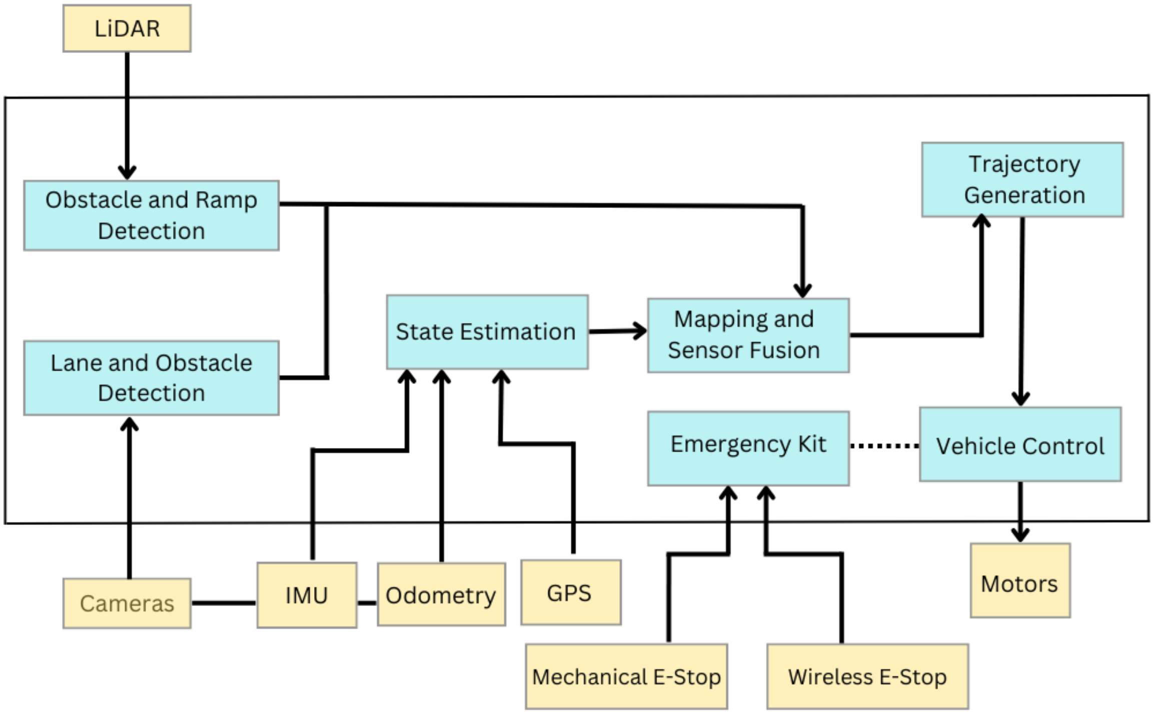
6.3 Software strategy and path planning

6.3.1 Software Strategy

It is based on the integration of various components - sensors, algorithms, and control systems - to perceive, understand, and interact with the environment. It articulates how the vehicle interprets sensor data, constructs a map of its environment, plans its path, and controls its actuators to execute the planned movements.

6.3.2 Path Planning

It involves charting an optimal course from the vehicle's current position to a designated goal. This process leverages the generated environmental map and utilizes ROS Move Base nodes, incorporating both local and global planning algorithms, to navigate efficiently and safely across diverse terrains.



Vehicle System Architecture

6.4. Map generation

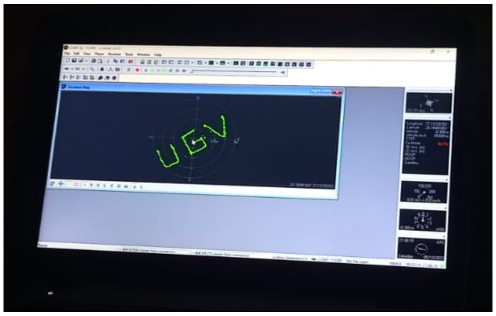
Map generation, or mapping, is the process of creating a digital representation of the UGV's environment based on the data harvested from the sensor suite. The stereo cameras provide dense visual data and depth perception, while the LIDAR scanner offers high-resolution distance measurements and detailed 2D point clouds. The vehicle employs laser based SLAM (Simultaneous Localization and Mapping) to create an environmental map and locate itself within the map concurrently.

6.5. Goal selection and path generation

The path planning algorithm starts with the specification of a destination or goal, which could be a specific GPS coordinate, a designated location on the map, or a relative position from the vehicle's current location.

Kurm uses Move Base node of ROS (Robot Operating System) that works on two tiered path planning approach:

I. The DWA (Dynamic Window Approach) local planner that is responsible for short-range planning.
II. The NavFn that is responsible for long-range planning and uses A* graph traversal algorithm for path generation.



6.6 Additional Creative Concepts
Our design employs innovative concepts to optimize single-lane navigation.

I. We've inverted traditional navigation principles by treating the lane as an obstacle. This approach simplifies the Kurm’s programming, enabling it to maintain its course within the lane without the need for complex algorithms.

II. We further enhance the UGV's operations by publishing lane data as a fake laser scan, a method that ensures seamless integration with lidar data. This strategy improves data reliability and consistency, thereby enhancing the robot’s navigation accuracy.

III. Finally, we have used high-quality GNSS antennas attached to metal plates. These plates act as both a ground plane, reducing signal loss and interference, and a reflector, directing the signals towards the desired direction. This approach improves the antenna reception capabilities, enhancing location accuracy and overall navigation precision.

7. Failure Modes, Failure Points and Resolutions

7.1. Failure Modes and Resolution
There are multiple possible causes for the bot failing to accomplish its task. Some of these have been discussed here.

Failure	Cause	Resolution
Lanes not being detected	Camera not calibrated properly, low processor/GPU power	Careful calibration to ensure that lanes are being detected in the given lighting conditions. Use of powerful computing machinery.
Incorrect transformation between GPS and local coordinates	Radio interference in GPS, tall obstructions near bot, base plate of GPS touching other conductors	Radio isolation of the bot environment. Ensuring bot is run in an open space with a clear view of the sky. Placing an insulative layer between base plate and other components.
Distortion in movebase	LIDAR or ZED camera connections loose	Reset movebase. Ensure connections are secure before launching the bot.
No path found	Error in movebase or sensors.	Recovery behavior initiated - rotate at the same point in space to find an unobstructed path.

Discrepancy in LIDAR readings	Mechanical failure	Reset navigation stack. Ensure connections are secure.

7.2. Failure Points and Resolution

S.NO.	Failure Points	Resolution
1.	Short circuiting in wires.	• Isolate the wires using heat shrink tubes. • Wrap duct tapes around wires.
2.	Power failure	Check, • If there are some loose connections in battery • Buck converter got damaged.
3.	Vehicle stuck and drive not being transferred to tires.	Check, • If screws are loosen up. • Required power is not being transferred to motors.
4.	Water Seepage inside the vehicle through the gaps	3 layered protections are provided for this problem by covering the gaps with duct tapes from the interior and then with rubber and carbon fiber tape from the exterior.
5.	Damage to the chassis structure due to collision	Spare aluminum extrusion weldments are kept for replacement if any damage occurs.

7.3 All failure prevention strategy

The bot is extensively tested on general courses, edge cases and in simulations to ensure that the software is able to autonomously handle a wide variety of unexpected situations. All errors and failures have been promptly dealt with and subsequently stress tested to ensure that similar errors can be handled without human intervention.

7.4. Vehicle Safety Design Concepts

I. We use a fire extinguisher that is attached to the bot, in case it catches fire due to short circuiting or damage in some component.
II. The battery and the components we are using kept at separate places to avoid damage to anyone.
III. We have kept a first-aid kit inside the robot so that the person injured by KURM can get the treatment at the earliest possible.

COST ESTIMATED (1USD = 82.25 INR)

Item	Specification	Quantity	Total Cost
Battery	Li-ion Cells 3.7V 2500mAh	1	35.74$

Lidar	RP Lidar AM31	1	875.37$
Motor Controller	AF-160 Motor Controller	1	595$
Motors	AF Brushed DC Motors	2	340$
Camera	Zed 2i Camera	1	500$
GPS Module	SparkFun UBlox F9P RTK2 GNSS module	1	389$
Receiver Antenna	GNSS Multiband Magnetic Mount Antenna	1	72.95$
Wireless Transmitter Module	REYAX RYLR896 LoRa module	1	42$
Wireless Receiver Module	REYAX RYLR896 LoRa module	1	42$
Kill Switch	Kill Push Button Switch	1	2.43$
Status Light	NeoPixel RGB Led Strip	1	8.51$
Microcontrollers	Arduino	2	12$
Fan	Cooling Fan	1	2.43$
Buck Converter	DC-DC Buck	2	12.15$
Jetson	Jetson Xavier NX	1	1143$
Screen	Waveshare 13.3in Screen	1	221$
Keyboard+Mouse	Raspberry Pi Keyboard and Mouse	1	24.3$
Aluminum Rods	6061 Aluminum Extrusion	-	121.58$
Acrylic Sheet	Acrylic Sheets	-	48.62$
Wheels	Wheels	3	60.79$

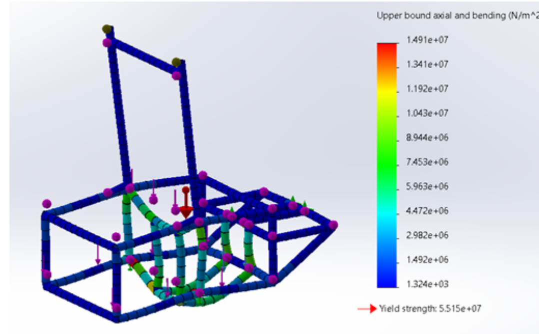
Total Estimated Cost - 4548.79 $

8. Simulations Employed

8.1. Simulations

Software: A dynamic model developed in python was seamlessly integrated with Gazebo to simulate various aspects of the vehicle. In addition, Rviz was utilized as a tool for visualizing, debugging, and strategically testing different real world scenarios. The combination of Rviz and Gazebo played an evident role in facilitating the design of software architecture.

Mechanical: Load analysis was done on the chassis of Kurm while designing to check the stresses on the vehicle. The weight of all the components and payload is 100 pounds at max. Taking the factor of safety equal to 2, the structural analysis of the chassis was done for 200 pounds. The following images show the structural analysis of chassis on CAD software.



9. Performance Testing to Date

Kurm was tested in an outdoor environment similar to the IGVC competition, featuring a track layout resembling the competition setup. To thoroughly evaluate the vehicle's performance, white lines were marked on the grass, and barrels were placed intermittently, creating an ideal pseudo-competition environment. The outdoor testing phase took place once all system modules were independently operational and seamlessly integrated.

To validate the mechanical aspects, rigorous tasks were performed, including ramp climbing, maneuvering on wet surfaces, and navigating rough terrain using RC control. The system's mechanical robustness was assessed by executing sudden maneuvers to ensure its stability and durability.

Electrical testing and validation were conducted to verify the proper functioning of each electronic component and sensor. This involved analyzing the signals of these components in Rviz to ensure they met the desired specifications. The integrity of the power distribution system was monitored using a digital serial oscilloscope, ensuring its reliability and performance.

10. Initial Performance Assessments

Kurm follows all the requirements specified in the rules of IGVC 23'. In the initial testing phase, each and every component and sensor was individually tested and passed all performance criteria.We have tested Kurm in both simulated and actual courses.

I. On-board computer (Jetson) was tested instead of controlling the bot by laptop. The performance of the bot was up to the mark.
II. A maximum speed of 5mph was achieved during testing.
III. The battery life during the testing phase was found to be 45 min. At full working capacity.
IV. Ramping ability has been rigorously tested over multiple inclines of up to 16-degree in inclination.
V. Lidar was individually tested for obstacle detection and avoidance.
VI. Zed camera was tested for visual odometry and white lane detection.
VII. Software algorithm (A* algorithm) for lane detection was tested successfully.