



Manipal Institute of Technology, Manipal
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Design Report



R.U.G.V.E.D SYSTEMS

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I hereby certify that the design and development of the vehicle RUGVED, 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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INDEX

1. INTRODUCTION	3
2. DESIGN PROCESS	3
3. TEAM ORGANISATION	3
4. DESCRIPTION OF MECHANICAL DESIGN	
4.1. OVERVIEW	4
4.2. STRUCTURAL DESIGN	4
4.3. MATERIAL	5
4.4. WHEELS	5
4.5. MOTORS	6
4.6. PERIPHERALS	6
4.7. WEATHERPROOFING	8
4.8. LACK OF SUSPENSION	8
4.9. DIMENSIONS AND SPECIFICATIONS	8
5. DESCRIPTION OF ELECTRONIC DESIGN	
5.1. OVERVIEW	9
5.2. DATA ACQUISITION DEVICES	9
5.3. DATA IMPLEMENTATION DEVICES	10
5.4. SAFETY DEVICES	10
5.5. POWER SYSTEM	10
5.6. INNOVATION	11
6. DESCRIPTION OF SOFTWARE STRATEGY	
6.1. OVERVIEW	12
6.2. PERCEPTION	12
6.3. LOCALIZATION	13
6.4. MAP GENERATION	13
6.5. PATH PLANNING	13
6.6. ADDITIONAL CREATIVE CONCEPTS	13
7. FAILURE MODES, FAILURE POINTS AND RESOLUTION	
7.1. SOFTWARE FAILURE MODES AND RESOLUTION	14
7.2. ELECTRONICS FAILURE MODES AND RESOLUTION	14
8. SIMULATIONS EMPLOYED	
8.1. MECHANICAL SIMULATION	14
8.2. SOFTWARE SIMULATION	14
9. PERFORMANCE TESTING	
9.1. MECHANICAL	14
9.2. ELECTRONICS	15
9.3. SOFTWARE	15
10. INITIAL PERFORMANCE ASSESEMENTS	15
11. COST ESTIMATE	15

1. Introduction

R.U.G.V.E.D Systems is a student based team comprising undergraduate students from various fields of engineering committed to making robots primed with cutting edge Artificial Intelligence. The bot has been designed to be autonomous, robust and modular. The report outlines the development and integration of the mechanical, the electronics and the software.

2. Design Process

The set of actions to be followed to achieve the problem statement were laid out after reading the problem statement. The process involved five stages that aimed at fulfilling primitive goals to succeed at the final objective. The following figure illustrates the design process:



Figure 1: Design Process

3. Team Organization

Team Leader Anupam Yedida			
Software	Mechanical	Electronics	Management
Sudhanshu Srivastav	Hemang Chaturvedi	Jayasimha Reddy	Abhishek Thakur
Adeel Ansari	Tanay Agarwal	Sai Raghunath K	Prateek Singh
Aakash Vashishtha	Amith Nair	Sumit Sharma	Vikash Shahi
Chirangivi Bhat	Alvina Ann Alex	Vipul Sureka	
Pranoy Ghosh	Arvind Addepalli	Ishita Boral	
Sambhav Singh Rohatgi	Pradeep Gandhe	Paresh KV	
Shashank Shekhar	Raswanth V	Kshitiz Rai	
Shreya Kashi	Rishi Chauhan	Rishabh Sinha	
	Shreyas Kumar Bhat	Shwetang Singh	
	Vanshika Todi		
	Vasundhara Verma		

4. Description of Mechanical Design

4.1 Overview

The bot has undergone stages of iterations to conclude to the final design. The objectives kept in mind from the mechanical aspect, now fulfilled are:

- a. Use of easily available material
- b. Efficient use of space
- c. Lower center of gravity
- d. Stability
- e. Maneuverability
- f. Optimal Waterproofing

The first iteration (Mark I) of the RUGVED bot was a simple Aluminum space frame with a compromising load-carrying capacity. The primary motive was to fabricate a platform for testing of electronic components. The second iteration (Mark II) involved compartmentalization and dedicating spaces for electronics, laptop and payload. This design was sturdy but had poor space management. A ground clearance of 11 inches was excessive for the terrain of IGVC and acted as a drawback by reducing stability on turning. High-torque motors were used on this chassis. The specifications mentioned by the manufacturer perfectly suited the requirements but in ground testing, the motors failed due to poor manufacturing quality.



Figure 2: The second iteration of RUGVED Bot (Mark II).

The third and the final iteration overcame the aforementioned drawbacks and involved space optimization, accommodation of all sensors and peripherals along with optimum waterproofing, better motor-wheel combination etc.

4.2 Structural design

The chassis is primarily a space frame that has been optimized for the specific requirements laid out by IGVC and other subsystems while maintaining strength, rigidity and stability of the structure. It satisfies the minimum dimensions according to IGVC rules and accommodates various components with efficient use of space. The arrangement of the components was done in a manner to ensure easily accessibility for

repair and replacement. Analysis was done on SolidWorks using concentrated and distributed loads and stress concentrations were identified. Accordingly

The design is a double level arrangement with the major components such as batteries, electronics, payload and LiDAR coming on the lower level. The 'level 1' constitutes the laptop case and the antenna. This level is hinged on the rear side so that it may be opened like a hatch to provide easy access to the electronic components, enclosed in the chassis.

The laptop was essential during the testing phase and also serves as a backup processor. Hence, a proper housing was necessary. The laptop case is a simple box with a hinged lid to provide easy access to the laptop and allows the screen to be used for observation during testing.

The base of the chassis uses many structural components arranged in a manner to minimize any stress concentration in high load bearing areas. However, due to less load on top, the number of vertical pipes and support pipes on 'level 1' have been kept to a minimum to reduce weight.



Figure 3: Space frame with wheels attached

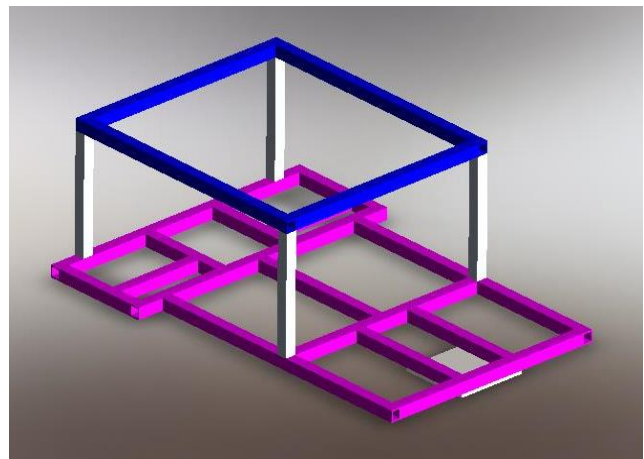


Figure 4: Bi-level design. Pink: Level zero, blue: Level one

4.3 Material

The chassis is a space frame made using 1"x 1" square pipes of Aluminum 6061 alloy. This alloy is a material of high strength with good corrosion resistance and weldability. Furthermore, it has excellent machinability which makes it suitable for constructing structural components. The alloy is lightweight, substantially reducing the weight of the chassis.

The outer covering and flooring is mainly done with 12mm thick PVC sheet which is innately waterproof and sturdy enough to allow mounting of the peripherals.

4.4 Wheels

The bot uses a three wheel configuration for drive, consisting of two drive wheels and a castor wheel. The drive wheels are on the rear with the castor wheel in the front. This configuration credits minimum turning radius of the bot.

For Mark II, 15" solid rubber wheels were used along with a 6" castor wheel. It was found that it had considerably less grip and suffered a substantial amount of wear while moving on the intended surface thereby affecting the overall performance.

Finally, the decision for shorter 8” drive wheels along with a 5” caster wheel was concluded in order to reduce the overall torque requirement of the motor. This lowered the centre of gravity of the bot, in turn improving its stability. Furthermore, the wheels provide better traction, reduce wear considerably and perform well on the intended surface.

4.5 Motors

4.5.1 Robokits planetary encoder geared motor RMCS-2004

However, initially preferred and used in Mark II, because of their economic value along with the suitability to the output required, as per specifications provided by manufacturer, these motors failed on testing. It was found that the shaft was of inferior quality and had no provision for any attachments to the wheel. The gear system had lower load-bearing capacity than required and was damaged during field testing.

4.5.2 Ampflow gearmotor E30-150-G

An optimum RPM and torque combination is required to traverse the entire IGVC track properly. These Ampflow motors gave a consistent output, perfectly agreeing with the calculations. The motor has a speed reducer, which can fit with the motor shaft and gives a reduction ratio of 8.3:1. The attachment is required to bring down the high RPM and increase the torque and uses a three-stage chain-and-sprocket mechanism. Apart from being economical, the motors are of sturdy built. Hence, a better suit for the requirements than the previous.

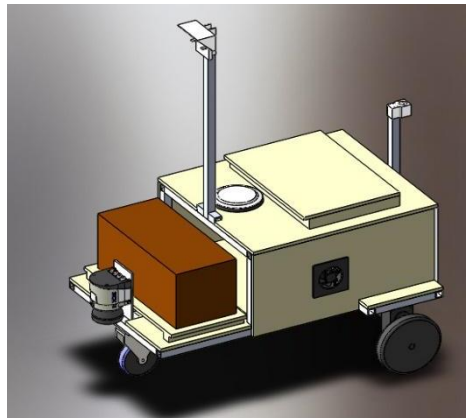


Figure 5: Rendering of the complete bot

4.6 Peripherals

The design of the bot accommodates devices like camera, LiDAR, GPS antenna, laptop and a payload. The bot has slots and mounts for installing various sensors and indicators.

4.6.1 LiDAR

The front of the bot supports the LiDAR on a mounting bracket with protection of optics hood. The bracket is installed on an Aluminum sheet, with the help of fasteners. The height has been fixed well above the ‘level 0’ to avoid hindrance with the caster wheel and for better obstacle detection.

4.6.2 Ultrasonic Sensors

The obstacle detection has a failsafe measure incorporated using ultrasonic sensors mounted at the front of the chassis on a bracket. One of them faces the front, two are placed at a 45 degree angle, on either

corner and another pair faces opposite sides of the chassis. The mounts are constructed out of PVC sheet. They easily accommodate the sensor and attach to the PVC.

4.6.3 Payload

The front of the chassis has space designated for placement of payload of the specified dimensions viz. 8x8x18in. The payload is held in its position without slippage by using treaded rubber padding underneath, and securing with elastic belts. This also reduces vibration between the bot and the payload. The belts are attached to the chassis in an ‘H’ formation to hold the payload firmly, allowing easy replacement, if needed.

4.6.4 Camera

The camera has been mounted on a pole of an optimum height for a larger field of view. The housing of the camera is a 3D printed ABS mount. The mount is held on top of the pole with the help of bolts and nuts. The camera is allowed to swivel on its joint but the tilt angle is fixed and aligned inside the mount. The hood protects the camera from rain and sun glare into the lens.

4.6.5 GPS Antenna

The cabinet on the ‘level 0’ that contains the electronics box and the batteries, has a lid that opens from the front. The front of the lid on ‘level 1’, has a fastener holding the GPS antenna perfectly. The GPS requires no weatherproofing.

4.6.6 Laptop

The top of the lid on ‘level 1’ has a compartment for placing the laptop. The compartment is built of dimensions accommodating a 15” screen laptop perfectly. It has holes for vents to prevent overheating of the processor due to a solid floor. Since the floor of this compartment is the lid of the cabinet, there is a single layer of PVC sheet instead of two. The laptop compartment also has a lid for protection.

4.6.7 Battery Indicators

The PVC sheet covering the rear of the bot has slots cut, to place the sensors that read the voltage of the battery throughout the run of the bot. The slots are dimensioned according to the specific sensors, making a friction fit. The sensors are enforced along the slot sides, sealant is used for waterproofing.

4.6.8 Mechanical E-stop

As specified by the IGVC guidelines, the mechanical e-stop is mounted at a height of over 2 ft in the rear center of the bot. The pole is extended from the bot’s rear center and houses a 3D printed ABS case for the e-stop. The case is a friction fit with the e-stop, held on the top of the pole with the help of nuts and bolts.

4.6.9 Router

A router for providing a network for communication has been attached to the pole supporting the mechanical e-stop. Enclosed within a plastic box, slots for connections have been cut and secured with a sealant.

4.6.10 Cooling Fans

The bot has a 3 fan system for ventilation and circulation of air within the bot. Two fans allow an inlet of air into the bot with one fan allowing outlet to the air containing the dissipated heat. The cooling fans are placed on both the side walls and the rear wall of the bot with the help of fasteners attached to the particle board, held in the slot on the PVC sheet with adhesive.

4.7 Weatherproofing

1. PVC (Poly Vinyl Chloride) foam board of 12mm thickness provides a cover to the entire bot. The gaps and edges are covered with silicone gel sealant and rubber padding sheet to make it completely waterproof.
2. The cooling fans have covers to seal off the gaps.
3. The mount for the camera is designed with 3D printed ABS material, with hood to protect it from rain.
4. A plastic box encases the router to protect it from moisture. The connections are secured in the cut slots with a sealant.
5. A case is made with PVC foam board, for the laptop, that is placed on top of 'level 1'.
6. The GPS antenna has an enclosure rating of IP69K.
7. The LiDAR has an enclosure rating of IP67.
8. The payload is placed in the front, protected with a plastic rain cover which can be removed as per requirement.

4.8 Lack of suspension

Using a suspension system was found to be unnecessary as the intended surface on which the bot would travel is relatively flat with minor irregularities. The vibrations are of low amplitude and can be dealt with by employing rubber paddings in critical areas and proper fastening of components.

A suspension system will add to the cost and weight of the bot along with the complexity of design. Hence, it was decided against using a suspension system.

4.9 Dimensions and Specifications

Length x Breadth x Height	36.6 x 26 x 13 in.
Aluminum frame weight (approx.)	10 kg
Gross weight (approx.)	60 kg
Ground clearance	9 in.
Height of camera pole	27.25 in.
Aluminum Alloy used	Aluminum 6061
Flooring material	PVC Foam Board
Drive wheel diameter	8 in.
Castor wheel diameter	5 in.

5. Description of Electronic Design

5.1 Overview

The electronics is divided into two broad classifications: data acquisition devices and data implementation devices.

The bot is capable of running in manual and autonomous modes. The failsafe measures include a wireless E-stop apart from the manual E-stop.

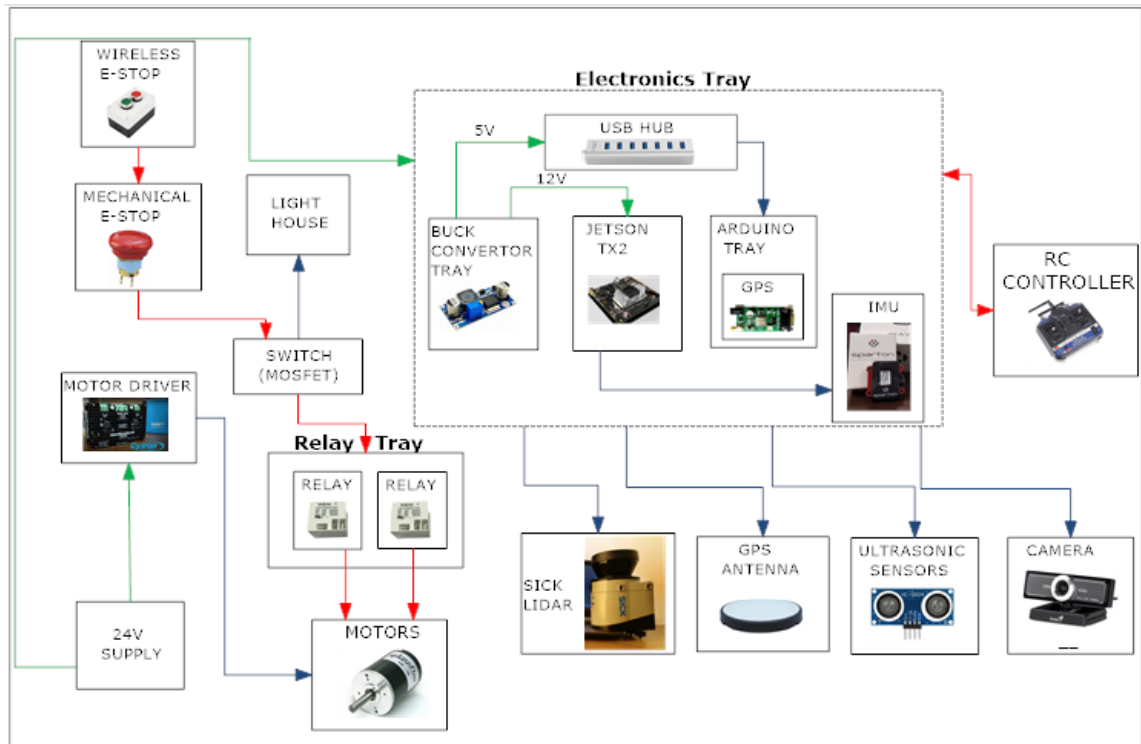


Figure 6: Electronics Layout

5.2 Data Acquisition Devices

5.2.1 GPS:

Skyfi labs SKG13BL has been used as the GPS receiver. The reason for using SKG13BL is because it has optimum accuracy required for waypoint navigation. The GPS signal is transmitted through serial communication to the mini PC.

The active antenna Hemisphere A45 is used with the GPS to increase its sensitivity.

5.2.2 LiDAR:

SICK LMS111 is a 2D LiDAR is being used by the bot. It has an angular field of view of 270° with resolution of 0.25° (to detect the surrounding with a precise detail) and a scanning frequency of 25Hz. The reason behind choosing SICK LMS111 over the previously decided Slamtec RP LiDAR is its angular resolution. The angular resolution of Slamtec was not enough to detect the prototype of mesh.

5.2.3 IMU:

Sparton AHRS 8P is being used as the IMU (Inertial Measurement Unit) for deducing the attitude of the bot like acceleration, direction and orientation. It is fully temperature calibrated to adjust to different temperature conditions in India and the US. The IMU data is acquired by its own custom breakout board.

5.2.4 Camera:

Genius WideCam F100 wide angle camera was chosen over two normal cameras to reduce the hardware and facilitate easy mounting. The field of vision obtained by modifying the two input feeds from two different cameras can be obtained by a single camera without any modification. In addition to that, it has manually adjustable zooming.

5.3 Data Implementation Devices

5.3.1 Motors:

Ampflow E30-150 is the motor used as it has a stall torque of 52 kg-cm which is required for the bot as per the calculations based on the weight, and the gradient of the slope in the track along with other parameters.

5.3.2 Motor Driver:

Cytron MDDS60 is the chosen motor driver because it can supply 60 Amps continuously and provide upto 100 Amps (only for a second). The maximum current intake of each motor is 61 Amps. Using these motor drivers, the motors run within a safe limit without damaging any components. An onboard temperature feedback for current limitation prevents the overheating of the MOSFET.

5.3.3 Encoder:

RMCS-5102 is an industrial grade optical encoder. It has an angular resolution of 0.09° and PPR(pulse per revolution) of 1000. Higher the encoder count, better the localization of the bot.

5.3.4 Light House:

The Light House has red and blue color LEDs. The red LED indicates the switch between the autonomous and manual mode according to the IGVC guidelines. The blue LED indicates the engagement of mechanical or wireless E-stop.

5.4 Safety Devices

5.4.1 Wireless E-Stop & E-Start:

The wireless E-Stop is a custom-made control, which when activated shuts down only the motor via two relays without disconnecting the main power supply. The wireless E-Start on the other hand, restores power to the motors.

5.4.2 Ultrasonic Sensors:

The ultrasonic sensors are used as a failsafe backup measure. If the bot gets too close to an object, the Arduino can take control until the bot is at a desired distance from the object.

5.5 Power System:

The main power unit is composed of two 12V (Lead acid) batteries connected in series to obtain 24V, as when required. Not all components run solely on either 12V or 24V supply. Hence different supply options are kept available for operation.

The power distribution table of all the electronic components is as given as follows:

Sensor	Power Consumption (max)	Voltage Range	Operating Voltage	Sources
Cytron MDDS60 Motor Driver	745W	7-45V	12V	12V Direct Source
AmpFlow E30-150 Motor	372.85W	12-36V	12V	Motor Driver
LMS111 LiDAR	60W	10.8-30V	12V	12V Direct Source
Skyfi labs SKG13BL GPS	85.8mW	3-4.4V	3.3V	5V buck converter
Hemisphere A45 Antenna	375mW	3.3-15V	3.3V	GPS via coaxial cable
Sparton AHRS 8P IMU	330mW	4-10V	4V	From USB Hub
Genius WideCam F100	2.5W	5V	5V	From USB Hub
Ultrasonic Sensor HC-SR04	75mW	5V	5V	From 5V buck converter
Jetson TX2	7.5W	12V	12V	12V buck converter

5.6 Innovation:

System Tray:

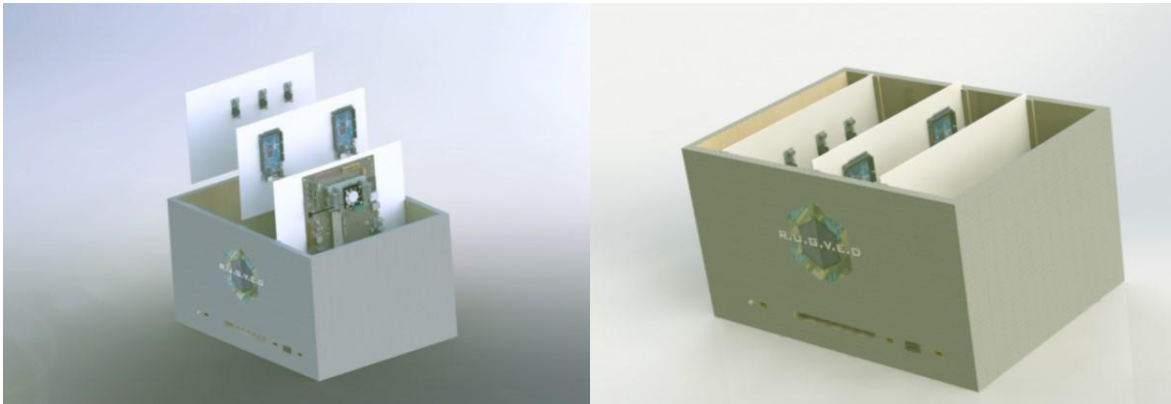


Figure 7: System Tray

1. System Tray houses mini PC, GPS, IMU and power distribution circuit. The purpose for making of the System tray is to allow quick debugging, placing of components and their replacement if required, apart from judicious use of space inside the bot.
2. The wiring in the tray is color coded for easy understanding and debugging
3. The connectors used, namely DB connectors and JST connectors, provide modularity allowing for neat placement and easier replacement of the components.
4. Each tray has a unique function:
 - a. The first tray houses the NVidia Jetson- the mini PC.
 - b. The second tray houses two Arduino Mega on one side along with a GPS module and an Arduino Uno on the other.
 - c. The third tray has buck converters on one side and a router on the other.

6. Description of Software Strategy

6.1 Overview

The bot's AI stack is written in C++ and Python and uses ROS Framework along with OpenCV libraries for Perception, Mapping and Navigation. It uses NVIDIA's Jetson TX2 for all the processing onboard. ROS (Robotics Operating System) has been used extensively as it provides a very powerful framework for developing and deploying autonomous robotics systems. It has support for many device drivers that seamlessly integrate into the bot.

6.2 Perception

6.2.1 Obstacles: The SICK LMS111 LiDAR is being used as the primary depth sensing device.

6.2.2 Lane and Pothole Detection: The detection of lanes and potholes is mainly achieved through contour detection using OpenCV. A detailed procedure is given below:

1. Gaussian blurring is applied to the image obtained from the camera which helps in reducing the noise from the filters that are applied later to the obtained image.
2. The image is converted to HSV and thresholds are used to extract only the white pixels from the image to get a brief outline of the lanes and potholes.

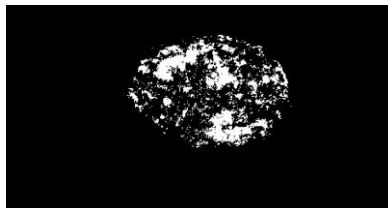


Figure 8: Processed potholes

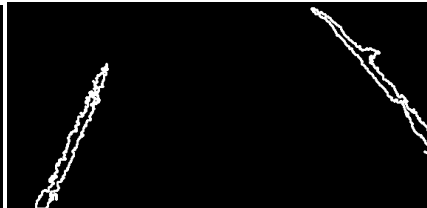


Figure 9: Processed lanes

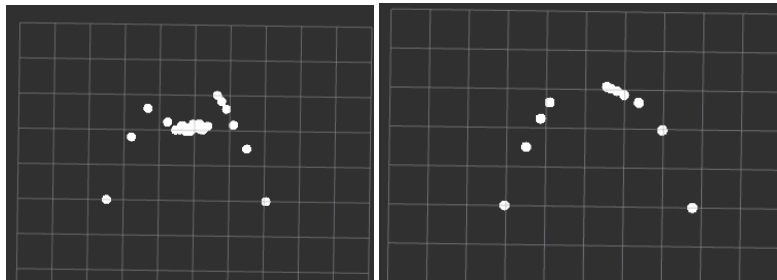


Figure 10: LaserScan of lanes and potholes visualised in RVIZ

3. The masked image obtained after HSV thresholding is gray-scaled so as to reduce computation while extracting contours.
4. Lanes and potholes are filtered from the gray-scaled image using OpenCV contour functions.
5. These lanes and potholes obtained are converted from rectangular pixel coordinates to polar coordinates after inverse perspective transform.
6. Finally, pixel to distance is applied and the coordinates are sent as a separate LaserScan data to the path planner to be updated in the costmap.

6.3 Localization

Localization is a technique by which the robot can orient and position itself correctly in an environment. The odometry extracted using the encoders is fairly accurate. However, it is possible that the encoder readings are faulty due to slippage.

The bot fuses the inertial measurements, global positioning with the odometry, using an Extended Kalman Filter. The EKF will give a filtered odometry as output.

6.4 Map Generation

The bot uses the ICP (Iterative Closest Point) algorithm based SLAM technique to map the course. ICP is a scan-matching algorithm which iteratively revises the transformation (combination of rotation and translation) to minimize the difference between two points in laser point cloud.

The SLAM algorithm is a simple incremental map building process which uses ICP to align the 2D laser scans to an occupancy grid map, which is the global reference frame as the global map.

6.5 Path Planning

The Auto-Nav course requires the bots to avoid obstacles as they traverse through the waypoints. This is achieved by the path planning stack which is divided into costmap generation and motion planning. Costmap is of two types: the local costmap and the global costmap. The global costmap references the map generated by mapping algorithm and the local costmap uses data from sensors to avoid obstacles in the immediate vicinity of the bot. The innovative approach taken by the bot's perception stack, enables it to take in two laser scans (one from LIDAR which detects obstacles and the other from camera which detects white lanes and potholes) as observation sources and updates the costmap.

The traditional path planners like Dijkstra's and A* require the bot to process the information regarding the map of its environment prior to the waypoint navigation. Dijkstra's always looks at the point of interest nearest to the start, so when the bot finally reaches the goal, it knows that the path it took to get there was the shortest. A* is very similar to Dijkstra except that it incorporates a guesstimate to calculate closeness of the given location to the goal. It does so by avoiding looking at certain places by having information of the bot's surroundings. The cumulative perception of the IGVC environment poses a huge problem for the algorithms mentioned above as each time the bot sees something new, the previous path is no longer valid.

To solve this problem, the bot uses D* lite which can plan and replan paths in real time in a dynamically changing environment. D* lite does not completely ignore the information of the environment other than the current path to the goal. This helps the algorithm to update the current path instead of entirely recalculating it, reducing the time taken for both path generation and following.

6.6 Additional Creative Concepts:

A diagnostic tool called Rugved Autonomous Diagnostic System or RADS has been developed to provide basic information about the status of the bot. The tool can be accessed via a Web Browser, Android App and a Desktop app.

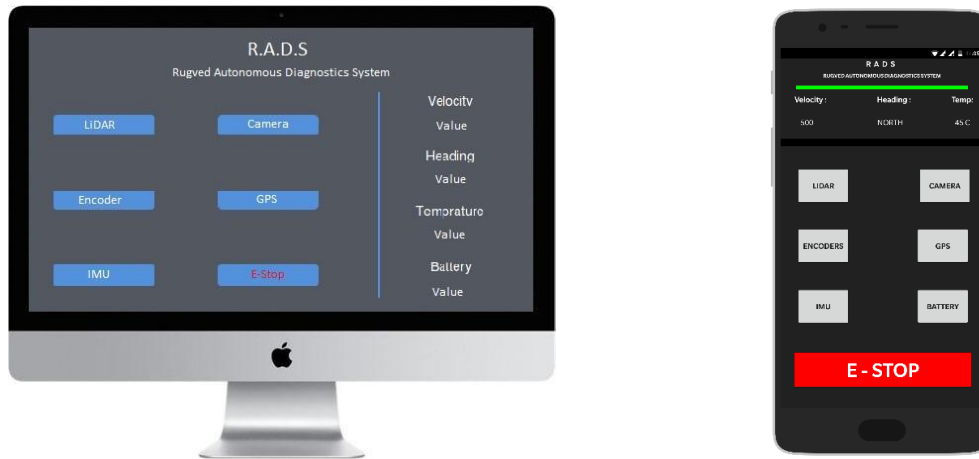


Figure 11: Rugved Autonomous Diagnostic System or RADS

7. Failure modes, Failure points and Resolution

7.1 Software Failure Mode and Resolution

- a) Path Planner unable to find a valid path: The bot shuts down all planning and mapping nodes, delete their data and restarts them. In case this doesn't work, the bot will travel 0.5 meters back and then nodes would be restarted with current waypoint as goal.
- b) Vision: The color of the lanes and potholes as perceived by the camera varies a lot with the amount of sunlight. The color difference can cause the lanes and pothole detection nodes to fail. To avoid this, the bot uses dynamic color mapping which brings down the role to color change to a minimum.

7.2 Electronics Failure Mode and Resolution

- a) Sensors failing due to unforeseen conditions: The sensors are arranged in such a way that they can be replaced in a short time. Backup sensors are also integrated.

8. Simulations Employed

8.1 Mechanical simulation

Analysis was performed on the chassis as a whole as well as individual components with concentrated and distributed loads on SolidWorks. The design was improved so as to prevent any stress concentrations. Initial tests showed weak points at many joint locations hence the material thickness of pipe was increased from 1.5mm to 3mm. In addition to that, reinforcement members were added.

8.2 Software simulation

The software stack was tested on ROS compliant physics engine Gazebo.

9. Performance Testing

9.1 Mechanical: Testing was done by running the bot on various surfaces such as asphalt road, concrete, grass etc. in straight line and through turns of different curvatures.

9.2 Electronics: All the sensors and connections were tested individually in the workshop before being put together on the bot to ensure proper connections and avoiding mishaps in future.

9.2 Software: To test the software stack, the data from sensors was collected manually and then simulations were run based on that data. After satisfactory results, the stack was tested on a custom grass track.

10. Initial Performance Assessments

During the initial performance testing, the bot's performance was as expected, except the camera vibrations which were due to the height of the pole it is mounted on. Better fastening of the pole and new mount for the camera solved this issue to a great extent. The Electronics and Software stack performed as anticipated.

11. Cost Estimate

S.No:	COMPONENTS	QTY	COST (INR)
1	JETSON TX2	1	67999
2	SPARTON IMU	1	91536
3	GPS	1	1100
4	HEMISPHERE A45 ANTENNA	1	95362
4	GENIUS WIDE ANGLE CAMERA	1	6600
5	ROTATRY ENCODERS	2	2500
6	CYTRON MOTOR DRIVER	1	13799
7	RADIO CONTROLLER	1	5000
8	RADIO FREQUENCY MODULE(NRF2L101)	1	790
9	ARDUINO	4	1500
10	BUCK CONVERTOR	3	450
11	GAUGEWIRES	3	990
12	AMPFLOW MOTORS	2	33,000
13	SICK LIDAR	1	386669
14	ALUMINIUM 6061 PIPES FOR CHASSIS	NA	6500
15	WELDING AND MACHINING	NA	5500
16	PVC SHEET FOR BODY	NA	3700
17	3D PRINTED MOUNTS	2	3520
18	MISC (FASTNERS)	NA	1100
	TOTAL		727606

This converts to US\$ 10,732 (approx.)