MOKSHA

Unmanned Ground Vehicle

M. S. Ramaiah Institute of Technology, INDIA

Intelligent Ground Vehicle Competition (IGVC 2012)

Faculty Advisor Declaration

This is to certify that the design and the implementation of the vehicle by the current student team has been significant and can be awarded credit in a senior degree course. The current student team has made significant improvents to the hardware and software design as compared to the previous year's team.

Dr. S. Sethu Selvi
Faculty Advisor

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1 Introduction

The robotics club of M. S. Ramaiah Institute of Technology (RoboMSR) presents MokshaUGV for the third consecutive year in this prestigious event. This year's vehicle is an improvised version of the previous one and has been a collaborative effort from a multidisciplinary nine-member team. Significant improvements have been made in terms of applying better algorithms and use of better hardware components to improve reliability and performance of the vehicle. The objective of this project was to build an autonomous ground vehicle capable of following a prescribed lane while avoiding obstacles in its path and navigate to the prescribed destination.

1.1 Design Innovations

The vehicle has undergone a few changes in the hardware and software departments leading to better performance, higher reliability and economical design. The key innovations have been described in the following sections.

1.1.1 Hardware Innovations

- **Modular Split Frame Construction:** Traditionally, ladder frame chassis have been used in the construction of vehicles bound to move on uneven terrain. However the recent time has seen the development of new chassis technology called Monocoque construction in which the entire body acts as the frame. The major cost imparting factor in these two technologies is development of suspension.
  This year's chassis is based on Split Frame Technology that includes suspension within the frame. The modular construction has enabled packing of the entire vehicle into a suitcase eliminating shipping costs. The dismantled vehicle is shown in Fig. (6).

- **Dynamic Map Construction Using Sweeping Sonar:** The use of a Servo to perform a panoramic sweep is incorporated into the design. This data is used to create a map of the frontal surroundings.
  The use of the servo has eliminated the usage of multiple sonars, thereby, making the design economical.

- **Dual Camera Processing:** Conventionally, Team Moksha has been using a single camera for computer vision i.e., detection of lanes. To overcome the limitations encountered by the previous versions, dual camera processing has been incorporated. The concept of dual camera was inspired by the chameleon's visual perception. This technique has led to a better field of vision (double compared to previous versions) which in turn improves the ability of the vehicle to understand its position relative to the lane.

- **Low center of gravity:** The placement of motors, motor-controller and the payload close to the ground has ensured a lower center of gravity. This improves the overall stability of the vehicle on uneven terrains.

1.1.2 Software Innovations

- **Compass-less algorithm for direction control:** This algorithm enables direction control without the use of an external compass. This is achieved by extracting the magnetic course over ground angle from the GPS data, that is mapped to the cardinal directions to act as an external compass.
- **Sonar Map Thresholding :** This algorithm thresholds the values into various zones depending upon distance. These zones are classified on a custom protocol and the most optimum direction is chosen for the vehicle, this signal is fed to the motor controller.

2 Planning Process

The entire project was carried out with a lot of planning. The team involves the following disciplines : Electronics & Communication, Instrumentation Technology, Computer Science and Mechanical Engineering. The team hierarchy is shown in Fig. (1).

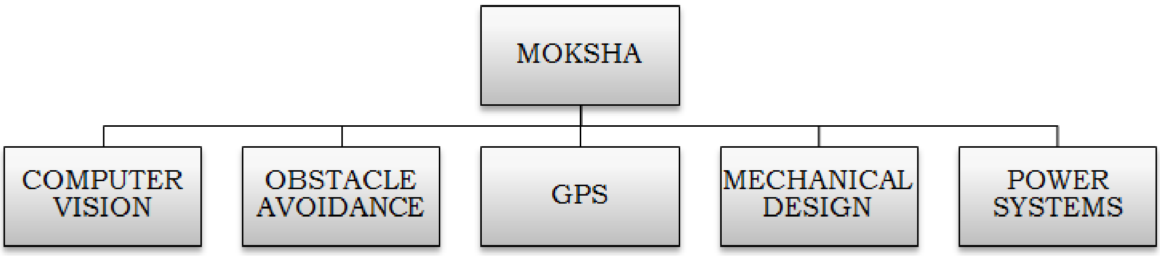


Figure 1: Team Hierarchy

Work classification among various team members is shown in Table (1).

Name	Branch	Year	Input Hours	Work Area
Abhilash C.	ME	III	100	MD
Charan S. G	ECE	II	150	OA
Divakar P. C	IT	II	150	GPS
Naveen R. Iyer	IT	II	200	GPS, FM
Nishcal K. N	ECE	II	200	CV, PS
Nitin J. Sanket	ECE	III	200	OA, PS
Nitish S. Prabhu	ECE	II	150	OA
Prajwal C.	ECE	II	150	CV
Sandeep G. S. P	ECE	III	200	GPS, PS

Table 1: Work Classification (MD - Mechanical Design, OA - Obstacle Avoidance, FM - Finance management, CV - Computer Vision, PS - Power Systems)

The project timeline is illustrated pictorially using a Gantt chart. The Gantt chart is shown in Fig.(2).

3 Mechanical Design

The main goal of the mechanical design is to provide a versatile platform such that the hardware and software can work in unison. Moksha uses a

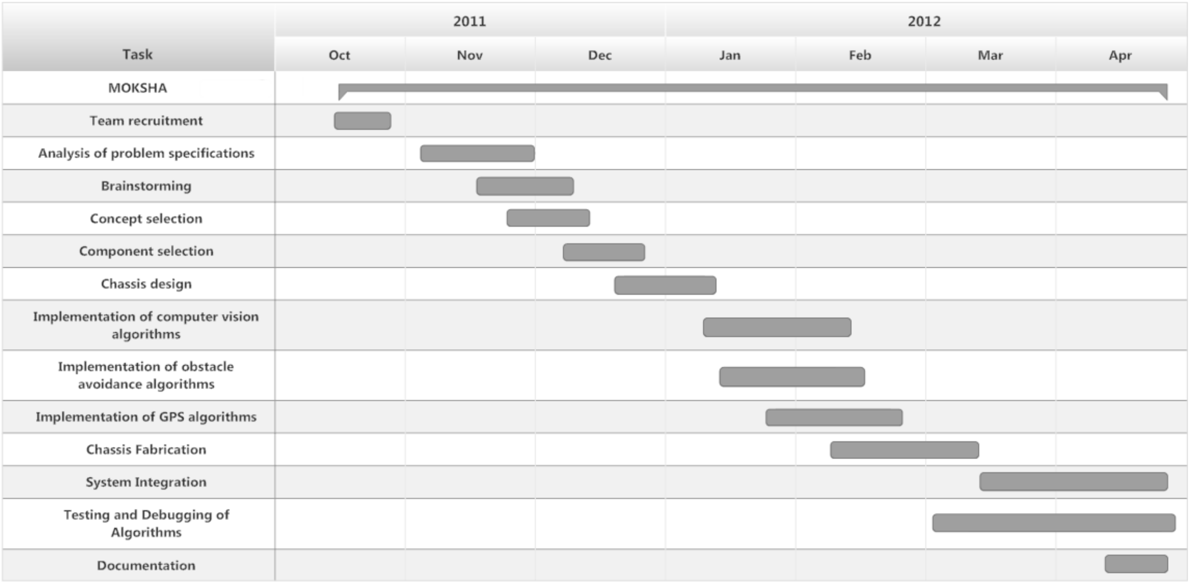


Figure 2: Gantt Chart

modular split-frame constrcution thus enabling reusabilitiy, upgradability, better stability for sensors and multi-terrain maneuverability. The split frame technology is a unique design wherein the chassis is divided into two parts which are interlinked to one another via a revolute joint placed at the center. The front and the rear portions of the chassis have independent motion thereby integrating suspension into the design.

The body of Moksha 2012 incorporates design features such as safety, rigidity, ease of access, efficient space utilization and appealing aesthetics into its design. The chassis was designed on SolidWorks (CAD Tool). The CAD models are shown in Fig. (3).

The mild steel plates were laser cut and bolted together to form a rigid structure. The chassis components were made weather-proof by a coating of primer and multiple layers of enamel paint. The vehicle after fabrication is shown in Fig. (4a), (4b) and (4c). A poly-urethane housing (Fig. (5)) with resin coating is used for the processing unit.

(a) Front View (b) Isometric View (c) Side View

Figure 3: CAD Design

(a) Front View

(b) Isometric View

(c) Side View

Figure 4: Actual Vehicle

Figure 5: Poly Urethane Housing for the Processing Unit

Figure 6: Dismantled Vehicle

The mechanical specifications are shown in Table (2).

Chassis Material	Mild Steel
Body Material	Poly urethane Foam with Resin Coating
Chassis Protection	Enamel Paint
Length	112 cm
Width	89 cm
Height	101 cm
Ground Clearance	8 cm
Chassis Weight	50 kg
Overall Weight	80 kg
Wheels	4 (2 Castor)
Maximum Payload Capacity	25 kg

Table 2: Mechanical Specifications

4 Electrical Systems

The power system of the vehicle is divided into various genres as described in the following subsections:

4.1 Power Supply

The vehicle is powered by a 12V, 34Ah maintainance-free lead acid battery for high current devices. The battery is connected to the vehicle's power supply board using 14AWG wires having a maximum current rating of 32 Ampacity. The 5V low current electronic circuits in the vehicle are powered via the USB port of the on-board processing unit.

4.2 Motors

The vehicle is equipped with two castor wheels in the front and two rear wheels of bigger radii attached to the high torque Motion Tech DC brushed motors. This difference in front and rear wheel radii has been inspired by F1 cars so as to increase the rear wheel grip, improve handling and thereby reducing the turn radius of the vehicle. Power consumption of the motor is rated at 450W with a maximum current rating of 4A and a maximum voltage rating of 24V. The motors are coupled to a gear reduction system with a gear ratio of 25:1.

4.3 Motor Controller

The Motor demands a high power motor driver such as 18v15 from Polulu Electronics. The versatility of this driver makes it suitable for a large range of currents and voltages. This module can deliver upto 15A of continuous current (without a heat sink) and a maximum continuous current of 21A (with a heat sink). The logic connections are designed to be interfaced with 5V systems. Microcontroller feeds the data into the motor-controller via the PWM signals to control the speed of the motor. The motor driver supports PWM frequencies as high as 40 kHz, though higher frequencies result in higher switching losses in the motor driver.

4.4 Sensors

The vehicle is governed by an array of sensors with varying power requirements as shown in Table (3).

Device	Qty.	Max. Current (A)	Max. Voltage (V)	Pmax (W)	Ptotal (W)
Motor	2	04.80	24	115.2	230.4
Servo Motor	1	0.150	05	0.750	0.750
Sonar	1	0.003	05	0.015	0.015
Camera	2	0.006	05	0.030	0.060
GPS Module	1	0.110	05	0.550	0.550
Motor-controller	2	03.00	12	36.00	72.00
Microcontroller	2	0.0036	05	0.018	0.036
Processing Unit	1	04.50	12	054.0	054.0
Total Power (W)					357.811

Table 3: Power Rating of various Components

5 Safety

The primary concern of an autonomous vehicle is safety. To ensure a strong and durable vehicle that is capable of operating safely and reliably, Moksha UGV includes several features that not only contribute to its performance, but also increase its safety, reliability and durability.

5.1 Mechanical E-stop

Mechanical E-stop is a mechanical switch used to cutoff the main power supply to the vehicle in emergency situations.

5.2 Wireless E-stop

In an unmanned vehicle there is a absolute necessity of having a external master control. For this purpose a radio link has been designed between the vehicle and the wireless emergency switch. The radio link operates at a sub 1 GHz frequency enabling it to be controlled from a range of about 100m with an antenna of length 22cm. This setup has been successfully tested upto a range of 100m.

6 Software Strategy

6.1 Computer Vision

Computer Vision demands for detection of the lane and to sustain the vehicle within the course. Two web-cameras of native resolution $(640 \times 480)px$ are used to achieve a better field of view. As mentioned earlier in the design innovations section this strategy enables the vehicle to better understand its relative position with respect to the lane.
The algorithm used is described below:

- Read live video feed from both the cameras.
- Extract Blue component from the frames chosen and apply Discrete Cosine Transform (DCT) depicted by Eq. (1) then the image is reconstructed using IDCT depicted by Eq. (2) after feature extraction.

$$X_{n1,n2} = \sum_{k1=0}^{K_1-1} \sum_{k2=0}^{K2-1} x_{k1,k2} \cos\left[\frac{\pi}{N_1}\left(n_1 + \frac{1}{2}\right) k_1\right] \cos\left[\frac{\pi}{N_2}\left(n_2 + \frac{1}{2}\right) k_2\right] \quad (1)$$

$$x_{n1,n2} = \sum_{k1=0}^{K_1-1} \sum_{k2=0}^{K2-1} X_{k1,k2} \cos\left[\frac{\pi}{N_1}\left(n_1 + \frac{1}{2}\right) k_1\right] \cos\left[\frac{\pi}{N_2}\left(n_2 + \frac{1}{2}\right) k_2\right] \quad (2)$$

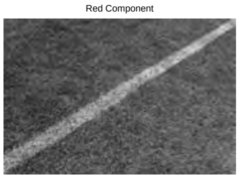
  Here, $X_{n1,n2}$ - 2D DCT Coefficients, $x_{n1,n2}$ - reconstructed image, N_1 and N_2 - dimensions of the image.

- Threshold the frame to obtain a binary image. To this binary image apply Canny Edge Detection (CED) followed by Hough Transform (HT) to obtain lines in the image.
- The area with the maximum concentration of lines is selected and the relative position of the vehicle with respect to the lane is sent to the decision algorithm of the motor controller.

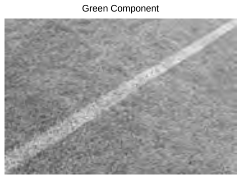
Qualitative Analysis:

- The input image is shown in Fig. (7a). The Red (IR), Green (IG) and Blue component (IB) images shown in Fig. (7b), (7c) and (7d) respectively. The histograms of IR, IG and IB are shown in Fig. (7e), (7f) and (7g) respectively.

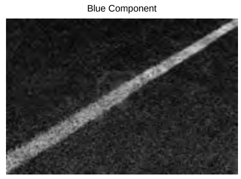
(a) Input Image (I)



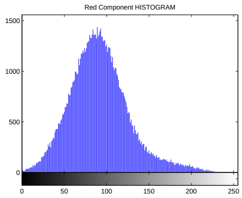
(b) Red Component (IR)



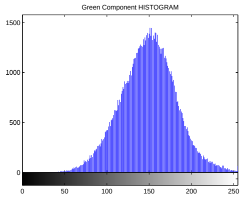
(c) Green Component (IG)



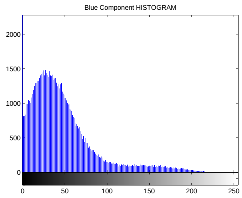
(d) Blue Component (IB)



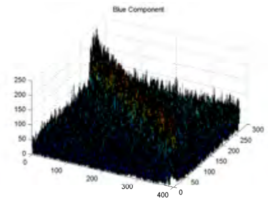
(e) IR Histogram



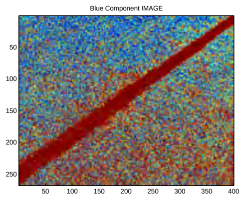
(f) IG Histogram



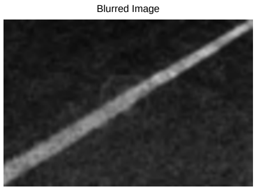
(g) IB Histogram



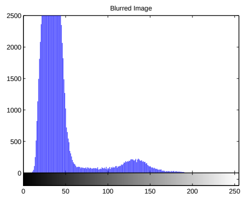
(h) Surf Of IB



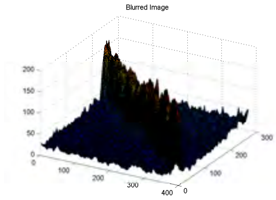
(i) Image Plot Of IB



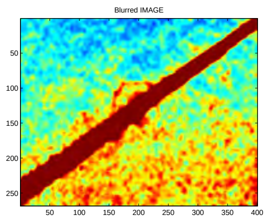
(j) Blurred Image of IB (BR)



(k) BR Histogram

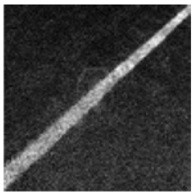


(l) Surf Of BR

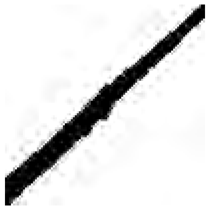


(m) Image Plot Of BR

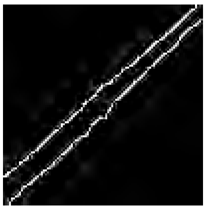
(n) Colormap Of DCT Coefficients



(o) Output After IDCT



(p) Output After Thresholding



(q) Output After Canny Edge Detection

(r) Output After Hough Transform

Figure 7: Stepwise Output of Lane Detection Algorithm

The green and blue components show the minimum and maximum classification of features between the grass areas and the white lines. However, due to reflection from the water droplets on the grass, Gaussian Noise appears on the image as small white dots i.e. bright dots on all the three components of the image. To improve the overall signal to noise ratio of the image, blurring operation is carried out. This can be represented as the difference between the largest peak (Lane) and the local maxima (Noise peaks) as a surface plots shown in Fig. (7h) and (7l). Noise appears as red dots in Image plot as shown in Fig. (7i) and (7m). The blurred image is shown in Fig. (7j). It can be clearly observed from the surf and image plots that signal to noise ratio drastically increases after blurring operation. A good classification between the pixels in the histogram is represented by a significant peak with a low spread value. The blurred image also provides a clear classification between the lane and the grass areas as presented in Fig. (7k).

- White lines being blobs of low frequency components, it is desired to remove the high frequency noise components such as grass blades and false reflections. DCT is a frequency based feature extractor. As mentioned before, white lines are blobs of low frequency that need to be classified by rejecting the higher frequency components. DCT moves all the low frequency components to the top left corner of the array as depicted in Fig. (7n) . By extracting only the left corner of the array, we eliminate almost all the high frequency components. This also reduces the image size by a significant factor. By applying IDCT, we get back the image as shown in Fig. (7o) which is used for further processing.
- Thresholding is the process of converting a grey scale image into a binary image .i.e., converting 0-255 scale to binary scale based on a predefined threshold. The output after thresholding operation is shown in Fig. (7p).
- The Canny edge detection (CED) algorithm finds edges by looking for local maxima of gradient of the image. The gradient is calculated using the derivative of the Gaussian filter. This method uses two thresholds, to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges. Hence this method is more immune to noise and more likely to detect true weak edges. This algorithm detects the approximate lines in our algorithm. The output of CED is shown in Fig. (7q).
- The Hough transform is used in extraction of lines from the filtered image. It is used to obtain the average slope of the lines detected and its relative distance from the vehicle. The detected lane is shown in Fig. (7r).

6.2 Obstacle Avoidance

Obstacle Avoidance demands for avoiding collision with obstacles and navigating the path safely. Obstacle Avoidance is achieved with the help of a sweeping Sonar. Sonar (*SO*und *N*avigation *A*nd *R*anging) is a technique that uses sound propagation to detect the presence of the objects and to measure the relative distance between the source and the object. Sonar measures the distance to an object by measuring the time it takes for a pulse of sound (ultrasonic sound) to make the round trip back to the transmitter after bouncing off the object.

Brief description of Sonar working:

- A burst of ultrasonic sound from a transmitter is propagated in a given direction.
- A clock or timer is started at the time of transmission.
- The receiver picks up the reflected signal or *echo*.
- The clock is stopped as soon as the echo is received and the elapsed time is proportional to the distance.

The main advantage of using a Sonar is that it is a cost effective, reliable and an efficient way in object detection and avoidance. The major drawback of using a sonar is the fluctuation of readings with respect to atmospheric conditions (humidity and moisture content) and noise (internal and external). The Sonar is mounted on a servo and a panoromic sweep is performed. This data is used to create a map of frontal surroundings as mentioned in design innovation section. This map is thresholded and classified into various zones based on distance values as shown in Fig. (8) and Table (4). Based on a custom protocol the optimum direction is chosen for the vehicle and this signal is fed to the motor-controller.
The data obtained is converted to binary based on a threshold. A filtering algorithm filters out some of the noise. As mentioned earlier, sonar output is fluctuating, to reduce the effect of fluctuation of values, two scans are performed (clockwise and anti-clockwise direction). The sonar output is assumed to have a maximum of one bit in error out of eleven bits of data . Logical operations are carried out to minimize the error.

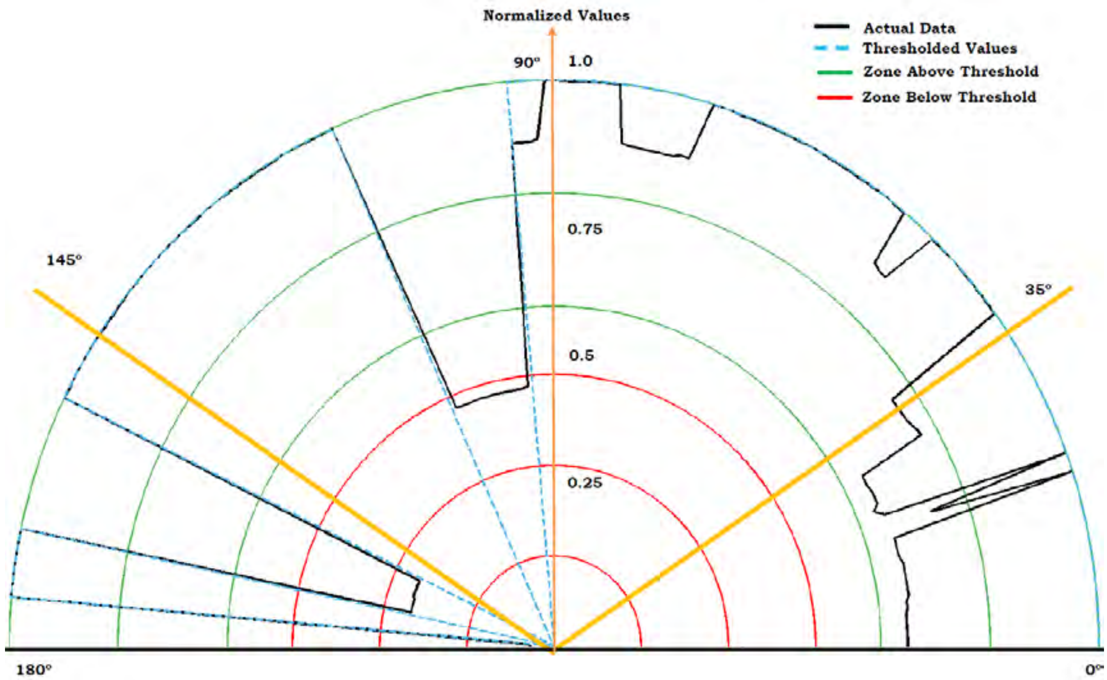


Figure 8: Panoramic Vision Plot of Sonar Data

Angle Min.	Angle Max.	Output Command
65	115	Forward
115	145	Left
35	65	Right

Table 4: Sonar Direction Classification

6.3 Waypoint Navigation

Waypoint navigation demands for navigating towards a destination coordinate using GPS data. A 12 channel Garmin GPS (Garmin OEM 18x) is used for the purpose of waypoint navigation. This module is a WAAS enabled module and can give an accuracy of less than 3 meters. Among the various NMEA 0183 data (industrial standards) that is procured from this module, $GPRMC string is extracted as it provides course heading angle along with the current latitude and longitude coordinates.

$$\$GPRMC, 155103, A, \mathbf{1301.1123}, N, \mathbf{01123.1234}, E, 000.2, \mathbf{057.9}, 230412, 079.2$$

The highlighted values are extracted from the string whenever needed and fed in to the decision program. A graphical understanding of algorithm is presented in Fig. (9).

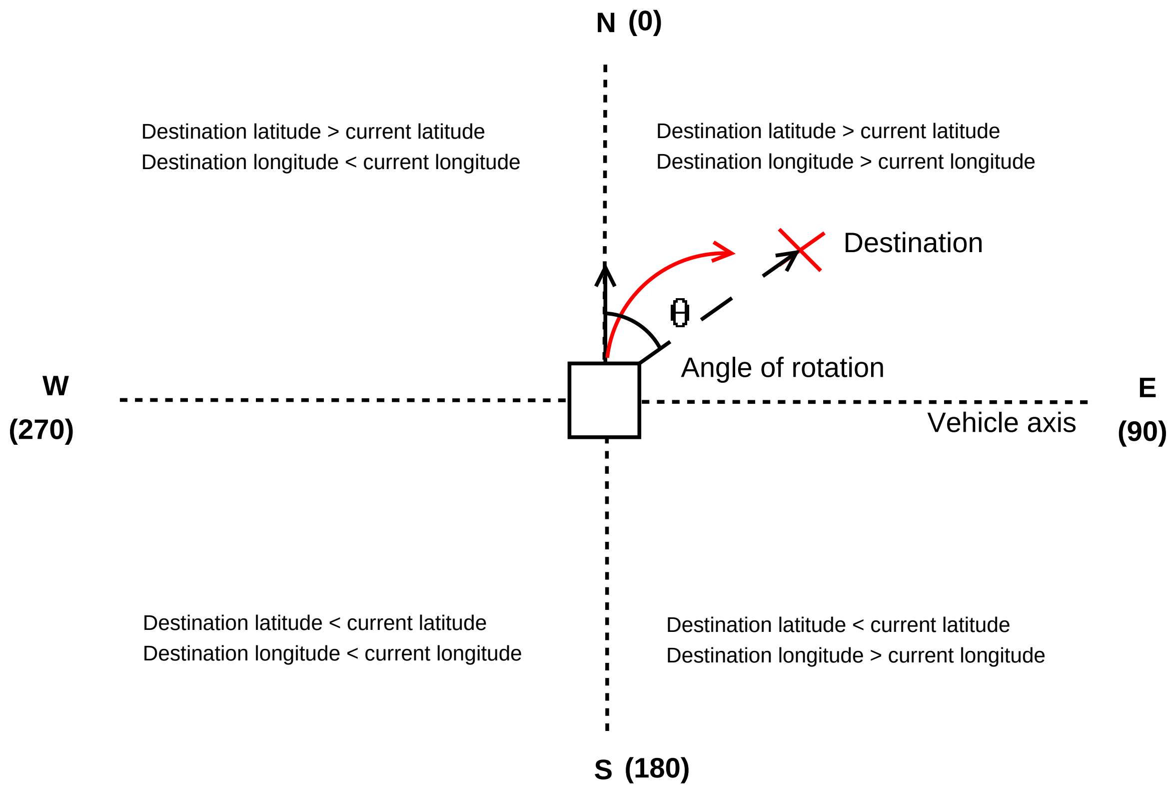
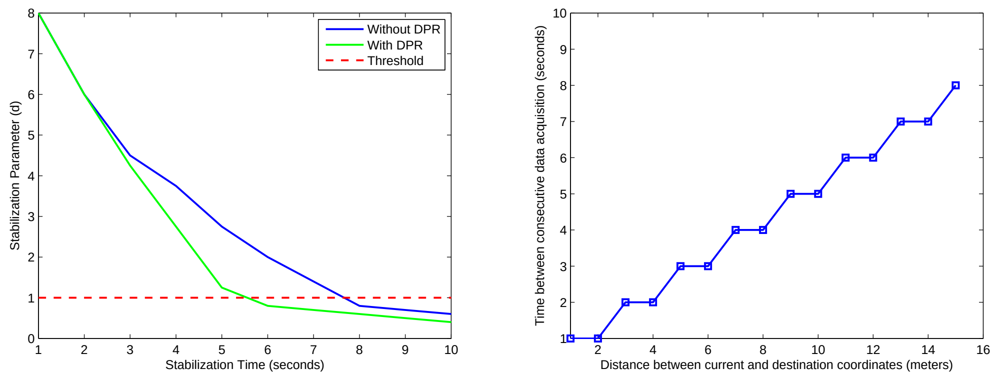


Figure 9: Graphical representation of algorithm

An improved compass less algorithm is developed by mapping the course heading angle given by the gps module with current and destination coordinates. The current coordinates is compared with the destination coordinates along with the course heading angle and direction of rotation is decided. Then the respective commands are given to the motor controller. The vehicle is halted for a certain amount of time (Stabilization time) to achieve stabilization of GPS coordinate values. The GPS module is capable of giving data every second. For the purpose of waypoint navigation a high rate of data acquisition is not required. Hence a novel algorithm called *Robust quantization* is deployed which decides the interval (Quantization Time) between two consecutive data samples. A plot of Quantization time versus the distance between consecutive co-ordinates is shown in Fig. (10b). The quantization time is varied in accordance to the distance between current and destination coordinates.

A significant improvement over the last year's algorithm is achieved by using *dynamic port reset* (DPR) algorithm. This opens the port only when the data is to be acquired, the port is closed after the acquisition of data. This has significantly reduced the Stabilization time as shown in Fig. (10a).



(a) Dynamic Port Reset

(b) Variation of Quantization Time

Figure 10: Evaluation of novel GPS Algorithms

6.4 System Integration

The collaboration between different modules is depicted in Fig. (11). The processing unit perceives its surroundings with the help of the following sensors: Two Cameras, Sonar and GPS module. The two cameras give the vehicle a view of the of the lanes in front. Sonar gives the vehicle a panoramic view of the frontal obstacles. GPS gives the course over ground inorder to reach the destination waypoint.

The computer vision algorithm and the obstacle avoidance algorithm work in tandem to give all possible routes avoiding the obstacles and keeping the vehicle within the lane. Upon the possibility of multiple choices, GPS algorithm prioritizes the desired choice. However, upon the occurrence of a single choice obstacle avoidance and computer vision are allocated the highest priority as compared to GPS. This technique of switching between the priority among the various sub systems dynamically is called as *Dynamic Priority Allocation (DPA)*. The combined signal is fed to the motor controller for movement of the vehicle.

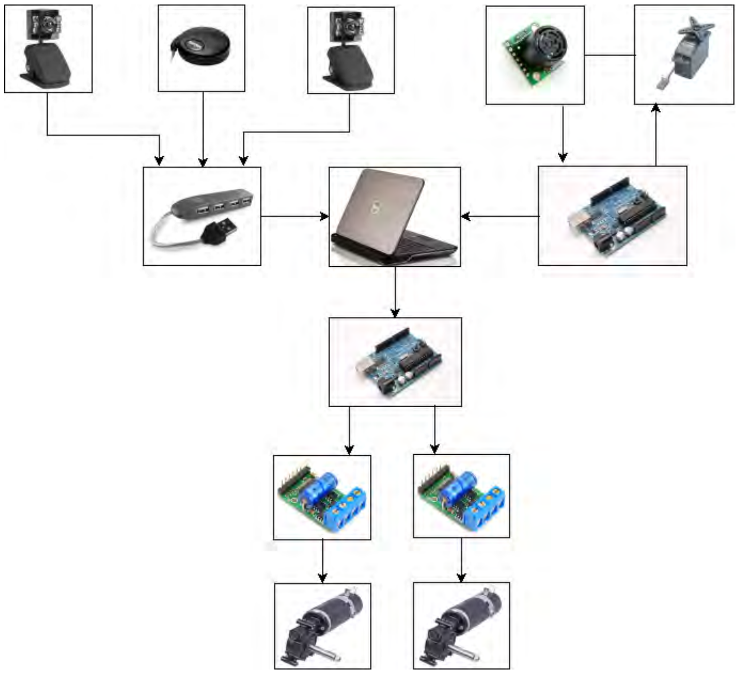
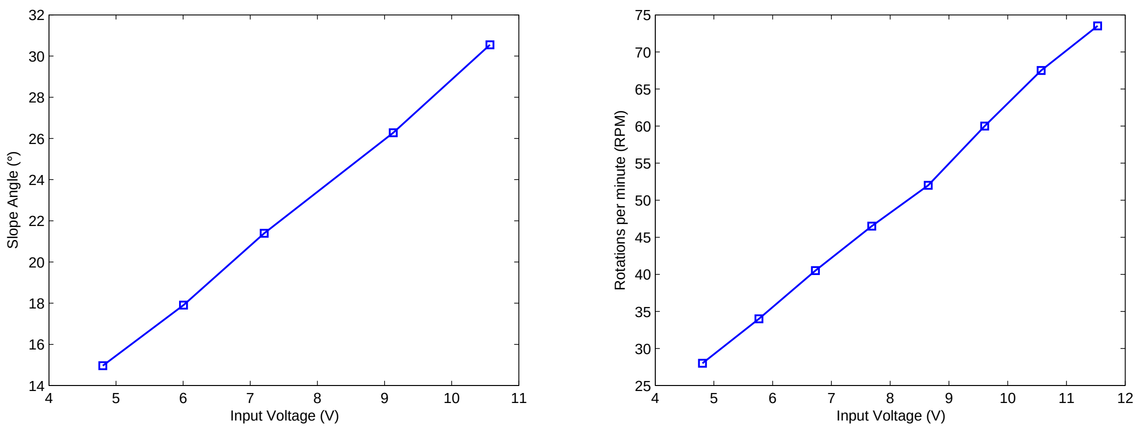


Figure 11: Interconnection of Various Sub-systems

7 Performance Evaluation

The analysis leading to the predicted performance of the vehicle is documented as follows :

- **Speed:** The vehicle makes use of two high torque Motion Tech DC brushed motors with a gear ratio of 25:1, individually. Diameter of the rear wheel is 32 cm and that of the front wheel is 21.5 cm. The tested speed of the vehicle with load is approximately 2.77 mph (74 rpm) and without load is 3.14 mph (84 rpm). (Fig. 12b).
- **Ramp Climbing Ability:** The ramp tests reveal that the vehicle stalls at an angle of 30 degrees and thus can ascend inclinations as per the IGVC standards. (Fig. 12a).



(a) Ramp Climbing Ability

(b) RPM Dependence on Voltage

Figure 12: Performance Evaluation Graphs

Coordinates	Sunny	Cloudy	Partially-Cloudy
Latitude (radians)	0.2274328	0.2274320	0.2274323
Longitude (radians)	1.3537679	1.3537686	1.3537684

Table 5: GPS Data obtained in different climatic conditions

- **Accuracy of arrival of GPS coordinates:** The GPS module used in Moksha UGV has an accuracy of less than 15 meters. The tests conducted in the absence of WAAS yielded an accuracy of about 12 to 18 meters, but since the competition is being held at a WAAS enabled arena, sufficient accuracy may be obtained to compete in IGVC. The actual GPS data obtained at the same position for different climatic conditions is shown in Table (5).
- **Distance at which the obstacle is detected:** The vehicles Sonar has a maximum range of 6.45m, which is much greater than the turn radius of the vehicle.

Other performance parameters are shown in Table (6).

Performance Parameters	Results
Maximum no load speed	3.14 mph
Maximum speed with load	2.77 mph
Maximum ramp climbing ability	30°
Maximum Tip-off angle	48°

Table 6: Performance Parameters

8 Cost Estimate

A detailed cost estimate is shown in Table (7).

Device	Quantity	Actual Cost	Cost to Team	Comments
Camera	2	$ 30.00	$ 30.00	-
Sonar	1	$ 50.00	$ 00.00	Previously Owned
Servo Motor	1	$ 10.00	$ 00.00	Previously Owned
Motor	2	$ 600.0	$ 00.00	Sponsored by Ostrich Mobility
Motor Controller	2	$ 90.85	$ 90.85	-
On-board computer	1	$ 1210	$ 00.00	Previously Owned
Vehicle Chassis	1	$ 300.0	$ 00.00	Sponsored by Ostrich Mobility
GPS Module	1	$ 70.00	$ 00.00	Previously Owned
Microcontrollers	2	$ 10.00	$ 10.00	-
Polyurethane Housing	1	$ 40.00	$ 00.00	Sponsored by ICP India
Battery	1	$ 60.00	$ 00.00	Previously Owned
USB Hub	1	$ 03.00	$ 03.00	-
Miscellaneous	-	$ 100.0	$ 100.0	-
Grand Total		$ 2573.85	$ 233.85	-

Table 7: Cost Estimate

9 Conclusions

Moksha is a constantly evolving UGV platform being equipped with improved hardware and software algorithms every year. Various novel algorithms such as panoramic sweep of sonar and Robust quantization are developed and were tested in the real world scenarios. The new algorithms and the updated hardware is expected to improve the performance this year.

10 Acknowledgement

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