

LAKSHYA



TEAM
UGV

LAKSHYA

The Unmanned Ground Vehicle

DESIGN REPORT



Delhi College of Engineering
Delhi, INDIA

Saurav Kumar, Puneet Kumar, Kaustubh Nehte, Varun Tangri, Shivangi, Varun Kaushik, Ankit Kukreja, Sankalp Arora, Sanjam Sidana, Sarabjot Singh & Mohit Kingra.

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INTRODUCTION

Team UGV from Delhi College of Engineering, New Delhi, INDIA presents 'LAKSHYA' - The Autonomous Unmanned Ground Vehicle. Lakshya, which means Target, is our entry to the most arduous international competition on Unmanned Ground Vehicles, i.e. IGVC 2008. The team comprises of only undergraduate students in their 6th and 4th semester of academic sessions and have designed and developed this vehicle in the last 15 months of their engineering career.

LAKSHYA is based on advanced engineering concepts and has everything which can challenge any engineering design. Based on highly precise cameras, lasers and sensors, Lakshya enters IGVC 2008 to set high standards. Robust mechanical design, powerful high level electronics and goal oriented intelligence are some of the features of this vehicle. This vehicle was made from the scratch and can operate on almost all terrains.

LAKSHYA is all geared up for IGVC 2008!

INNOVATIONS & DESIGN PROCESS

During the initial days of our work on this vehicle, we thought of a robust design, novel architecture and optimized software set that could shape this vehicle in to a commercial product rather than just being a robot. In process we came out with various designs and tested them from point to point for their mechanical advantages. The final design that we aim to bring for this competition is mechanically the most

DESIGN 1



Our first design. It was a 3 wheeled vehicle with an IC engine. It was controlled using a remote control having a range of 30 feet. It was rejected due to the lack of control in steering.

DESIGN 2



Our second design. This one was a 4 wheeled vehicle made up of iron. This chassis had the capability in rear wheels to rotate 360 degrees about the axis shown. This chassis was rejected due to its high weight and lack of suspensions.

DESIGN 3



Our third vehicle. This was a 4 wheeled vehicle and was expected to be our final design but was rejected due to excessive pressure on the shafts of the motors. This design was the best looking design with amazing sporty look.

advantageous design and holds the capability of running on rugged terrains and uneven surfaces and possess good ramp climbing capacity. The softwares that we have implemented on this vehicle are optimized. Parallel execution of multiple codes at a time required multi-threading to be introduced in our softwares and has been successfully implemented on this vehicle too.

TEAM STRUCTURE

NAME OF MEMBER	AREA OF WORK	QUALIFICATION
Saurav Kumar	Team Leader. Computer Vision and AI	Undergrad, 6th sem.
Puneet Kumar	Tech Head. Computer Vision and Programming	Undergrad, 6th sem.
Kaustubh Nehte	Programming and Communications	Undergrad, 6th sem.
Shivangi	Power Systems	Undergrad, 6th sem.
Varun Tangri	Hardware Design and Corporate Relations	Undergrad, 6th sem.
Varunn Kaushik	Public Relations	Undergrad, 6th sem.
Ankit Kukreja	Mechanical Design	Undergrad, 4th sem.
Sankalp Arora	Sensors and Embedded Systems	Undergrad, 4th sem.
Mohit Kingra	Programming	Undergrad, 4th sem.
Sanjam Sidana	Electrical systems and Safety	Undergrad, 4th sem.
Sarabjot Singh	Hardware Design	Undergrad, 4th Sem.

DESIGN DEVELOPMENT

Designing Lakshya was a big challenge for the team. We required a vehicle which should have the capability to navigate through uneven terrains like slopes and potholes and must still maintain its trajectory. Keeping in mind all those possible situations we came forth with a 4 wheel drive system with independent suspension powered by 2 DC Servo motors. This gave our vehicle a stable motion along with

greater control on steering. Wheels are connected to the motors by a gear reduction and a chain which provides the motion to the wheels. 4 suspensions provide the vehicle with greater shock absorbing capabilities.

CHASSIS



Original Chassis using Aluminum 6063.

The robot has a custom chassis, which was tailored to meet the IGVC requirements. The chassis is made of welded aluminum bars and sheet metal. The platform is strong enough to hold heavy weight of the payload as well as the batteries and sturdy enough to make sharp turns at 5 miles an hour. The whole system is compact and easily maneuverable. Two QUICKSILVER MOTORS are used to drive the vehicle.

Prior to actual construction of the robot, each component was designed and modelled in detail in an effort to minimize manufacturing mistakes and flaws. The layout of components and structure of the chassis were modeled using Solid Works, allowing for critical decisions regarding basic structure and available space to be made before actual manufacturing. A majority of the necessary parts were machined by students from purchased stock material. With the frame welded together, other parts such as the motors were mounted. Finally, additional components such as the sensors, camera, and electronics were added to allow the robot to function autonomously.

MOBILITY

The fundamental design of Lakshya is somewhat like a tank where the wheels are driven using motorbike chains. The four-wheel configuration provides a stable platform for all the components. The functionality of the robot lies in the fact that two separate motors drive each of the side wheels. Each of the motors provides ample torque so that even if one pair of wheel gets stuck others will move independently. This gets the vehicle out of potholes and since the robot is maneuvered by an intelligent control system it will regain its path.

Steering is accomplished using a differential drive mechanism and makes the vehicle proceed in the right direction as calculated by the software. The specialty of differential drive steering is that it provides the possibility for the vehicle to rotate 360

degrees about the vertical axis passing through the center without moving in forward direction. So our vehicle can take sharp turns and can neatly avoid obstacles encountered on the track.

CHASSIS RELIABILITY

This chassis is designed to work on almost all terrains be it uneven, slopy or having pitfalls. The frame is made up of aluminum 6063 material which is strong enough to carry the load of the components mounted on this vehicle. The upper body of this vehicle is made up of an iron frame with platforms provided to mount devices. The chassis is 100% reliable and is fit to work in the environment provided by IGVC. Most of the hardware on top of this vehicle is electronic and hence require weather proofing. All the components are rigidly and neatly packed and hence the stability on uneven terrains is achieved. The attention to weather proofing allows Lakshya to compete come rain or shine.

DRIVE GEAR

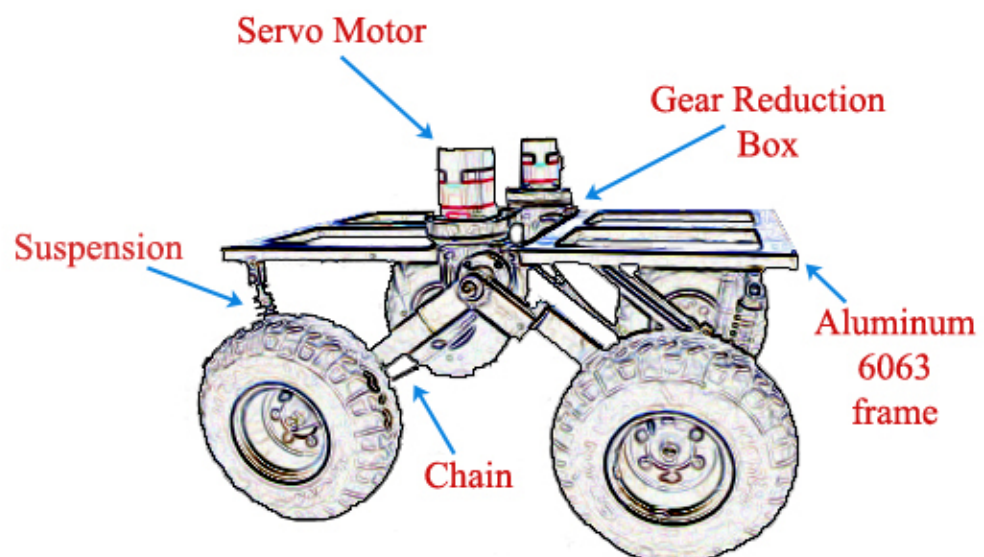
Lakshya is driven using two QuickSilver I - Grade 34HC-1 Servo Motors. The components of each drive system include a 16 inch composite drive wheel, a 20:1 gear reduction box, 4 motorbike chains to drive the wheels and 4 independent suspensions for each wheel. The initial designs made by Team UGV were exerting excessive pressure on the shafts of the motors and thus we required a vehicle that should avoid this situation. We then mounted the motors (vertically) as shown in the picture below and attached the gear reductions below the motors. The gear reductions were then fixed to the chassis. This chassis can be completely dismantled into pieces within few minutes. The shafts of gear reductions are then attached to the chains which drive the wheels.

DRIVE DETAILS

4 wheels, 20:1 Gear Reduction, Differential drive using chains. Each motor driving pair of side wheels. Independent suspension

Motors: QuickSilver I - Grade 34HC - 1 DC Servo.

Material: Aluminum 6063.



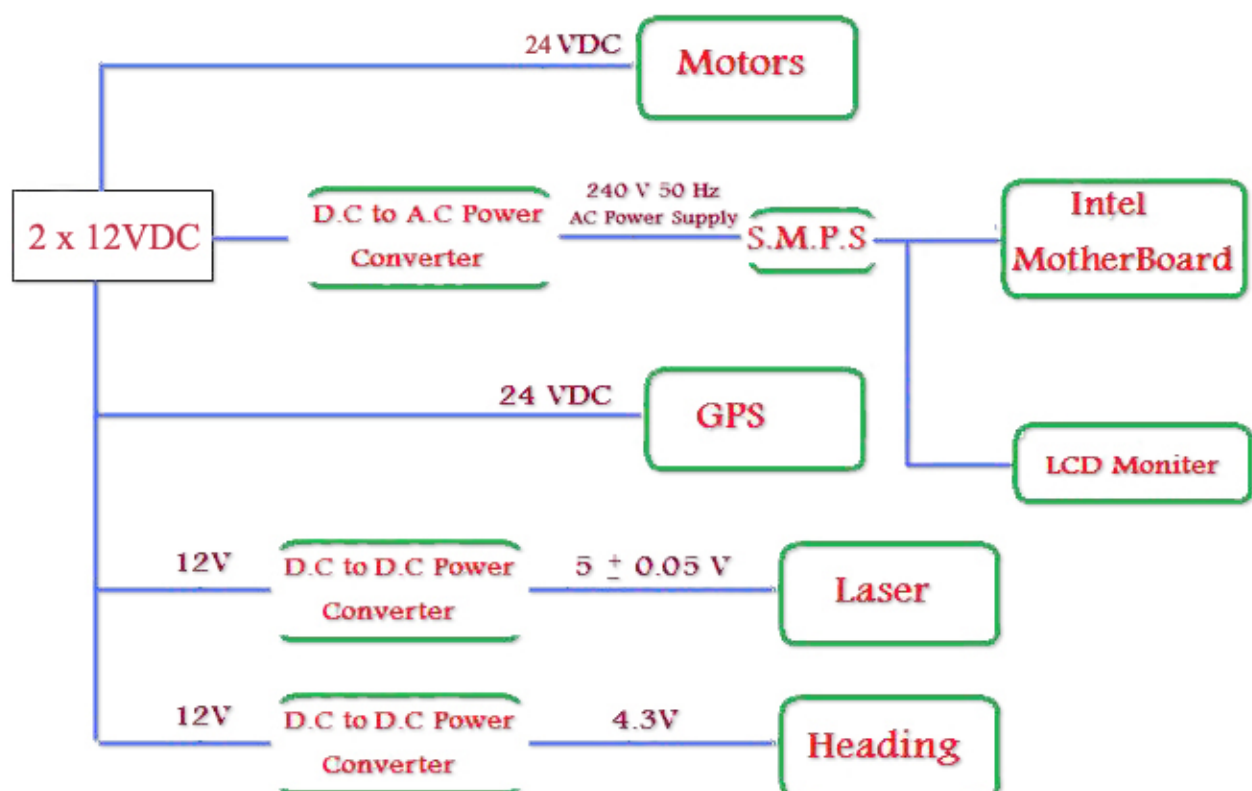
ELECTRICAL & POWER SYSTEM

The electrical system provides appropriate power for each vehicle component and supports communication between the computer, sensors, and actuators. Simplicity, safety, durability, and efficient use of space were all considered during the development of the electrical system of Lakshya.

POWER DISTRIBUTION

Two 12 Volt sealed Li-Ion batteries connected in series supply 24 Volts for the entire system. We have used switches to distribute power amongst various devices. DC to AC converter was used to produce AC power which was then supplied to SMPS to produce regulated switched mode power which powers the Motherboard and TFT monitor. The Laser scanner can bear a maximum of 1% fluctuation in its operational voltage of 5 volts. Therefore a special DC to DC converter was designed for Laser scanner. GPS can work for any voltage between 8 to 40 Volts so we provided GPS with 24VDC power supply. Heading required a operational voltage of 4.3 V which was given through a another custom made DC to DC Converter.

We have designed a wireless and a manual E-stop on our own. Wireless E-stop can work for a maximum of 50 feets range. E-stop disables the power supply to motors thereby making the vehicle to stop. The entire power system is drawn as shown in the figure below.



SENSORS

Lakshya employs a series of sensors for precision motion control. We have the following sensors deployed on our vehicle.

1) **BumbleBee StereoVision Camera:** The BumbleBee is a stereo vision system developed by Point Grey Research. The system is being used to detect both obstacles and lines on the course.

Technical Specifications:

Sensor: Two Sony 1/3" progressive scan CCDs, Color/BW.
Resolution and FPS: 640x480 at 48FPS or 1024x768 at 18FPS.
Lenses: 3.8mm (70° HFOV) or 6mm (50° HFOV) focal length.
Calibration: Pre-calibrated to within 0.05 pixel RMS error.
General Purpose IO: GPIO pins for external trigger / strobe.



2) **Hokuyo Laser Scanner:** The Laser Range Finder scans in a horizontal plane and returns the vehicle's distance from the obstacle. Hokuyo's laser provide cost effective solution and can scan upto 4 meters perfect for the conditions imposed by IGVC.



Technical Specifications:

1. Hokuyo's URG-04LX detectable range is 20mm to 4000mm
2. 100msec/scan
3. 5V operating voltage
4. 240° area scanning range with 0.36° angular resolution
5. USB and Serial (RS-232) interfaces for maximum flexibility

3) **Garmin 17HVS GPS:** The GPS is used for getting position information. Latitude and Longitude positions are received by a GPS receiver which we are going to use for the estimation of waypoints during Navigation Challenge.

Technical Specifications:

1. 8 to 40 Vdc unregulated
2. 60 mA @ 8 Vdc; 40 mA @ 12 Vdc; 15 mA @ 40 Vdc
3. Sensitivity: -165 dBW minimum
4. WAAS-enabled, 12 parallel channel GPS receiver continuously tracks and uses up to 12 satellites to compute and update your position. WATER PROOF.

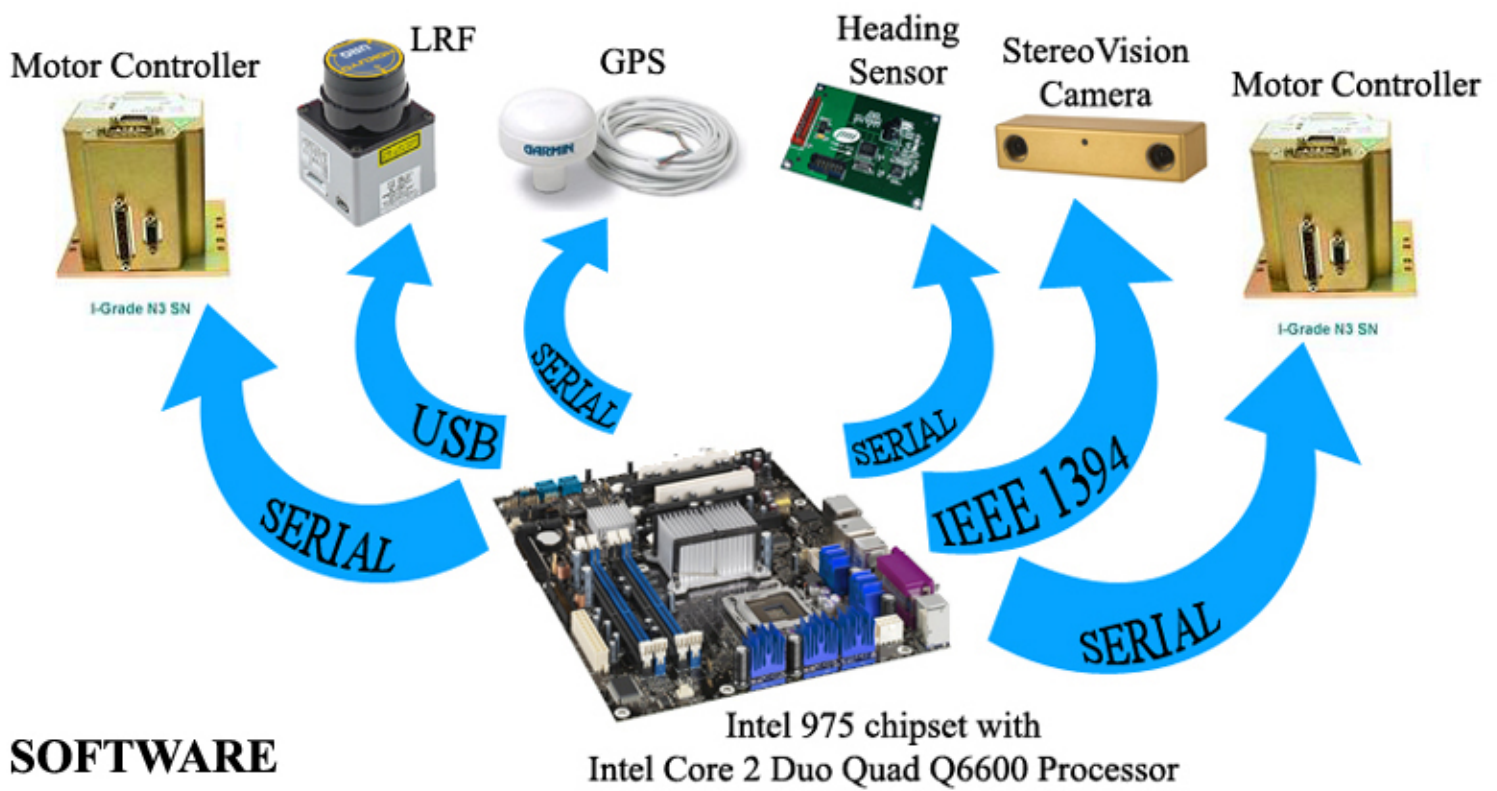


4) **PNI TCM2.5 Heading Sensor:** To get heading information relative to North.



Technical Specifications:

Accuracy throughout tilt range: 0.8° RMS
Resolution: 0.1°; *Repeatability:* ±0.1°



SOFTWARE

Initial stages of software implementation were based on MATLAB 7.1 but due to higher processing time and less effective usage of computer resources we shifted to Microsoft Visual Studio C++ 8.0. Software system utilised Microsoft Foundation Class, OpenCV and Point Grey Research Libraries to complete Computer Vision and Obstacle Detection task along with providing Graphical User Interface.

1. Computer Specification

The onboard CPU is a standard commercially available Intel Core 2 Duo Quad Q6600 processor placed upon Server Based 975 Mother Board with 2 GB of 1033 FSB RAM. The computer communicates with the sensors and motors by either USB, RS-232 serial, or by an IEEE 1394 port. The operating system is Microsoft Windows XP Professional.

2. Multi-Threading and Inter Process Communication

Limitation of Sequential based programming model is that a mutually exclusive step (step involving acquiring data from GPS and step involving acquiring data from Heading Sensor are not dependent on each other i.e. they are mutually exclusive step.) has to wait for the CPU to process it before the processing of the previous step finishes. Usage of thread improves the effective usage of computer resources and processing time. Multithreading is implemented using Server Client approach. UDP is used for inter process communication. Each mutually exclusive step is invoked by client side program via a thread and data is transferred to server side using UDP. Picking up correct data is necessary hence there is a need of time stamping.

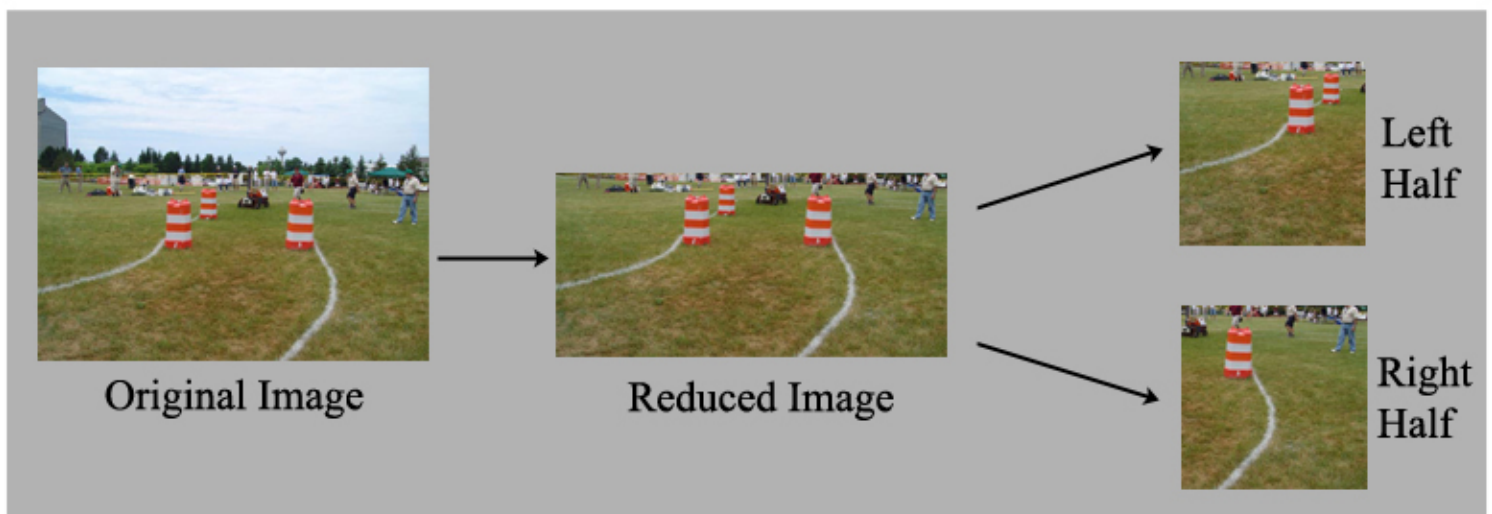
3. Autonomous Challenge Softwares

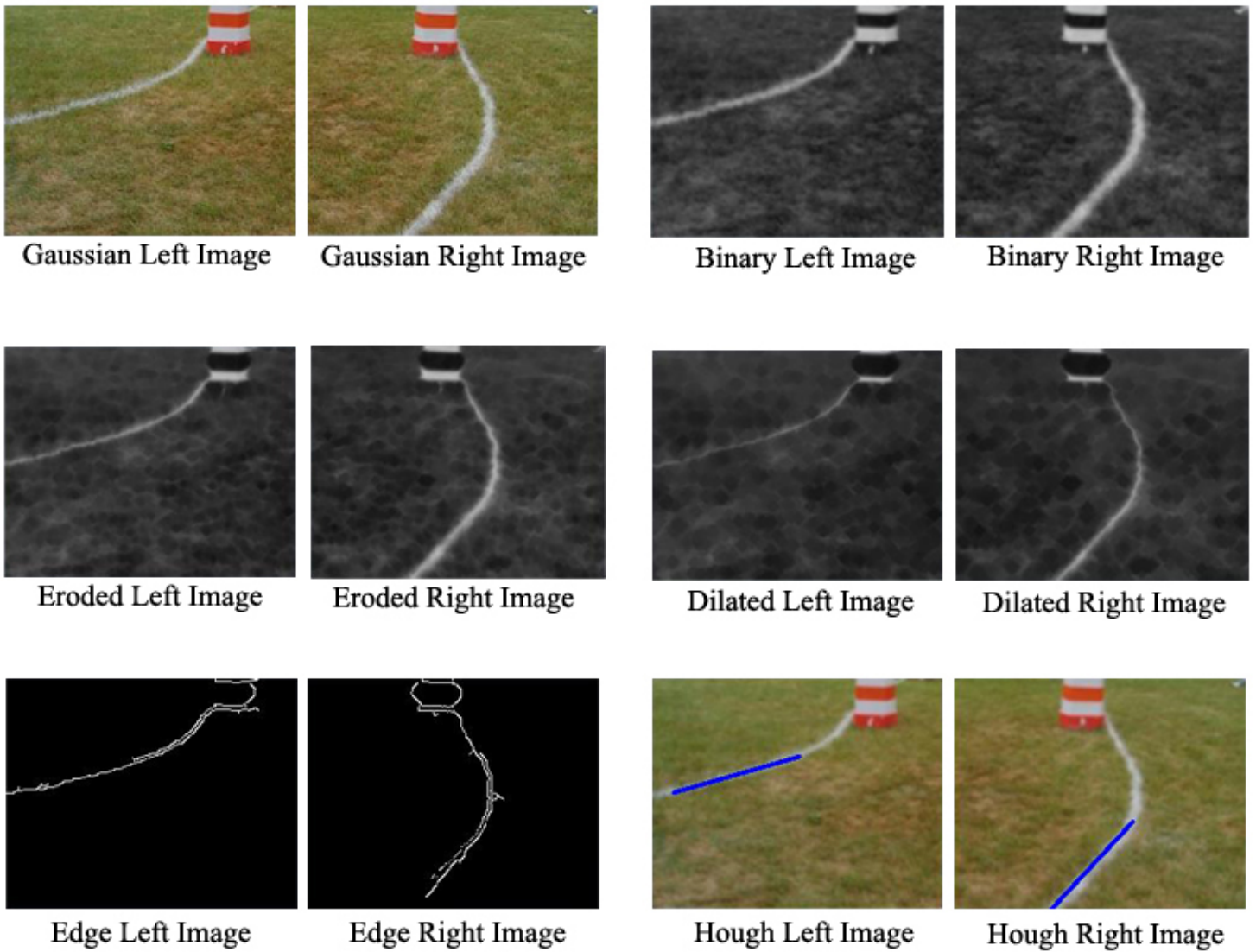
VISION - IMAGE PROCESSING

Image processing is one of the crucial processing in any unmanned information system because it provides us with many useful information at very low cost and computational burden. Our image processing software uses Point Grey BumbleBee stereo vision camera to determine relative heading and to detect simulated circle. The overview of the line and heading determination algorithm is described first and Simulated Potholes detection is described afterwards. One of the camera images is acquired for the line detection algorithm. Bumble Bee Stereo Vision's maximum resolution is 1024*768 but to reduce computational burden and processing time we acquire an image at 640*480. The acquired image is first reduced to remove the image area above horizon.

A) Line and Heading Determination

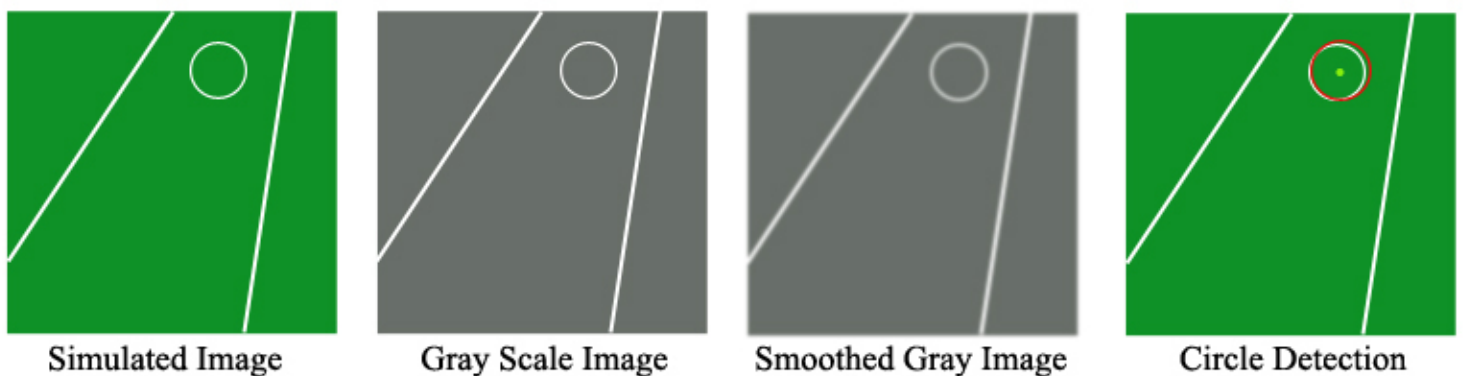
Reduced image is then split in two, representing the view to the left and to the right of the vehicle. Gaussian of the each half is calculated by convolving source image with 5 X 5 Gaussian kernel. Blue channel of the Gaussian RGB image is used to create the binary image. Next step is to create a 3 X 3 elliptical structural element. This structural element is used to perform morphological erosion and dilation. Canny filter is applied over the eroded image to calculate edge in the image. Though initially it was planned that curve fitting will be used to determine heading but due to lack of time we couldn't implement an algorithm based on curve fitting. Most dominant line occurring in each half of the image is identified using Hough transform. Angle corresponding to dominant line in each half is compared to the previous angle and accordingly required relative heading is calculated. This method works equally well for solid or dashed lines. In case of a line is not detected in any of the half then a separate decision tree is used to calculate the heading.





B) Simulated Potholes Detection

“Comparative study of Hough Transform methods for Circle Finding “by H.K. Yuen, et.al was referenced for Hough based circle detection. Reduced Colour image is first converted to Gray scale image. A Gaussian 9x9 Kernel is applied over this Gray scale image to smoothen the Gray image otherwise many false circle would be detected. Hough transform is applied over the smoothed gray image to detect the circle.

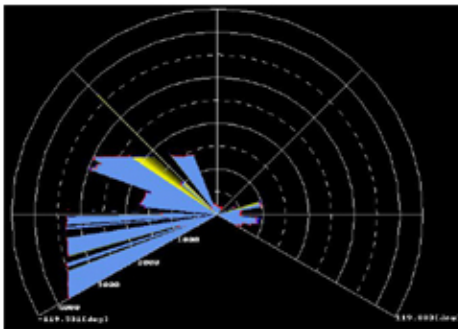


Every Detected circle is encoded as 3 floating-point numbers: center coordinates (x, y) and the radius. The area occupied by the circle is passed as blocked sector to the obstacle mapping algorithm.

OBSTACLE AVOIDANCE ALGORITHM

1. Occupancy Grid and Sensor Fusion

Occupancy Grid is obtained using the obstacle data from Hokuyo Laser and Stereo Vision Camera. Information provided by laser is much more reliable than from the camera. Laser provides polar obstacle data of the form (d, θ) where d is the maximum depth till which laser could go before returning after hitting an obstacle along the angle θ . Stereo vision camera gives depth data which is of the form (x, y, z) where x, y, z are real time coordinates. To fuse these data there arise a need of fusion algorithm.



Simulated Laser Output



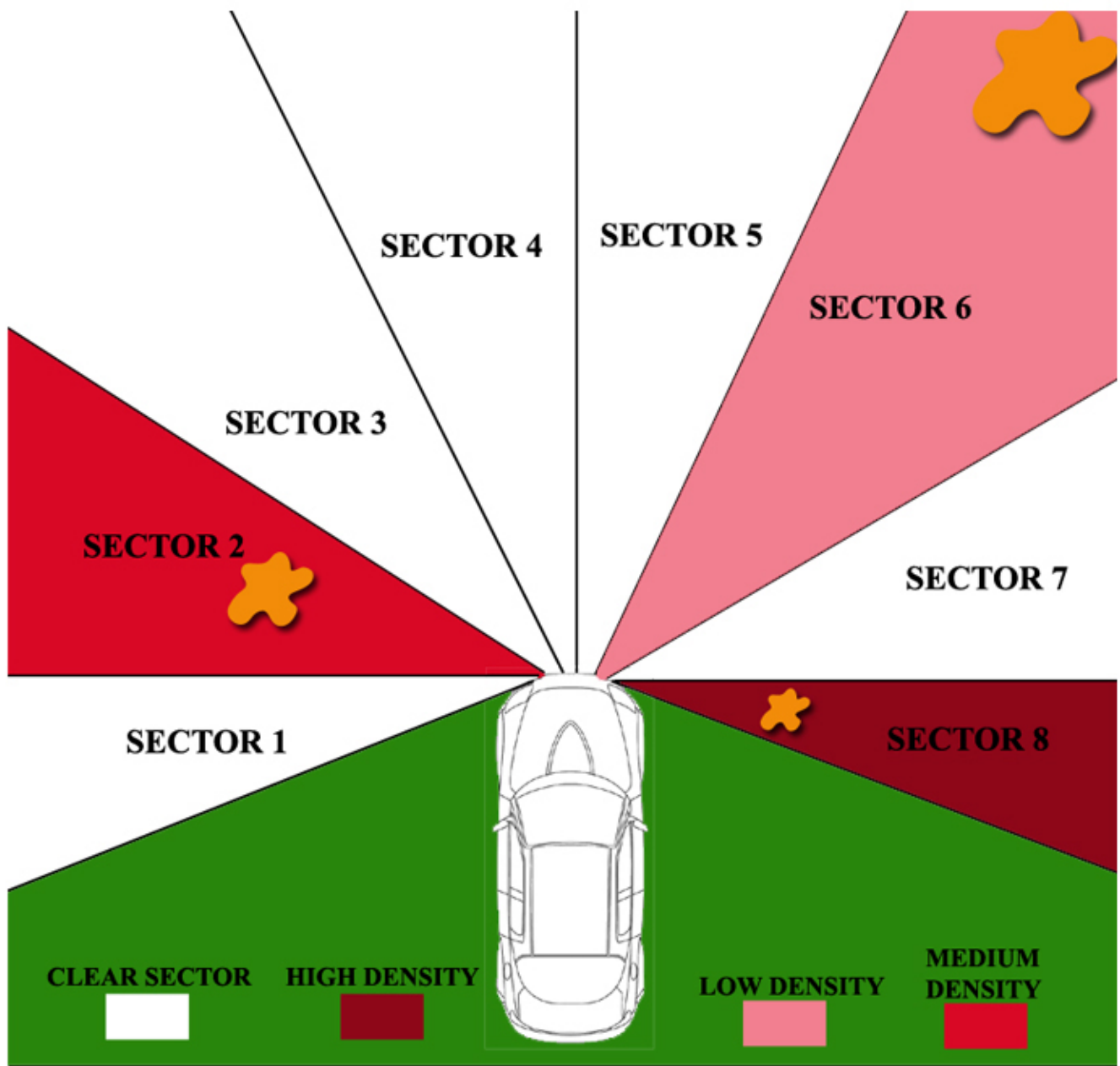
Disparity Output

Our algorithm creates the occupancy grid in the standard ray-tracing type manner. Grid walks along each scan line to determine the occupancy of the cells in the ray's path. Finally a decision tree determines the occupancy value corresponding to each grid.

2. Obstacle Avoidance

Our algorithm infuses the basic ideas of fuzzy approach with the 'VFH+: Reliable Obstacle Avoidance for Fast Mobile Robots' by J. Borenstein and Iwan Ulrich, thus providing an algorithm which is much closer to real world behaviour for an autonomous vehicle. The input data on which VFH+ works has been remodelled by grouping them into relevant sectors. Local path planning is decided depending upon the various cases that emerge due to the different values these sectors can hold.

The data from the Fusion Algorithm, in the form of distance of the obstacle from the vehicle at each angular degree is grouped into seven sectors in order to fuzzify the input data. The different distances of the obstacles from the vehicle have been given different weights in order to give higher weight-age to the closer obstacles. Depending upon the weight of each sector, one out of the 4 values i.e. 3,2,1,0 corresponding to high obstacle density, medium obstacle density, low density and clear are assigned to each sector. Inspired from fuzzy approach, various relations have been defined between these sectors in order to calculate the closest possible direction to the target heading direction having the required clearance.



Graphical Data Representation of Obstacle Avoidance Algorithm

4. Navigation Challenge Software (Global Path Planning)

Waypoints provided during the competition will be fed into an algorithm which sorts these waypoints keeping in view the fact that when the vehicle traverses these waypoints, it completes the cycle in shortest possible time.

After the navigation software receives the waypoint it checks for the current GPS location. Using the GPS location it calculates the required heading to reach the waypoint. Occupancy Grid is used to calculate the actual heading direction for the vehicle keeping in mind that vehicle doesn't hit into any obstacle. Path Planning algorithm gives motor the required commands to move and after the vehicle completes the required movement, GPS location is checked again. If vehicle has reached the waypoint, next waypoint is provided to the software else above loop is run until vehicle reaches the waypoint.

PERFORMANCE REVIEW

Lakshya performance has been assessed and studied through software and practical experiments. Initial design of Lakshya contained many flaws and limitations which were subsequently improved to make the vehicle more robust to withstand jerks and to have a better manoeuvrability.

Speed

Vehicle is equipped with two Quicksilver Silvermax 34HC-1 brushless DC motors with 20:1 reduction gearheads have a no-load output speed rating of 300 rotations per minute. Using 16" tires, the vehicle can obtain a maximum rated speed of 11.5 mph. During the competition, since the speed limit is 5mph so the integrated motor control software will enforce a strict five mph speed limit for both the autonomous and navigation challenges.

Ramp Climbing Ability

Although the ramp climbing ability for the vehicle is not been tested yet in the real arena but viewing the stall torque of Silvermax 34HC-1, it is sure that vehicle will be able to transverse a 15% grade (8.5 degrees).

Obstacle Distance Detection

The scanning laser rangefinder has a range of 4 meters (13.12 feet) and a scanning angle of 240 Deg. but the current obstacle avoidance software ignores obstacles that are further than 105 Deg from the vehicles heading in each direction thus taking a 210 Deg scan in front of vehicle. This Angular range is sufficient to allow consideration of obstacles and to determine the best forward path of the vehicle fast enough to slow down the vehicle to look for obstacle.

The Stereo vision system is also be used to create disparity map so they can also identify barrels and potholes. Obstacles within a distance range from 5 -7 meters in front of the vehicle are been taken into taken account for sensor fusion.

GPS Waypoint Accuracy

Vehicle uses Garmin WAAS enabled 17HVS which has an accuracy of 3 m in WAAS mode. Due to lack of very much accurate GPS system the vehicle relies on software system for circle detection.

Accuracy of Heading Sensor

The digital compass used on Lakshya displays a $\pm 0.8^\circ$ RMS heading accuracy depending on the amount of tilt experienced by the unit which is very much accurate for movement of Lakshya at low speed of 5mph.

CONTROL SYSTEMS

The control system consists of a differential steering system with power supplied to all four wheels. Data from laser sensor and camera is combined to find a heading angle which is closest to our actual target heading. The control program then calculates the speed and number of rotations each of the motor is required to rotate, in order to turn the required angle and the data is sent to motors. The control program, calculates an appropriate constant radius - circular trajectory for the vehicle (greater is the change in heading angle, smaller is the radius of the vehicles trajectory). Now during turning, the data from the surrounding is continuously collected and instead of waiting the vehicle to turn, the vehicle's kinetic conditions are changed during the turn itself.

Hence instead of relying on a fixed idea of the surrounding and prior to committing its move, the vehicle checks the environment in real time, which makes it capable to deal with environment having moving obstacles and results in a smoother motion of the vehicle.

POSITION DETERMINATION

The position of the vehicle is determined by taking GPS and motor encoder data. Since the data from GPS is quite inaccurate and noisy, we fuse this data with motor encoders to find corrected position. Another problem is faced while accounting for the dynamic radius circular trajectory of the vehicle. Both these problems are overcome by sampling the encoder values continuously and taking into account the change in speed of the motors. Hence the change in vehicle's position is calculated using encoder values which is fused with GPS data using kalman filter.

SAFETY CONSIDERATIONS

While designing and developing Lakshya, safety has been the most important objective. The team implemented many safety features in the mechanical, electrical, and software systems for e.g. self braking by motors, shutting down the power supply when E-Stop is pressed within the given range, stopping the Motor threads immediately when vehicle reaches a dead stop.

JOINT ARCHITECTURE FOR UNMANNED SYSTEMS (JAUS)

In its first attempt at IGVC, Team UGV is all geared up to take part in the JAUS Challenge. Till now we have almost implemented JAUS Level - II using socket programming in C++. The decoding of the JAUS header is all done according to the rules imposed by IGVC. We have made our own libraries for the decoding of JAUS header. We are also developing JAUS using RE2 JAUS SDK. We will try to attempt 2 different versions of JAUS programs developed by Team UGV and the one that would be working fine shall be implemented.

VEHICLE COST

COMPONENTS	Actual Cost	Cost to Team
34HC-1 QuickSilver DC Servo Motors	\$4656	\$3166
BumbleBee StereoVision Camera	\$2495	\$2495
Garmin 17HVS GPS	\$107	\$450
Hokuyo URG Laser Range Finder	\$2800	\$1735
PNI TCM2.5 Heading Sensor	\$769	\$0
Onboard Computer	\$1480	\$1480
Aluminum 6063 Chassis and Body Fabrication	\$1000	\$1000
Li- Ion Batteries	\$750	\$750
Electrical Power Distribution Box	\$375	\$375
PCI to Serial Converter	\$150	\$150
Gear Reduction	\$400	\$400
TOTAL	\$14,982	\$12,001

*Conversion Factor: 1 USD = 40 INR

CONCLUSION

Lakshya is a cost effective solution to the need of unmanned systems. It is all set to participate at IGVC 2008 and would try its level best to win the competition.

ACKNOWLEDGEMENT

Team UGV would like to thank our faculty advisors, Prof. R.K Sinha and Prof. K.L Deori, for their constant support during the making of this vehicle. Without their support this vehicle would not have taken the shape it has taken.

SPONSORS

We would like to thank our sponsors for their help and support. Team UGV is highly indebted to the following sponsors:



Department of Scientific and Industrial Research
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Government of INDIA



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