IGVC 2011

University of Calgary

Design Report

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1   INTRODUCTION

This exciting year marks the first ever entry of the University of Calgary in the Intelligent Ground Vehicle Competition. From the Inception of the team by team leader Zareef Zahrat, the subdivisions Sensor Team, Vision Team, Power Train Team, Software Team and Business Team were created to ensure the smooth development of the robot. The τ-RUS is the product of the team's efforts and will be spearheading the team into its first IGVC competition.
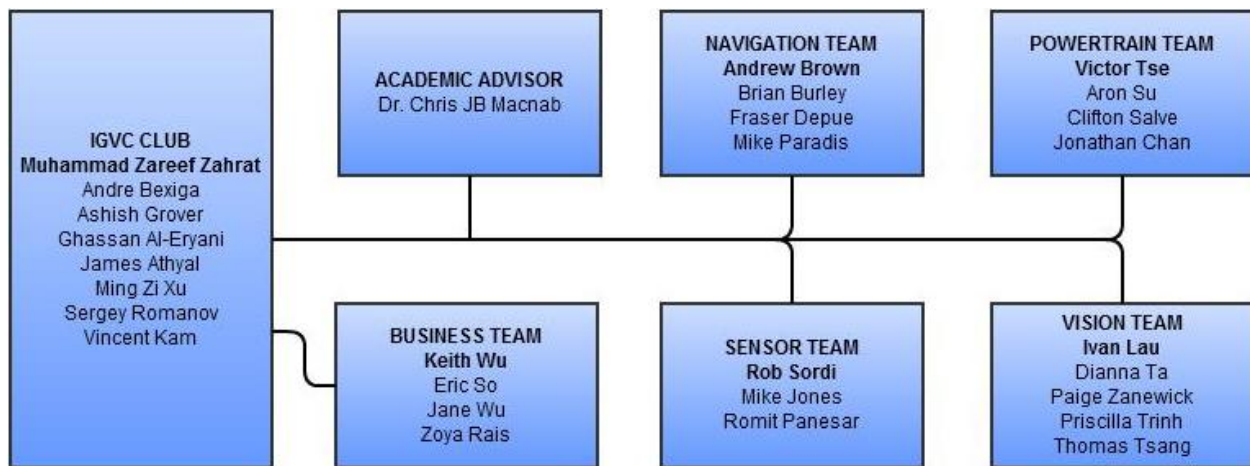
2   DESIGN PROCESS

2.1   Team Organization

Figure 1: Team Structure

The team consists of the IGVC club and four fourth year design project groups. A business team and a software team are within the IGVC club. The four fourth year groups are the Navigation Team, Powertrain Team, Sensor Team and Vision Team. All team members were undergraduates at the beginning of this project. The goals of the various teams are as follows:

Navigation Team: The navigation team was in charge of making a software system that would receive input from the Sensor and Vision Teams. The data would be processed into an angle for the robot to rotate and a distance for it to travel. The system must then deliver these outputs to the Powertrain Team.

Powertrain Team: The powertrain team was responsible with the design and selection of the wheels, motors and motorcontrollers. Additionally, they were also responsible for ensuring that not only the motors of the vehicle had power but that every component on the τ-RUS was powered. Finally, they had to ensure that, given a set of directions from the navigation team, the vehicle would correctly follow those directions.

Sensor Team: The sensor team was tasked with the creation of a sensor array that would collect non-visual data regarding the robot's surroundings before passing that data to the navigation system.

Vision Team: The vision team was responsible for ensuring that the τ-RUS had a reliable and efficient optics system. The system would be used to collect visual data regarding the robot's surroundings before passing that data to the navigation system for processing.
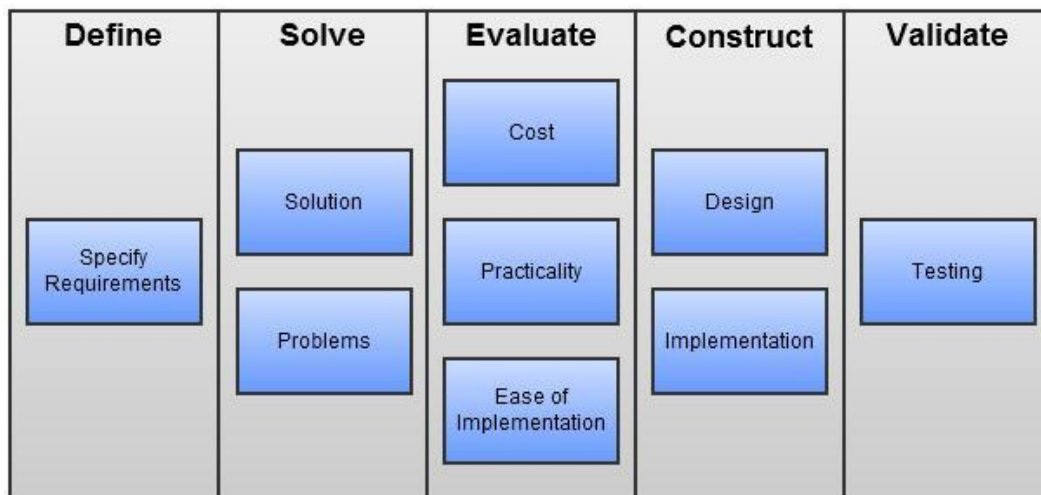
2.2 Decision-Making

Figure 2: Decision-Making Procedure

Team meetings occurred twice a week throughout the year. The fourth year groups had additional weekly meetings. When odds and ends that concerned the robot had no specific team to address, the IGVC Club would be tasked to answer it. The IGVC Club finalized all decisions made regarding the robot as well.

Through meetings, our design and decision-making process started with defining the requirements for the vehicle. Various solutions would be brought up along with the problems within each solution. If a solution seemed like it would work, it would be evaluated. As we are a first time IGVC entry starting from scratch – the cost, practicality, and ease of implementation are very important factors in deciding whether we would implement a particular solution. When a solution was decided on and passed evaluation, the solution would then be brought to action. Lastly, the implemented solution would be tested to see how well it held up the requirements and met expectations.

2.3 Software Development

Each of the fourth year groups were to develop their own software for their team. The vision team's software required that a matrix that represented the obstacles and pathing in the field ahead of the robot. The sensor team's software required that it could produce a matrix representing obstacle distances using a laser rangefinder in addition to interpreting data from the GPS and orientation sensor and converting it into useable information for the navigation team. The navigation team's software is to accept inputs from the vision and sensor team and apply an algorithm that would produce the best path for the robot. The powertrain team's software needed to accept a distance and a rotation value from the navigation software and ensure that the robot actually followed the commands. Protocols and standards were developed between teams in order to ease software integration.

2.4 Design Innovations

Fail-Safe Drive Configuration: In the event that a motor or motorcontroller experiences failure, the vehicle has been designed such that it will still be able to operate. This is discussed in more detail later in the report.

Virtual Flag-Born Obstacles: In order to deal with going in between flags, virtual obstacles are created that prevent the vehicle from going around the flag set. This is discussed in section 5.1.

3   MECHANICAL DESIGN

3.1   Chassis

The chassis of the τ-RUS is built upon the metal frame of a Razor Dune Buggy. Component mounts, made of medium density fiberboard and metal, are directly attached to the frame to complete the chassis. The pre-existing frame was chosen not only because of time constraints, but because it fulfilled the strength and size requirements we were expecting of our chassis. The frame was specified to handle our goal weight range (150lb to 200lb), but could support much more (550lb+). We also wanted the vehicle to be compact enough to fit through a door and for navigating through obstacles – the frame size was just over the minimum requirements for the competition. Additionally, the chassis provided a suspension system in the form of a shock absorber.

3.2   Steering Configuration

A four wheel differential drive system was chosen for the τ-RUS. A differential drive system (skid steering) was selected so that the vehicle could have a zero degree turning radius. This would improve obstacle avoidance in close quarters. A four wheel drive system was chosen with reliability in mind in order to reduce the chance of the vehicle getting stuck. This was implemented by having four powered wheels mounted in a relatively square formation in order to implement a skid steering system.

3.3   Drivetrain

The τ-RUS is driven by four NPC-T74 geared motors. Each of the motors includes a 20:1 gearbox and is capable of producing 1.7hp. Four powerful motors, in addition to two separate motor controllers, were chosen and configured such that in the event of a motor or motor controller failure – the vehicle would still be able to operate at an acceptable level with only one motor controller and two motors.

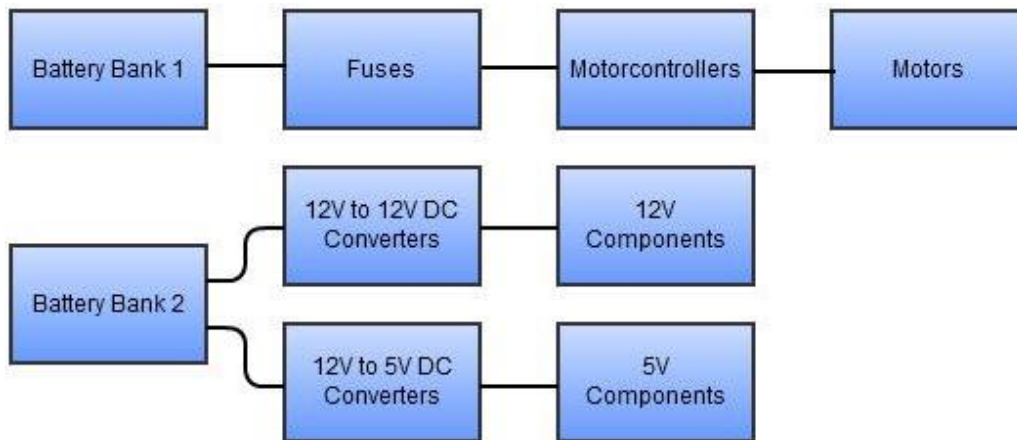# 4 ELECTRONIC DESIGN

4.1 Power Distribution System

Figure 3: Power Distribution Chart

Power distribution onboard the τ-RUS was designed to completely isolate sensitive electronic components and signals from the electronic noise from the motors. Two electronically isolated battery banks exist on the vehicle. The first battery bank consists of two Optima YellowTop Deep Cycle Batteries configured in series in order to provide 24 volts to the four motors through the motor controller. The second battery bank consists of two smaller capacity 12 volt batteries that are configured in parallel in order to provide power to the rest of the components via 12V to 12V and 12V to 5V voltage regulating DC to DC converters.

4.2 Sensors

Figure 4: Sensor System Layout
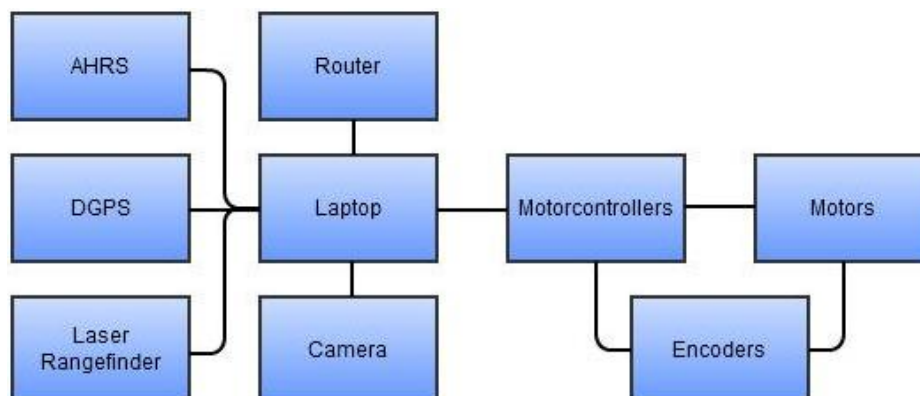
The sensor system consists of an attitude heading reference system (AHRS), differential GPS (DGPS) and a light detection and ranging (LIDAR) unit. These units are connected to the laptop through RS-232 and USB interfaces.

AHRS: A VectorNav-100 orientation sensor is onboard the τ-RUS. A 3-axis accelerometer, 3-axis gyroscope and 3-axis magnometer provides the orientation of the vehicle in 3D space. Multiple outputs types such as pitch, yaw, roll, heading and acceleration provide valuable information for the navigation system.

Figure 5: AHRS

DGPS: The Hemisphere GPS Crescent A100 Smart Antenna is incorporated into the τ-RUS's sensor system. This device provides positioning data to the navigation system during the Navigation Challenge of the competition. The GPS is mounted over the camera/tripod in order to ensure that an unobstructed GPS signal is obtained.

Figure 7: DGPS

LIDAR: The Hokuyo URG-04LX-UG01 laser rangefinder is used for obstacle detection on the τ-RUS. The laser is capable of detecting obstacles 5.6 meters away over a 240 degree range with a 0.36 degree angular resolution. Data transfer and power are through a USB interface.

Figure 6: LIDAR

4.3 Vision

The τ-RUS uses a Unibrain Fire-I 400^{TM} Color Industrial Camera for its vision system. This camera has a ¼" CCD with a resolution of 640x480 and can operate at up to 30 frames per second. The use of RGB filters in a Bayer array provide for color accurate images. Its IEEE-1394a 400Mbps FireWire interface also provides power to the unit. The camera is connected to the laptop via a firewire ExpressCard. A Fujinon FE185C046HA-1 fish-eye lens is attached to the camera in order to provide a 185 degree field of vision. The wide field of vision allows for a

Figure 8: Unibrain Fire-I 400 Camera

Figure 9: Fujinon Fish-Eye Lens

large overlap between the vision and sensor team's probability matrices – giving us more data to work with when the navigation system's algorithms are implemented.

4.4   Control

The τ-RUS is ultimately controlled through the motorcontroller. The motorcontroller can be controlled through the connected laptop, or by a wireless gaming controller via the laptop. Additionally, the motorcontroller can be connected to a radio frequency receiver and can then be controlled by a radio frequency remote.

5   SOFTWARE STRATEGY AND SYSTEMS INTEGRATION

The τ-RUS is implementing a stop-look-go system in order to navigate through the obstacle course. Once the robot is stopped, the current image from the camera and that data from the LIDAR sweeps are captured. Both the image and the data are used to construct an obstacle probability matrix which is then combined in the navigation software. Using this data and/or GPS data, the navigation system would produce a heading and a distance to be traveled. These outputs are relayed to the motorcontrollers such that the vehicle rotates by X number of degrees and travels Y distance. The encoders, AHRS, and/or GPS are then referenced as the vehicle moves towards its target location. Once the target location is reached, the robot stops and the process is repeated.

5.1   Lane Following and Mapping Techniques

Once the vehicle is stopped, the vision system waits until the navigation system sends a data request signal. The current image in the camera is then captured and transformed into a bird's eye view

Figure 10: Original Image

using a loaded homographic matrix in order to correct the skewed image. This bird's eye view image is then subjected to line and object
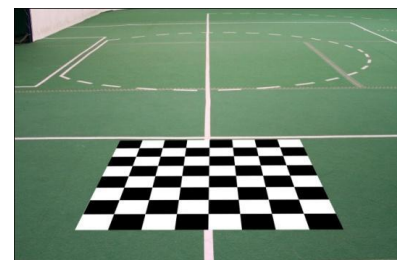
detection algorithms. The image is first converted into grayscale before being smoothed through a Gaussian filter. This is then passed through a binary threshold filter. Any remaining noise in the image is removed through erosion and dilation filters.
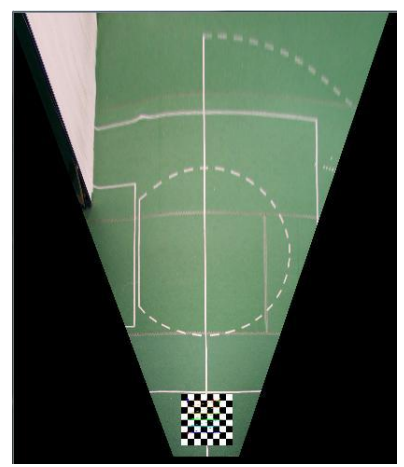
In order to deal with the red and green flags, the left and right of the flags, respectively, are considered hard obstacles. To detect the flags, the original captured image is converted into the HSV color space. Through HSV, rather than RGB, colors are more easily detected through hue. Predetermined values of hues are compared with the image in order to detect green and red objects. Any confusion between a green flag and grass is avoided by subtracting areas of the image where the shade of green is within a certain range of our calibrated value of grass. The image is then smoothed, eroded, and dilated. The vision system then searches the filtered image for contours that are within 10 cm and 30 cm in width and height while containing results from the color filter that are above a set threshold value. After obstacle lines are added to the left and right of flags, the image is converted into grayscale.

The two grayscale images are then combined before being separated into 10 cm by 10 cm blocks in which the gray scale pixels within them are averaged. Lighter shades are taken to be obstacles and paths the robot should avoid and stay within, respectively. This creates an obstacle probability matrix in which the probability of an object being present is normalized to a value between 0 and 100.

5.2 Obstacle Avoidance

In addition to the obstacle probability matrix produced by the camera, another obstacle probability matrix is created by the laser rangefinder. When requested, the laser rangefinder would capture the current sweep data and map it into an obstacle matrix. The matrices from both the vision and sensor systems are combined in order to follow paths, pass between flags, and avoid obstacles. The information obtained from the laser sweep is also used to determine the distance to be traveled.

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5.3   Autonomous

Once the vehicle is stopped, it will request an obstacle matrix from both the sensor and vision systems. When the two obstacle matrices are obtained, they are combined to form the current probability matrix. The vehicle itself is placed in the bottom center of the probability matrix. A series of rays are "shot out" from the robots position in a 180 degree arc. Each ray will impact an object at a different distance. The farther away the object is, the greater the free path and the higher value that the ray will be assigned. A plot is formed of free path as a function of path direction. This function creates a curve with local maxima at angles where there are longer clear paths. With this information, we can determine the safest direction for travel. Along with this direction, a function representing a target destination is used to determine the actual route of travel. This will be explained in the following section.

5.4   Navigation

In order to take GPS into account, a triangular member function is created that represents the direction of the next GPS waypoint. This plot, along with the representation of the safest directions of travel are "ANDed" together in order to find the actual direction of travel. The larger of the arrows represents the optimal path. It will always follow the most open path that is in the approximate direction of its next GPS target. In order to account for situations where the robot is wedged in a corner or approaches a group of obstacles the wrong way, the robot will turn around 180 degrees and move for a certain distance before resuming normal operation. This will happen when the free-path fuzzy membership function is all below a certain threshold (no free path within the robot's sensor arc). If the target fuzzy membership triangle is not within the robot's frontal arc, it will turn in 90 degree increments until it can see the target's member function.
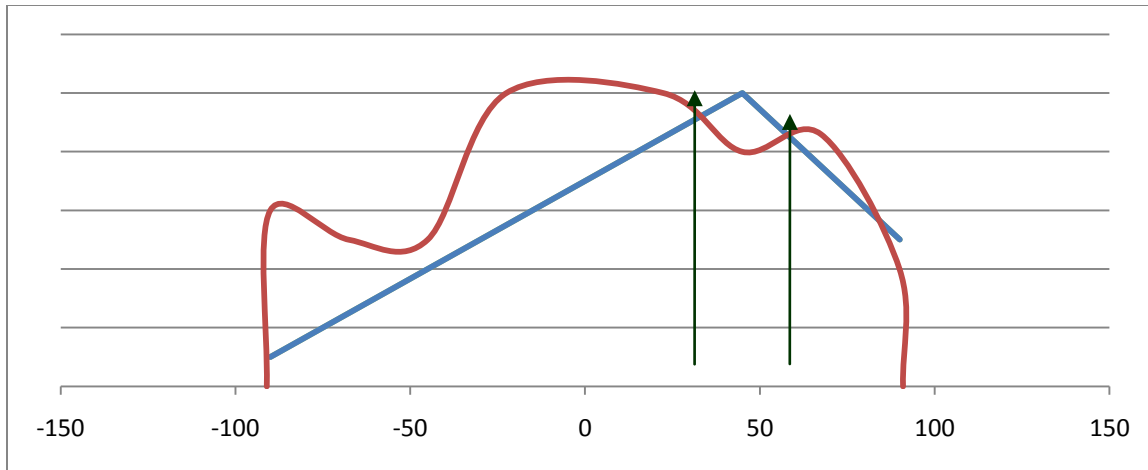
6 SAFETY, RELIABILITY AND DURABILITY

A goal throughout the design process of this vehicle was to make sure that it was safe, reliable, and durable. In addition to the safety requirement of onboard and wireless emergency stops, several fuses were implemented in the electric circuits to prevent any circuit loads that could potentially start a fire or damage sensitive electronics. Complete electrical isolation of the sensitive electronics to the motors preserve signal integrity and reduces the chance of the vehicle's navigation systems losing control and sending erroneous signals to the motorcontrollers. Non-spill batteries eliminate the risk of battery acid spilling or leaking out.

The vehicle features two motorcontrollers, each of which control a set of wheels (front and back). In the case of motor or motorcontroller failure, the motors chosen are powerful enough such that the vehicle can still operate with only two wheels. All software is loaded onto the single laptop, instead of through multiple laptops and microcontrollers. This eliminates some of the reliability issues with accurately communicating between computing units.

The vehicle's frame can support a weight of over 550 lb (including its own ~200lb weight). The fact that it can carry more than its own body weight makes the vehicle durable towards any loads that it may carry or tow. Additionally, the wheels chosen for the robot are puncture-proof

so that the danger of sharp hazards popping a tire is eliminated. The outer-shell is designed to be water resistant so that the robot can still functionally operate in mild weather conditions.

7   PREDICTED PERFORMANCE

The robot is capable of travelling over 7km/h in addition to easily climbing slopes of over 15 degrees. The battery life of the robot lasts well over an hour. We verified through testing that the LIDAR is capable of detecting all obstacles within 3m with 95% accuracy and place the obstacles within 10 cm. We also verified that the combination of the other sensors could determine the position of the robot within 1m and its heading within 5 degrees.

8 COST ESTIMATE

DESCRIPTION	QTY	UNIT PRICE	COST
Hokuyo URG-04LX-UG01 Scanning Laser Rangefinder	1	$1,270.92	$1,270.92
Razor Dune Buggy	1	$469.99	$469.99
500 MHz ARM9 SBC w/ 128 MB DDR-RAM and 512 MB Flash	1	$269.00	$269.00
8-30VDC On-Board Switching-Mode Power Regulator	1	$28.00	$28.00
Development Kit for TS-7800 w/ 2GB SD	1	$100.00	$100.00
Hemisphere GPS A100 Smart Antenna	1	$1,600.00	$1,600.00
VN-100 Orientation Sensor	1	$50.44	$50.44
Kowa 3.5mm C-Mount Lens	1	$142.00	$142.00
Mounting Hub for T64 to tire/wheel assembly	4	$20.00	$80.00
Foam-Filled, K352 tread bolt circle	4	$47.00	$188.00
Motorbox/Gearbox 24v, 235 RPM 4-pole inline	4	$328.66	$1,314.64
ASUS HP Notebook	1	$479.99	$479.99
Arduino Mega Microcontroller	1	$68.20	$68.20
PC Mount Toggle Switch	1	$4.75	$4.75
RoboteQ AX2850 - 2 x 120 SmartAmps 12V-40V Robot Controller	2	$670.61	$1,341.22
GM2/3/8/9 Wheel Watcher Kit	1	$42.00	$42.00
Shaft-Mount Optical Encoder	1	$241.30	$241.30
OCZ Vertex 2e 60GB 2.5" SATA II	1	$129.99	$129.99
StarTech 2Pt 1294b ExpressCard	1	$79.99	$79.99
Miniature Fisheye Lens with IR cut coating	1	$99.00	$99.00
Lens adapter	1	$15.00	$15.00
Miscellaneous buttons and joysticks	1	$54.22	$54.22
Miscellaneous gear motors and accessories	1	$54.82	$54.82
Raw glass and metal	1	$266.33	$266.33
LIDAR	1	$1,270.92	$1,270.92
VN-100 Development Kit	1	$800.00	$800.00
Fire-i 400 Color Camera (VGA, 30 FPS)	1	$349.00	$349.00
Solder cups, dongle, automotive blades	1	$153.78	$153.78
DC converters, connector housing	1	$466.47	$466.47
		SUBTOTAL	$11,429.97
	TAX	5.00%	$571.50
		TOTAL	$12,001.47

9   CONCLUSION

Τ-RUS autonomous robot was built by IGVC club in collaboration with 4th year students from electrical, computer and software engineering majors. Since the University of Calgary is participating for the first time, the design of the Τ-RUS robot is kept as simple as possible. Everything was built from the ground up except the chassis. Every measure has been taken into account to protect the electronic components from shock, or from rain. The robot's advanced zero-point turn ability improves mobility on the ground, allowing the robot to turn in place. All the software and hardware components can be upgraded easily in future designs. The robot is all set to participate in the competition and the team believes that the robot will perform superbly in this year's competition.