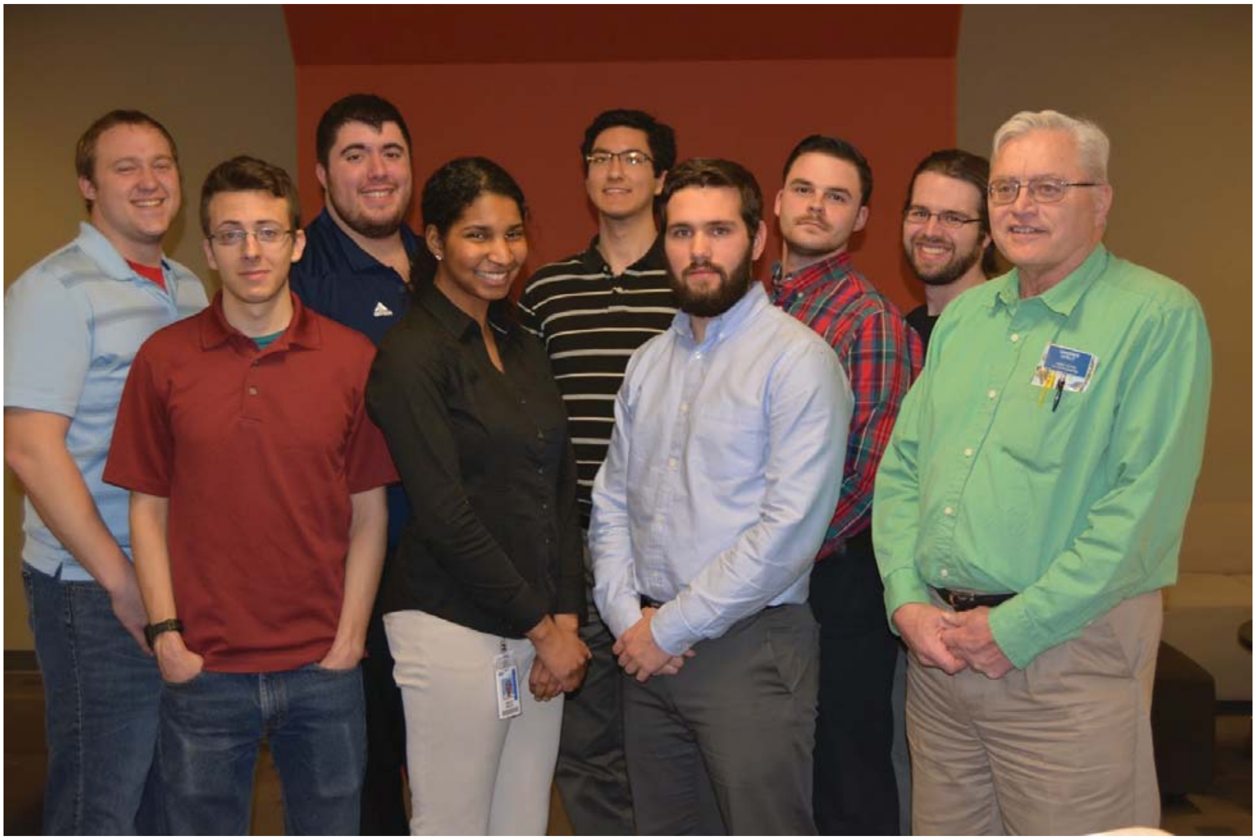
TURTLEBOT

Lawrence Technological University



Team Members (from left to right): Philip Bigos, John Marnon, Joseph Cox, Kristin Jordan, Mark Kenny, Vince Nicolazzo, Alex Lessnau, Anthony Knapp, Luis Rodriguez (not pictured)

I certify that the engineering design of the vehicle described in this report, TurtleBot, has been significant and equivalent to each team member earning senior design credit for their work on this project.

Jim Kerns
Department of Mechanical Engineering
Lawrence Technological University

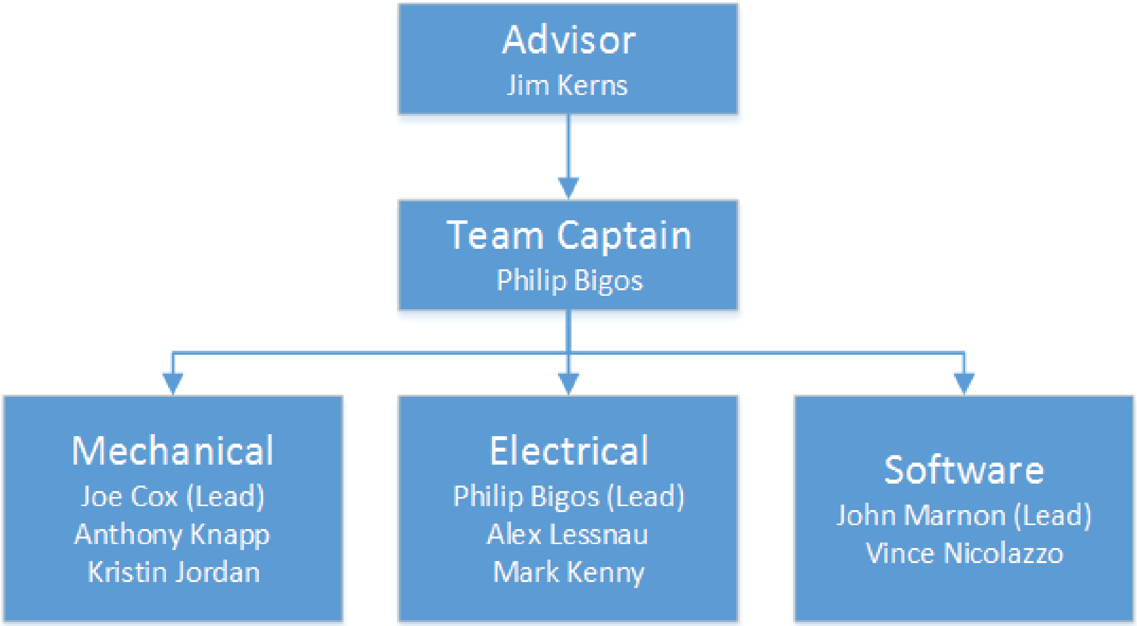
1 INTRODUCTION

Lawrence Technological University's Blue Devil Robotics team was founded in the fall of 2014 in preparation for the 2015 Intelligent Ground Vehicle Competition (IGVC). The team's vision is to distinguish Lawrence Tech's new Robotics program at both the state and national level.

Team members' knowledge of robotics has grown through the building of Blue Devil Robotics' first IGVC robot, TurtleBot. IGVC has helped further develop the team members' knowledge of robotics engineering resulting in the Blue Devil Robotics' first IGVC robot, TurtleBot. As a first year team with limited funding it became a team goal to produce a competitive robot at minimal cost. Throughout the 2014-2015 school year TurtleBot was designed to be the most efficient and rugged vehicle possible. This team's entry is unique as it is composed of primarily Robotics Engineering students. Having students with in a multi-disciplinary degree allows for better communication and understanding between each sub-team. TurtleBot has been the proud work of nearly 8,000 man hours.

2 TEAM ORGANIZATION

The Team Captain handles registration and guides the sub teams as they establish their team schedules. Team leads are responsible for organizing their specific team's meetings and events. Leads maintain open communication between the other team leads and working with those on their team to assign and complete tasks in a timely, efficient manner.



3 Budget

A major concern throughout the course of this project was locating and ensuring project funding. As a first year team, it is difficult to establish sponsors especially at a school with already well-funded teams. As a result TurtleBot's design focused on cost-efficiency and robustness. As presented in the figure below, the robot's cost just exceeds two-thousand dollars. Even though the team had limited funds, it is still expected that TurtleBot will prove to be a competitive robot.

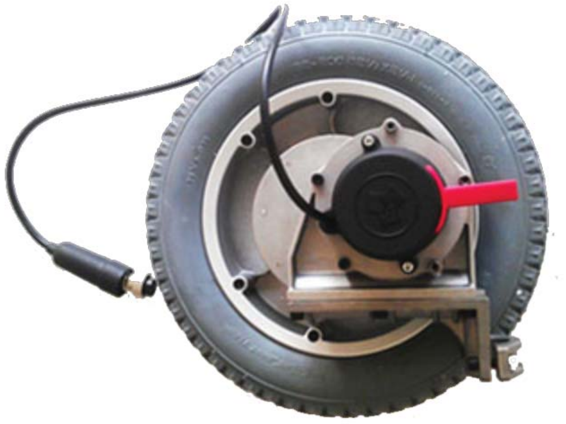
2015 Blue Devils Robotics B.O.M.		
Item	**Cost**	**Team Cost**
GPS (Smart phone)	$300	$0
Laptop	$2,200	$0
Material	$400	$400
Wheel Chair Motor Units	$1,200	$1,200
Cameras	$80	$80
Batteries	$144	$144
Controllers	$133	$133
LIDAR Unit	$5,000	$0
Electrical	$100	$84
Misc.	$50	$50
Total:	$9,607	$2,901

4 Mechanical1

4.1 Mechanical Overview

The overall design of the robot (Fig #) was a result of the priorities that were set when we started the competition. Still keeping in mind that we had limited funds, we design with the robot with a simple 1 in x 1 in x 1/16 in square steel tubing frame, something that was both cheap and rugged. The Chassis was designed in a way so that everything could be easily accessible, and repairs or installations could be made on the fly with ease. Because this vehicle would be subjected to the elements, the entire steel frame was painted to ensure structural integrity. The inside of the chassis was also sealed to insure that even with a torrential downpour, the electronics would not be harmed or damaged by water.

4.2 Powertrain



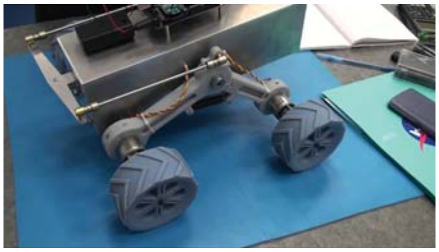
The vehicle is powered by 4 independent, 24 volt 250 watt, 12 inch brushless wheelchair hub motors. The motors on each side of the robot were controlled in parallel to each other to create a skid scer drivetrain. Each hub motor includes an encoder, emergency brake, and gear box. The emergency brake is always activated until the robot moves, which disengages the break. The breaks can be manually disengaged, but the motors will not run until they are reengaged. The encoders allow us to electronically monitor and control the speed of the robot. The built in gearbox on the other hand limits the speed of the motor to 5 mph, the top speed allowed during the competition. Because these brushless hub motors are built for wheelchairs, they have the ability to move large amounts of mass in a variety of terrains, if that be over concrete, rocks, grass, or up and down slopes.

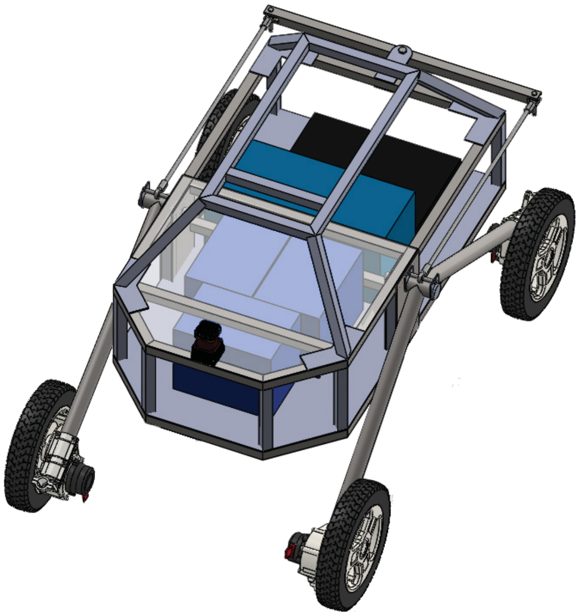
4.3 Chassis Design

The simple chassis design provides a clean look to the eye, and allows us easy access to the organized electrical components of the robot located inside. The 1 in x 1 in x 1/16 steel chassis frame is divided into a upper and lower section. The upper section houses all of our electrical components like motor controllers, boards, and converters. The lower section contains the batteries, mass, and laptop that runs the robot. Both sections can easily be separated from each other if need be. Each section is open, and everything is easily accessible for quick repairs or changes. Everything is covered and protected by a polycarbonate panel shell that seals against the steel frame, ensuring no water gets let in. The hinges for the polycarbonate panels are made from seat belt material that has been sewn together and coated with a water repelling spray to insure the water rolls off and doesn't soak through into the robot. The chassis frame has also been sprayed with Rustoleum to kept the integrity of the steal by insuring the moisture in the air and oils from human interaction doesn't cause rust. The chassis also has a filtered cooling system that maintains a cool temperature in the chassis without letting in dirt, or dust particles in the air and water.

4.4 Suspension Design

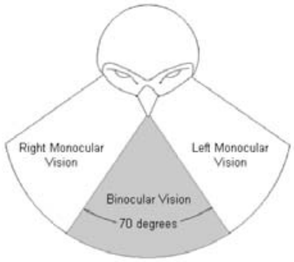
The suspension system design is by far the most unique aspect of the TurtleBot. With limited funds, we knew that we wouldn't be able to create a complex suspension system. We did understand though the importance of having a suspension system and its impact on not only our driving abilities, but our sensor data. So, as a result, we designed and built a suspension system inspired by NASA's Mars Lunar Rover program and there rocker-bogie suspension system. As it can be seen from the figure below, the left control arm depends on the right control arm and vice versa. As one side lifts, it causes the other side to push down. As a result, chassis movements are dampened, which result in better sensor readings.





The control arm sections located on either side of the chassis are attached to the chassis with a custom made aluminum shoulder bolt. Each arm is made out of 1.5 inch steel tubing, which attaches to the wheelchair hub motors. Because of the large linear forces and torques applied to this section of the robot, this is where we most likely will have failures in our system.

4.5 Robot Head Design

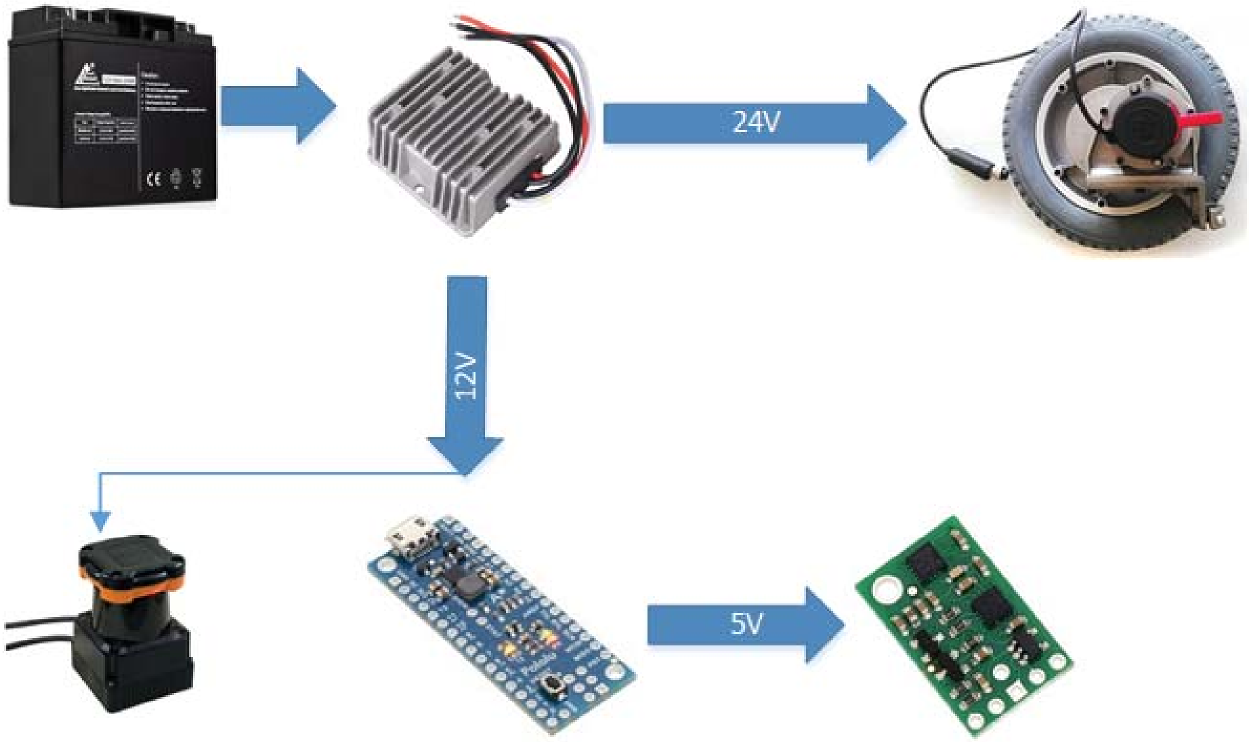


An autonomous vehicle is nothing without its vision system. So, an important aspect of our robot is our vision camera system. Using two cameras instead of one, we were able to overlay both cameras to create a larger field of view, much like a birds, compared to just having one camera. The head was built out of 1.5 inch PVC pipe, and attached to the chassis with a 3D-printed mount. The cameras are mounted in independent 3D-printed eye sockets that can move left to right along the PVC head. Each camera mount can rotate up, down, and side to side. Once the correct field of view is obtained, the mount is clamped and locked up to keep the desired position.

5 ELECTRICAL

5.1 Overview

The purpose of the power system on TurtleBot is to distribute the correct amount of electrical power to each component on the vehicle. Power requirements for each sub-system within the intelligent ground vehicle project were obtained by communicating with each of the groups. This resulted in a 24V system for the motors and a 12V system for the navigation components and onboard controllers.



5.2 Batteries

The designed battery life of the turtle was based on testing for 2 hours. Under average power consumption the motors will draw around 20 amps. As a major objective of our build was to save money we went with low cost 12V 18Ah batteries. These will create a 24V 36Ah system which will give approximately two hours of testing. As showing in the figure above the system is split into 24V and 12V subsystems.

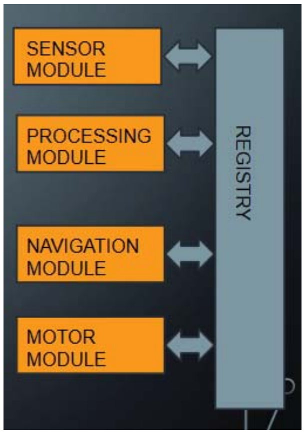
5.3 E-Stop

There are both a wireless estop and a hardwired estop. These are wired to the electromagnet brake and will stop the motors from being able to rotate no matter what is sent from the motor controllers.

6 SOFTWARE

6.1 PROGRAM ARCHITECTURE

A major design philosophy was to write the code in such a way that functions can be removed, altered, or added without leading to adverse effects on the remaining code. This was achieved through the use of a Registry and Module Architecture. A Module contains a set of processing instructions based on the current state of the system: startup, processing, and shutdown. These Modules can then be selected by the user to be loaded into the Registry for the next run cycle. The Registry is a list of active Modules and maintains operational order and system state.

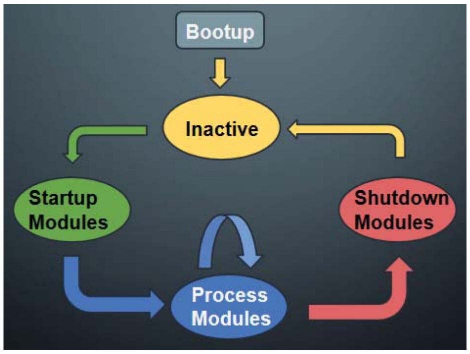


Inactive

- StereoVision
- Logger
- RandomDataGenerator
- RandomDataListener
- ForcedDelay
- GPS_Interface
- GPS_Visualizer

Active

- ConsoleLogger
- LIDAR_Interface
- LIDAR_Visualizer



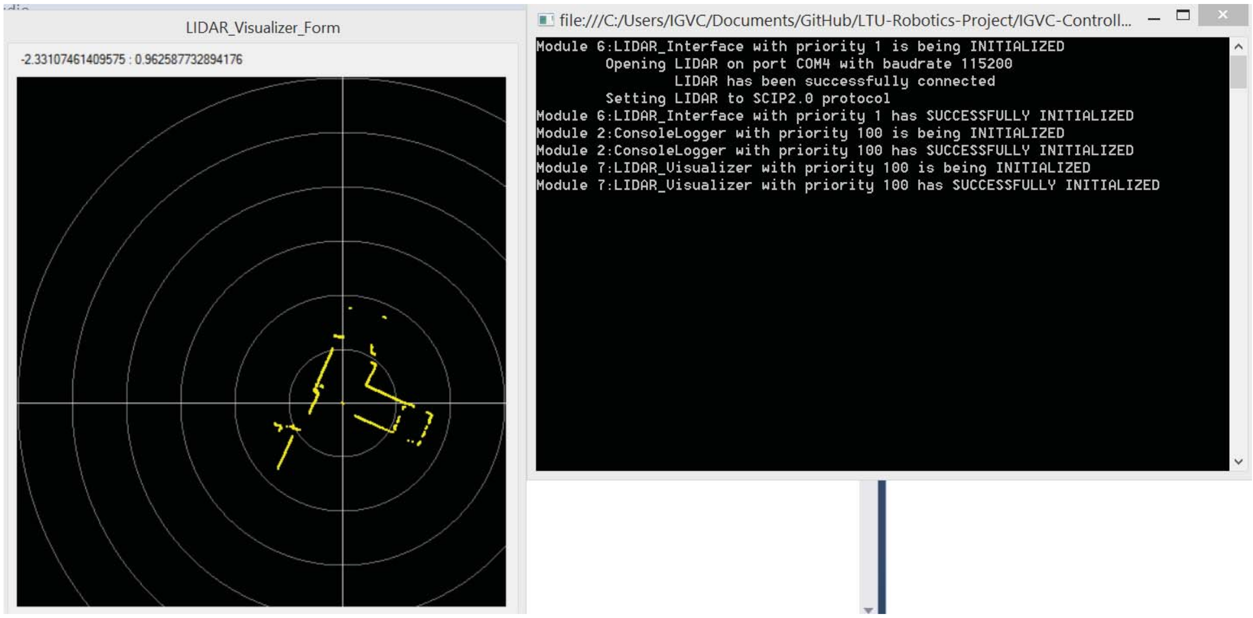
Communication among the various Modules is handled through the registry by a simplified version of a messaging system that we developed called Inter-Module-Variables. These variables allow any module to listen to and broadcast any variable it needs. It is also safe so that a module can edit on a copy of the data so later modules will keep access to the original version unless the variable is rebroadcasted.

6.2 POSITION AND HEADING

TurtleBot makes use of position and heading sensors in addition to predictions developed from its previous state and the desired outputs to develop a stable position and heading. The direct sensing of position and heading comes from a cell phone's GPS and an Inertial Measurement Unit breakout board. Using a cell phone for GPS information reduces the cost of TurtleBot while still maintaining the necessary precision and accuracy to fulfill the competition requirements. This information is averaged with the expected change in position from the accelerometers in the IMU and the motor encoder feedback to obtain position and heading information with reduced noise and error.

6.3 OBSTACLE DETECTION

TurtleBot uses several sources for sensing and navigation. For obstacle detection TurtleBot features a double monocular vision rig. It uses two wide angle cameras with 120 degree range of view each mounted to the frame with a very small overlap in their range of view. The images obtained from these cameras are then undistorted from the wide angle lense of the camera and matched together to create one large continuous image with a field of view that exceeds 180 degrees. This allows TurtleBot to view obstacles to the sides as well as forwards to handle obstacle heavy locations that may require point turns.

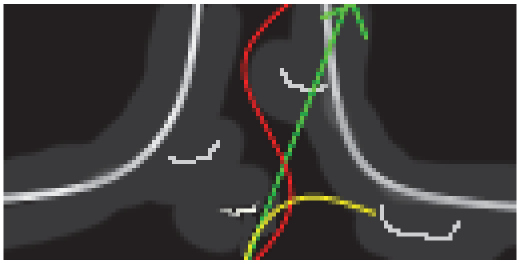


```
Module 6:LIDAR_Interface with priority 1 is being INITIALIZED
        Opening LIDAR on port COM4 with baudrate 115200
                LIDAR has been successfully connected
        Setting LIDAR to SCIP2.0 protocol
Module 6:LIDAR_Interface with priority 1 has SUCCESSFULLY INITIALIZED
Module 2:ConsoleLogger with priority 100 is being INITIALIZED
Module 2:ConsoleLogger with priority 100 has SUCCESSFULLY INITIALIZED
Module 7:LIDAR_Visualizer with priority 100 is being INITIALIZED
Module 7:LIDAR_Visualizer with priority 100 has SUCCESSFULLY INITIALIZED
```

TurtleBot also features a Hokuyo UTM-30LX LIDAR that is capable of detecting solid objects up to 30 meters indoors. Testing shows that it sees about 12 meters outdoors with a reliable detection angle of about 20 degrees. The system polls the LIDAR as needed to reduce energy consumption.

White lines are detected using an assisted threshold that takes environmental lighting into account. A Hue-Saturation-Value filter is run over the image to detect strong human made colors such as orange, red, and yellow to also pick up obstacles while ignoring natural objects that are not obstructions such as grass, dirt, and sticks. An obstacle map is created using the projected coordinates of the obstacles detected by the LIDAR and from image processing.

6.4 PATH PLANNING



TurtleBot implements a modified version of A* pathing. TurtleBot takes the detected obstacles from the obstacle detection modules and develops a Navigation Map (NaviMap). The NaviMap starts with developing a series of XY cells centered on TurtleBot. Each cell corresponds to a certain area. Using a large area per cell reduces the processing time of the pathing with the cost of a lower resolution path. The detected obstacles are then used to propagate the map with impassible cells. Both white lines (dashed and solid) and solid objects are treated as impassible.

The NaviMap then goes through a pre-processing filter that scans each cell and considers the closest cell detected. That cell then receives a pathing penalty based on its proximity to an impassable cell. At a distance about half the size of the robot (~2 feet) the new NaviMap will be marked as impassible. This closes the gaps that appear in the dashed lines. Within a 2 to 4 feet range a penalty ranging from near infinite to near one, respectively, is applied proportional to its proximity to the impassible cell. This allows the pathing to avoid getting too close to an obstacle when possible while only preventing a final path that would otherwise collide with the obstacle. A penalty is also applied to the region of the NaviMap that is below TurtleBot that allows for the robot to turn around only if there is no forward path.

The NaviMap is then processed using A* pathing. The start point is being treated as the center of the robot (about center-low in the NaviMap). The end point is calculated based on the relative position of a GPS waypoint. The path then proceeds following the standard A* algorithm with the only modification being what counts as a successful path. A successful path can be found if the point reached is the actual waypoint. If the the endpoint is blocked by obstacles from its current position or is beyond the NaviMap TurtleBot will count reaching the edge of the NaviMap as a valid path.

TurtleBot then takes this path and attempts to produce a trajectory based on differential steering that creates the closest match with the earlier parts of the path having a higher matching requirement. The trajectory is always treated as if TurtleBot starts the curve going forward. This velocity differential is then sent to the controllers to make the motors match this stage of the trajectory. The path and trajectory are recalculated every process cycle so the later stages of the path do not need to match the output trajectory.

7 CONCLUSION

Throughout the year we as a team worked on bringing together a rugged, cost-effective robot. The Turtlebot is made with less expensive parts but can take a hit. Working as a team of mainly Robotic Engineering students we were able to put our multidisciplinary degree to use throughout this year working on IGVC.

Work Cited

Bird vision Picture
http://blog.getnarrative.com/wp-content/uploads/2014/04/owl-vision.png

Golden Motor
http://www.goldenmotor.com/