ROBOJACKETS 2014 DESIGN REPORT

Georgia Institute of Technology
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INTRODUCTION

RoboJackets is the competitive robotics organization for students at the Georgia Institute of Technology. Founded in 1999 as a BattleBots team, the organization has grown to include the RoboCup Small Size League, the Intelligent Ground Vehicle Competition, the International Autonomous Robot Racing Challenge, and a large outreach team. Though the organization is chartered under the school of mechanical engineering, our members represent nearly every department on campus, predominantly computer science, mechanical engineering, aerospace engineering, and electrical engineering. Having first competed in IGVC in 2004, the RoboJackets have competed in every IGVC since 2006, finishing in the top 10 on the autonomous course for six consecutive years.

TEAM MEMBERS

Our team is organized into mechanical, software, and electrical subteams. Each subteam contributes designs, assemblies, and code per the requirements of the competition and other subteams. Table 1 shows a listing of our membership.

Table 1. RoboJackets IGVC 2014 Membership

Name	Degree	Role
Matthew Barulic	BS Computer Science, 2nd Year	Project Manager, Software Lead
Kyle Bates	BS Electrical Engineering, 2nd Year	Electrical Lead
Claire Bergman	BS Mechanical Engineering, 3rd Year	Software
Al Chaussee	BS Computer Science, 2nd Year	Software
Joseph Hickey	MS Mechanical Engineering, 1st Year	Mechanical
Emanuel Jones	MS Mechanical Engineering, 2nd Year	Mechanical
Rohan Iyengar	BS Electrical Engineering, 1st Year	Electrical
Dea Gyu Kim	BS Mechanical Engineering, 2nd Year	Mechanical Lead
Cecilia Liu	BS Mechanical Engineering, 1st Year	Mechanical
Orlin Velev	BS Mechanical Engineering, 1st Year	Mechanical
Jonathan Williams	BS Mechanical Engineering, 2nd Year	Mechanical
Victor Ying	BS Electrical Engineering, 2nd Year	Electrical

MECHANICAL

This year’s mechanical work in preparation for the 2014 competition largely revolved around improving and upgrading systems and sensors while maintaining the same basic four-wheeled design from the 2013 competition season. While our robot proved to be a stable platform, the vehicle encountered difficulties at competition last year, largely stemming from an inadequately designed suspension. Armed with a comprehensive understanding of the vehicle’s shortcomings, the following design goals were pursued this year:

1. Redesign the suspension

2. Implement a wheel decoupling mechanism
3. Integrate new sensors
4. Improve vehicle weatherproofing

Design Premise

The vehicle is built for the purpose of being an off-road vehicle capable of handling difficult situations without human intervention. This requires the ability to cope with a variety of terrains, in addition to the ways those terrains change in inclement weather. The team's past experience with IGVC has shown that adverse weather conditions are not uncommon. Towards the goal of a robust platform in these harsh conditions, significant work has been done to ensure the maintainability of the vehicle and most especially, the safety of its operators.

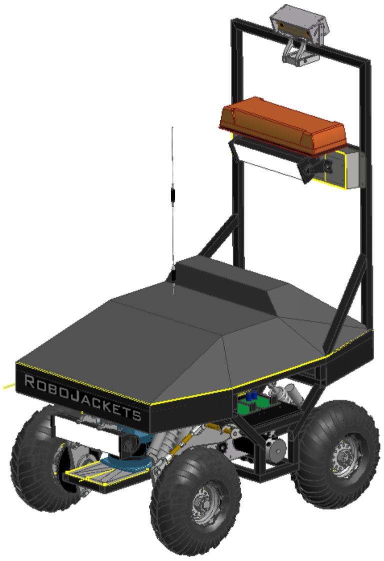

Figure 1. Mistii

Chassis

The structure of the robot is composed primarily of 1"x1" square steel tubing that is MIG welded and painted to avoid corrosion. The frame has four main sections, highlighted in Figure 1:

1. The electronics trays
2. The core, which houses powertrain components such as batteries, gearboxes, and motors
3. The mast, which mounts the sensors and switches
4. The LIDAR and payload bays

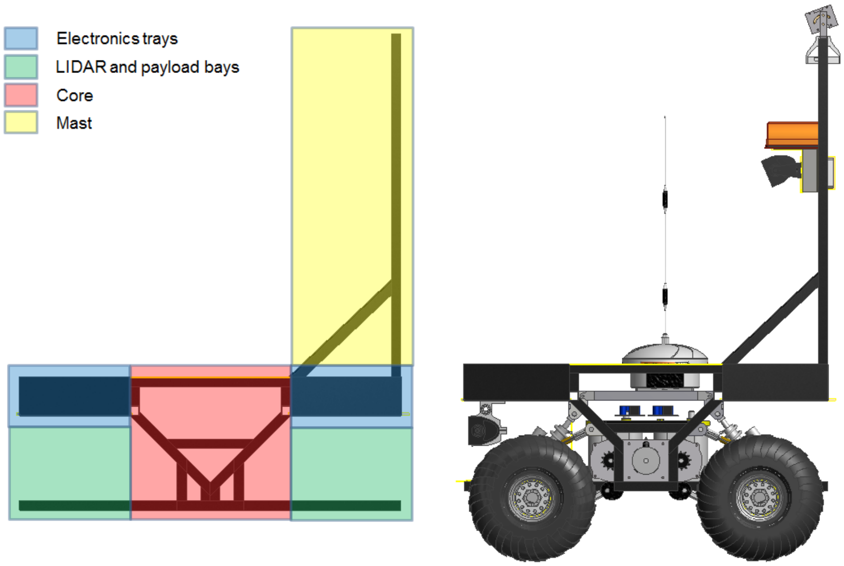

Figure 2. The four main sections of Mistii

Mast

The robot sports a 58” tall mast which provides the mounting structure for the stereoscopic camera and the inertial measurement unit. During the 2013 competition season and in previous years, the GPS was mounted to the top of the mast. However, due to the size of the new GPS unit and its antennae, this sensor was relocated to the core of the robot to be within the competition height requirement.

All switches for accessories and emergency requirements are also mounted midway up the mast. This switch panel, shown in Figure 2, includes headlights for night time testing, the main power switch, emergency stop, and a battery indicator. Because testing the robot can sometimes yield unexpected results, the emergency stop has been mounted directly in the middle of the mast and at a forehead height for easy activation.

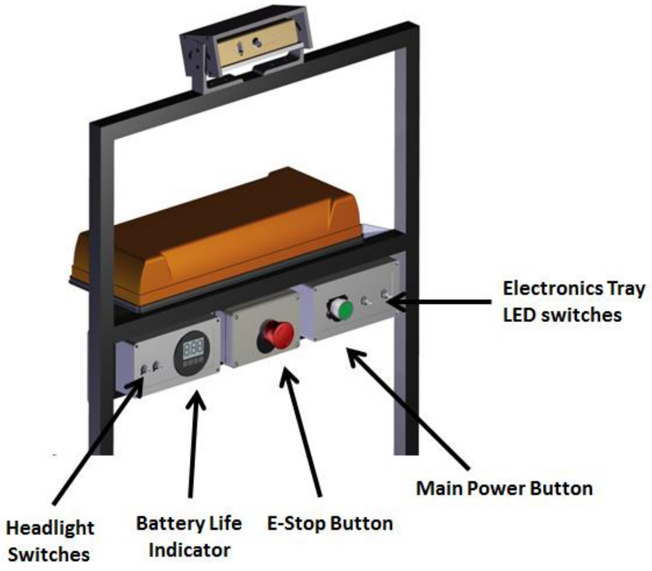

Figure 3. Mistii's Mast

Drive System

The vehicle operates using skid-steer dynamics, with each side powered by its own central motor. Each motor is rated at peak 4.5 HP for a total of 9 HP. Custom-made, two stage gearboxes link these motors to the wheel axles via chains and sprockets. The gross reduction from the gearbox to the wheel is 30-to-1 to provide sufficient torque to each wheel. Figure 3 shows a rendering of the motor and custom-machined gearboxes.

Figure 4. 2-Stage Gearbox With and Without Cover Plate.

The rear of each gearbox also includes an encoder to measure the displacement of the robot. Figure 4 shows an exploded view of all components in the assembly.

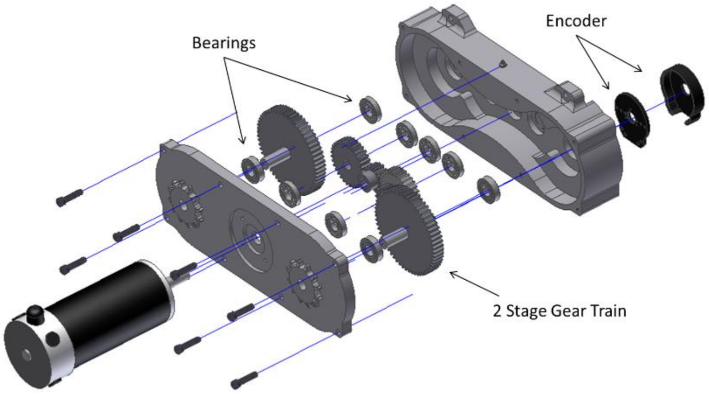

Figure 5. Gearbox Exploded View

Wheel Decoupling Mechanism

Such a massive machine requires great effort to move when its own systems are powered off. Significant work was put into making a system to easily decouple the wheels from the drivetrain. This allows the robot to be moved by hand without having to fight against the powerful motors and the reduction of the gearboxes, speeding up both testing and transportation.

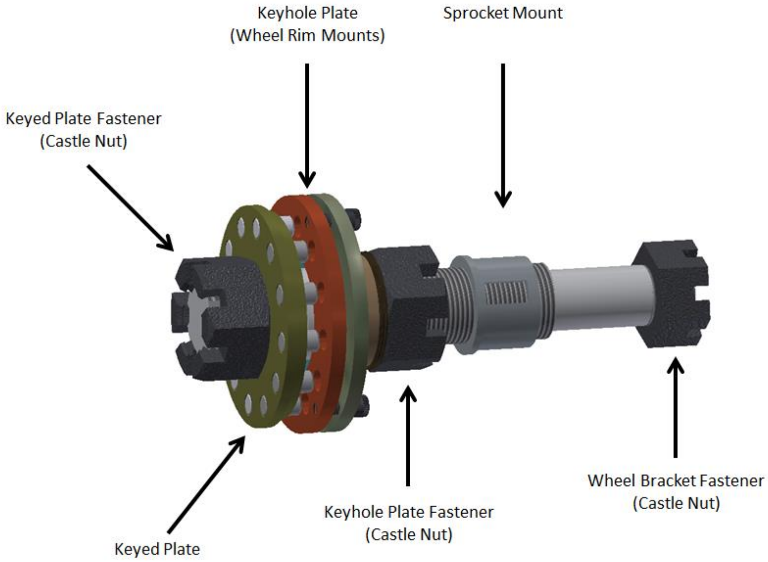

Figure 6. Wheel Axle With Decoupling Mechanism Highlighted.

The decoupling mechanism is composed of three major components:

1. A multi diameter shaft (wheel axle) with a D-profile on the outboard end. This shaft is chain driven by the output from the gearbox.

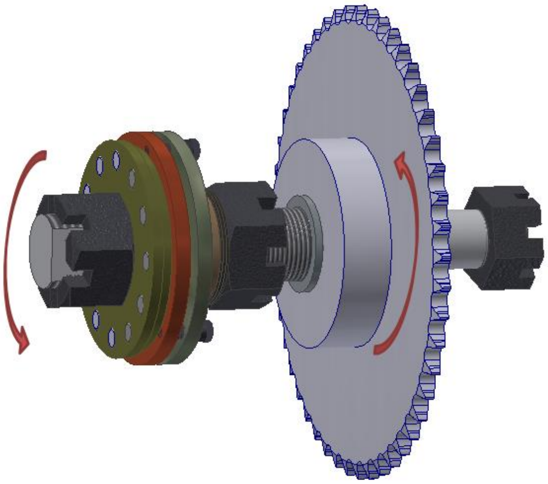

Figure 7. Motion When Wheel Is Locked To Axle

2. A plate with keyholes that is fixed to the rim of the wheel. This keyhole plate rests on a bearing such that it can freely spin with respect to the wheel axle unless engaged by the keyed plate
3. A keyed plate with tapered dowel pins. This plate sits on the D-profile of the shaft. The pins locate into the holes on the keyhole plate to rotationally lock the wheel to the axle. Axial position along the wheel axle is constrained by a large castle nut.

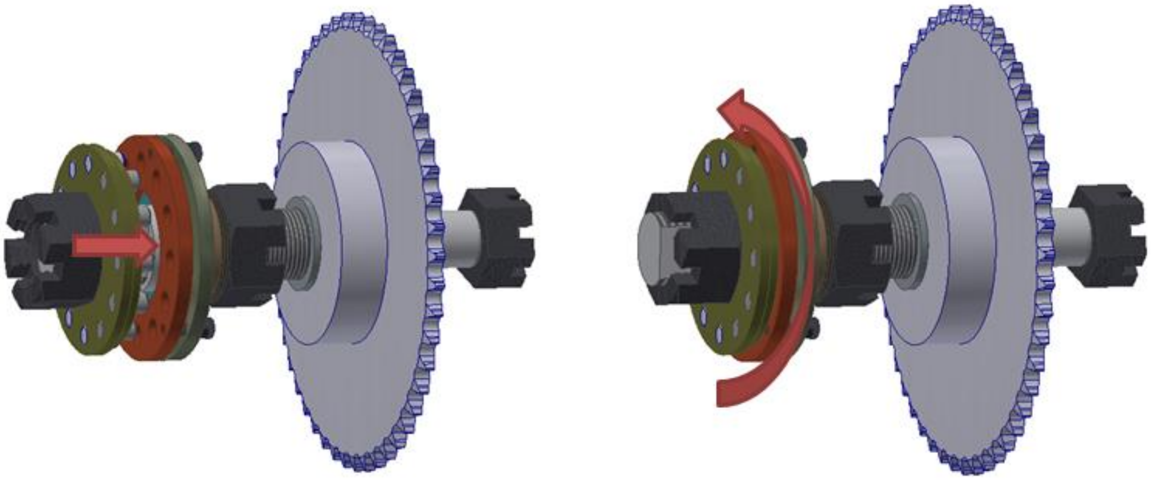

Figure 8. Engaging the Decoupling Mechanism

Suspension

The robot was designed with independent suspension that allows each wheel 5 inches of travel, lending the design advanced ride dynamics and ensuring stability while traversing rough terrain. The design incorporates Fox DHX RC4 coilover dampers combined with 100 lb/in. springs, as well as 14” pneumatic wheels, allowing the robot to roll over most terrain with ease. While this design is more mechanically complex than those seen in previous years, it allows for a superior ride dynamic and smoother operation in general.

A design flaw in the robot during the 2013 competition year meant that while under load, the wheels would have an undesirable camber angle. This caused misalignment between the chain and sprockets, forcing the chain to either derail or seize up. One goal for the 2014 competition year was to improve this design to ensure the sprockets would maintain proper alignment.

Redesign. The underlying problem of the suspension was that the weight of the robot produced a moment that the control arms could not sufficiently counteract, causing significant misalignment of all components connected to the control arms, namely the wheel axle and sprockets. The optimal solution to this problem was to limit lateral motion of the control arms. The addition of plates to the control arms proved to be effective in preventing lateral motion, as the plates would be shear loaded and easily able to resist deformation. Figure 9 shows the suspension assembly.

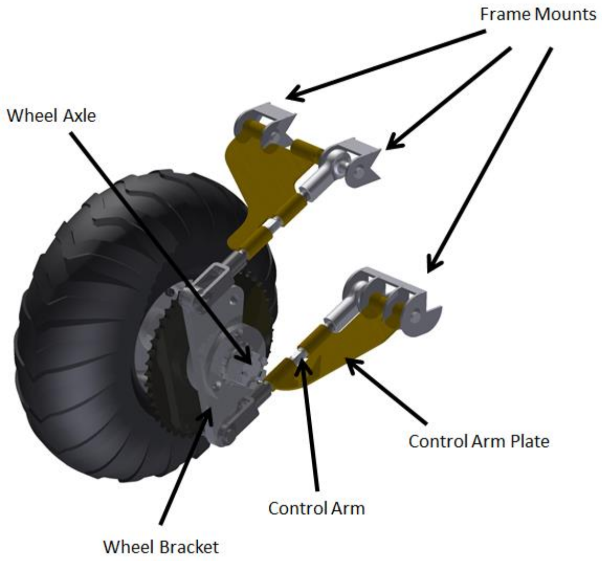

Figure 9. One of Mistii's Suspension Assemblies

Chain Tensioning Mechanism. The new control arms were turned from ½" steel rods by our team members. These control arms directly mount to the wheel bracket, which houses the wheel axle. The ends of these control arm rods are threaded in opposing directions that enable simple tension adjustment of the suspension, effectively making a heavy-duty turnbuckle that is easily adjusted with a wrench. This made suspension tuning a much less time consuming process compared to last year and allowed for a greater degree of precision in adjustments, ensuring tight tolerances and properly tensioned chain. This new suspension system has been much more effective in constraining unwanted motion and has allowed for a greater load capacity of the robot.

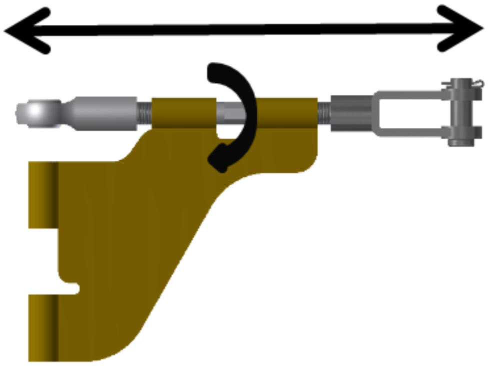

Figure 10. The Control Arm's Turnbuckle Mechanism

Weatherproffing

Frame. Special emphasis has been taken to ensure the robot is all-weather capable. Firstly, the electronics trays are welded on all edges to the chassis, allowing rigid support and no water penetration. Additionally, a large polycarbonate panel is installed on the top of the robot to allow such that rainwater runs off to the sides and down the exterior of the vehicle.

Powertrain. The two central gearboxes utilize sealed bearings on the output shafts as well as the input shaft, and are tightly packed with grease to aid in lubrication and water repulsion. The motor controllers, which are mounted directly above the gearboxes, are protected from mud sling and rainwater by both the top body panel and additional body panels mounted on all sides of the controllers. The two lead acid batteries that power the robot are stored in a plastic enclosure at the very center of the robot, and are also protected by the exterior body panels.

Sensors. Because the GPS was moved to the core of the robot, this required a redesign of the main body panel. Previously, flat polycarbonate panels were used to cover the frame due to their ease of manufacture. For the 2014 competition year, a custom contoured single body panel was made to ensure for a water-tight design.

The stereoscopic camera on the mast incorporates a plastic panel that covers all electrical connections, while the IMU is housed in a custom-machined water-tight box. Additionally, all switches and buttons on the mast are housed in washdown boxes to prevent any connections from getting wet.

Ease of Maintenance and Safety

One of the major goals of the mechanical design is to create a design that is reliable and rugged, while also being easy to operate and maintain. The following is a list of improvements made to the system to ensure maintainability maintenance and safety in the overall design:

- Electronics mounted on removable ESD plastic to prevent accidental electrical discharges.
- Electronics tray-illuminating LEDs mounted inside robot to improve internal visibility
- All shafts with retaining rings have been replaced with shoulder screws and nuts on all suspension components, making these parts significantly easier to remove and tweak.
- Powertrain/wheel decoupling mechanism to ease robot mobility
- Turnbuckle mechanism on suspension to allow easy tensioning or removal of chain
- E-stop mounted at forehead height

ELECTRICAL

Computing Power

Primary Computer. Nearly all computation is handled by the on-board laptop. Mistii carries an MSI GT660R, containing a Quad-Core Intel Core i7 CPU, CUDA enabled NVIDIA 285M GPU, and 6 GB of RAM. This computer is responsible for most sensor data processing and all path planning and control algorithms.

Microcontrollers. Communication and control of much of the hardware is handled using the popular Arduino UNO microcontroller. Mistii features two of these controllers. One handles motor control and encoder interface. The other interacts with all of Mistii's lights, along with e-stop and battery monitoring functionality.

Custom Arduino "shields" were designed and built by our team members to facilitate this hardware interaction. These boards match the layout of the Arduino UNO's expansion pins and help to organize the external circuitry and connection routing. Figure 3 gives the layouts used to print our Arduino shields.

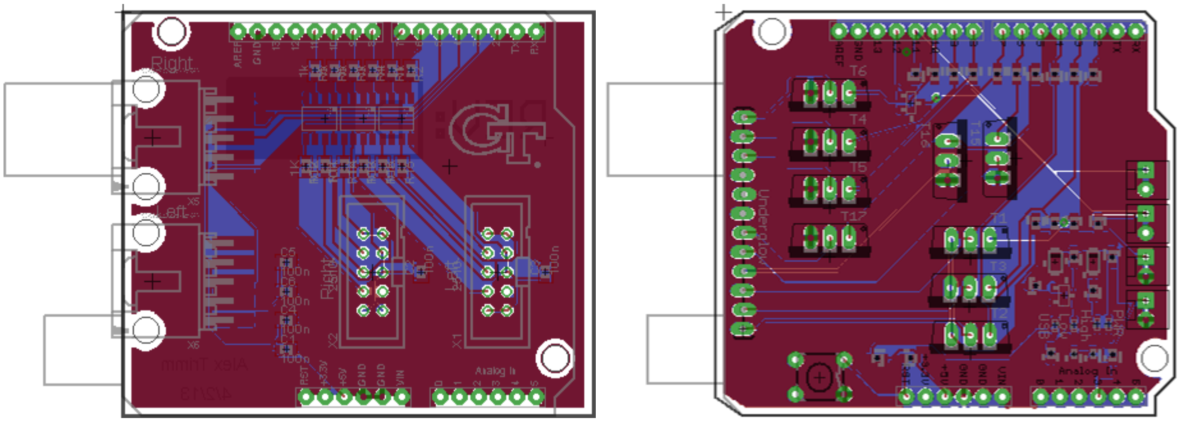

Figure 11. Layouts of Our Custom Arduino Shields (Left: Motor Shield, Right: Light Shield)

Sensors

LIDAR. Mistii employs a Sick LMS 200 LIDAR to provide convenient and straightforward obstacle detection. The LIDAR has a 180 ◦ FOV and a 10 meter range.

Stereo Camera. Mistii is the first Georgia Tech IGVC robot to utilize a stereo camera. The stereo camera chosen is a Bumblebee 2 made by Point Grey Technologies. This camera delivers two 1024x768 images at 20 fps. The camera uses a FireWire connection to interface with the main laptop.

GPS. A GPS is used to provide world position to the robot, allowing obstacles to be placed in world space and allowing waypoints to be followed. An Outback A321 Smart Antenna is mounted near the center of the robot. This GPS is accurate to within 0.3 m with WAAS corrections. Location data is sent over serial connections to the software at 10 Hz.

IMU. Mistii also utilizes an ArduPilot Mega 2.5 IMU. This IMU includes a 3-axis accelerometer, 3-axis gyroscope and a 3-axis magnetometer as well as a barometric pressure sensor. The board contains an ATmega2560 chip allowing custom programming and serial communication over a USB connection.

Encoders. Each gearbox is connected to a quadrature wheel encoder, allowing wheel rate and absolute distance to be measured. This allows the velocity of the robot to be measured, as well as the distance the robot has travelled. The encoders are US Digital E3's, with 200 counts per revolution and an index channel. One quadrature line from each encoder is connected to an interrupt pin on the microcontroller, which uses this input to calculate closed-loop control errors.

Power

Sources. Main power for the robot comes from two deep-cycle, lead acid, gel-cell batteries. These batteries are connected in series to produce a nominal 24 VDC supply. Each battery provides 48 Amp-Hours of energy, making the robot's total capacity 1052 Watt-Hours. This increased capacity over previous designs counteracts the increased mass of Mistii over her predecessors and leaves the total estimated runtime at approximately 1 hour of driving.

Distribution. The batteries are connected to a power distribution board, fuse-limited to 40 amps, cutting power in the event of a motor stall to prevent damage to the H-bridge and motor. Each motor is connected to two OSMC H-bridges, which allow the motors to be driven from the Arduino microcontroller. Each OSMC is capable of switching up to 50 VDC at 160A continuous / 300A peak, allowing significant margin above our standard operating power of around 24 VDC / 20 A. Power is also provided to several DC-DC buck converters, which output 5 VDC, 12 VDC, and 19.5 VDC for the other electronics on the robot.

SOFTWARE

Much of this year's work on our code base has aimed to build a complete navigation solution atop last year's foundational work. Taking advantage of the advanced Qt Framework, our code base is written in C++ with an event-based design paradigm. These events are managed by Qt's signals and slots API and allow us to coordinate the multiple execution threads that communicate to and process data from our sensors.

Lane detection

Being such a fundamental part of the competition, lane detection receives a large focus in our software efforts. This year's code features improvements over our previous efforts. First, an averaging of the brightness across the image allows our algorithm to account for more dynamic lighting conditions than has been possible for us in the past. These conditions are taken into account when the image is filtered for the color range found in the painted lines. Finally, an erosion-dilation procedure is used to filter out noise and help ensure that the algorithm is selecting only the lines. This filtered image is then parsed into a point cloud representation of the lines in physical units in a coordinate system centered at the camera's location. This point cloud format is then broadcast to the other elements of the system.

Mapping

In addition to the vision system, a LIDAR device is used to detect obstacles that rise up from the ground. Both of these point clouds are received by our mapping system. This system uses the advanced features of the Open Perception Foundation's Point Cloud Library (PCL). Our system uses PCL to filter the point clouds for noise, translate them into global coordinates, and merge them into an efficient map of the course.

Path Planning

Mistii's path planning is a form of the A* graph search algorithm. We first switched from potential fields to full-map graph search last year, and began working on an implementation that planned based on the actions our robot can actually generate. To explain, most conventional graph search algorithms, when implemented in continuous environments, work by first discretizing the search space into a grid or graph of nodes connecting midpoints between obstacles. While this allows for convenient application of graph theory to a more complicated setting, it can often produce paths that require post-processing to convert them into actions a nonholonomic robot can actually perform. This post-processing often includes smoothing turns into manageable curves. Rounding these corners may lead to collisions, which leads to these smoothing algorithms to be laden with collision detection logic.

Unsatisfied with this common approach, we decided to develop a problem definition for our A* planner that accounted for the kinematics of our vehicle. We found that these kinematics can be described succinctly with two terms: a linear velocity and an angular velocity. Different combinations of these two values produce a spectrum of arcs with varying radii. Our planner uses these arcs to determine available actions and successor states. While the resulting discretization of space is not an evenly spread graph, the paths produced are smooth chains of arcs that require no post-processing to generate sets of robot commands.

While we are quite happy with the results of our implementation thus far, we have identified some drawbacks to this approach. The most extreme weakness for our purposes is the difficulty in transitioning to a more dynamic planner. In a task such as IGVC, where new data about the map is obtained at every turn, it can greatly increase planning speed if the algorithm can reuse parts of its current path that are still drivable. One common modification to achieve this is the D* family of algorithms. These algorithms assume a consistent graph between iterations, which, unfortunately, is difficult to generate in our kinematics-based action system. One of our big challenges for next year will be updating our planner to more efficiently handle the dynamic nature of our partially-observable course.

Materials and Cost

Table 2. BOM for Mistii

Item	Value ($)	Cost to Team ($)	2014 Cost ($)
Steel Tube	200	200	0
4x Dampers	2380	2380	0
SICK LMS 200	5000	430	430
Point Grey BumbleBee 2	2495	1380	0
2x DC Motor	900	900	0
4x Motor Controller	820	820	0
2x Gearbox	1000	1000	0
Laptop	1300	1300	0
FireWire PCI Adapter	40	40	0
2x Battery	460	460	0
ArduPilot Mega 2.5 IMU	180	180	0
Arduino Uno	30	30	0
2x Headlights	500	500	0
Safety Beacon	350	350	0
E-Stop	80	80	0
Wireless E-Stop	50	50	0
USB Hub	5	5	0
Laptop Power Converter	50	50	0
24V-12V DC Converter	30	30	0
Outback A321 GPS	7000	7000	7000
2x Optical Encoder	170	170	0
Misc Mechanical	2200	2200	950
Misc Electrical	300	300	100

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