IGVC2015-MISTII

ROBOJACKETS 2015 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 2015 IGVC Membership

Name	Degree	Role
Matthew Barulic	BS Computer Science, 3rd year	Software
Richard Chaussee	BS Computer Science, 3rd year	Software Lead
Kelvin Chong	BS Mechanical Engineering, 1st year	Mechanical
Himanshu Dedge	BS Mechanical Engineering, 1st year	Mechanical
Zachary Goddard	BS Mechanical Engineering, 1st year	Mechanical
Alexander Gurney	BS Computer Science, 3rd year	Software
Matthew Keezer	BS Computer Science, 1st year	Software
DeaGyu Kim	BS Mechanical Engineering, 3rd year	Mechanical
Jeffrey McKendree	BS Mechanical Engineering, 1st year	Mechanical
Jong Hoo Park	BS Mechanical Engineering, 3rd year	Mechanical
Orlin Velev	BS Mechanical Engineering, 2nd year	Project Manager

MECHANICAL

The mechanical efforts in 2015 focused on achieving the following goals:

1. Improve handling on Rough Terrain
2. Improve robustness of drive system
3. Improve reliability of suspension

The vehicle was transformed from a four wheel skid-steer platform to a three wheeled design with individually powered rear wheels and an unpowered front caster wheel. This allowed the vehicle to retain the robustness and all terrain capabilities of the prior year's design while improving handling and steering. This involved significant modifications to the drive system and lower chassis of the robot, as well as the relocation of sensors. This redesign has helped to address many of the suspension problems that have occurred in prior years and has improved the stability of the vehicle.

Figure 1. Mistii

Design Premise

The vehicle is designed with an emphasis on off-road vehicle capabilities and handling difficult situations without human intervention. This requires the ability to cope with a variety of terrains (e.g. rocks, mud) and weather conditions. 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.

Chassis

The structure of the robot, shown in Figure 2, is composed primarily of 1"x1" square steel tubing that is MIG welded and painted to avoid corrosion, with a smaller amount of 1"x2" tubing to support the new rear suspension and drive system. Modifications for the 2015 season included the removal of the LIDAR trays and vestigial mounting brackets on the underside of the robot to create more space for the suspension.

Figure 2. Chassis

Mast

The robot sports a 58” tall mast, shown in Figure 3, 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 during the 2014 season to be within the competition height requirement.

All switches for accessories and emergency requirements are also mounted midway up the mast. This switch panel includes headlights for night time testing, the main power switch, emergency stop, and a battery indicator.

Figure 3. Mast and Related Equipment

Drive System

Previous iterations utilized a chain drive system that exhibited problems including inconsistent performance and chain derailing due to sprocket misalignment.To remedy these shortcomings, it was decided that the direct drive system shown in Figure 4a and 4b, capable of powering each of the rear wheels independently, would be the most effective solution. This decision was made on the basis of simplicity, cost-effectiveness, and robustness.

The fact that the motor and gearbox are attached directly to the drive axle ensures a more direct transfer of energy to the wheels, and this simplicity is further aided by the use of a worm and worm gear to attain the desired gear ratio of 30:1. This is a much more compact solution than the gearbox used in prior years, and allows the high speed output of the 4.5 horsepower electric motors to be converted to a lower speed, higher torque output to the drive wheels. This is important because the robot is limited to a top speed of 10 miles per hour, which the motors could easily achieve, but it often requires a significant amount of torque to move the robot from a standstill, especially if the front caster wheel is not initially aligned to the direction of motion.

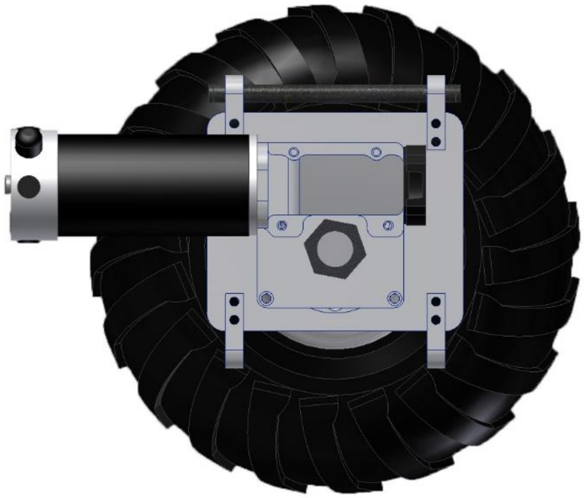

Figure 4a. Profile View of the Motor and Gearbox Drive System

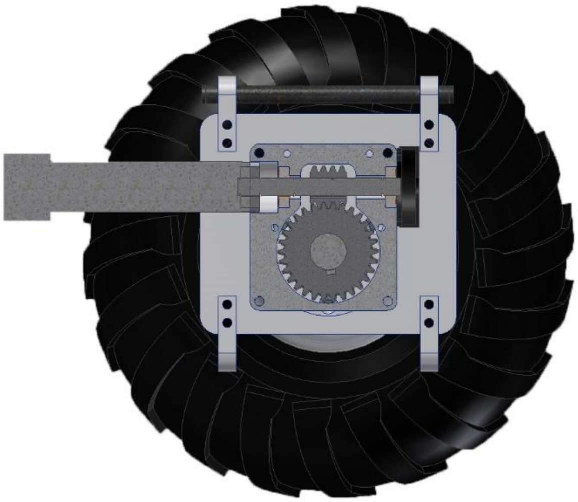

Figure 4b. Section View of Gearbox Interior and Drive System

Decoupling Mechanism

This year’s design included some minor modifications to the largely successful decoupling mechanism from the 2014 robot. This mechanism, illustrated in Figure 5a-c, 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. The custom driveshaft that was designed and fabricated last year was turned down to accommodate a gearbox rather than a sprocket. The use of a keyed plate with dowel pins remained the primary mechanism of force transfer between the rotating shaft and wheel. In addition, lock nuts were employed to replace the original castle nuts to further ensure the rigidity of the system.

Figure 5a. Decoupling System and Drive Assembly

Figure 5b. Exploded View of Decoupling Mechanism Assembly

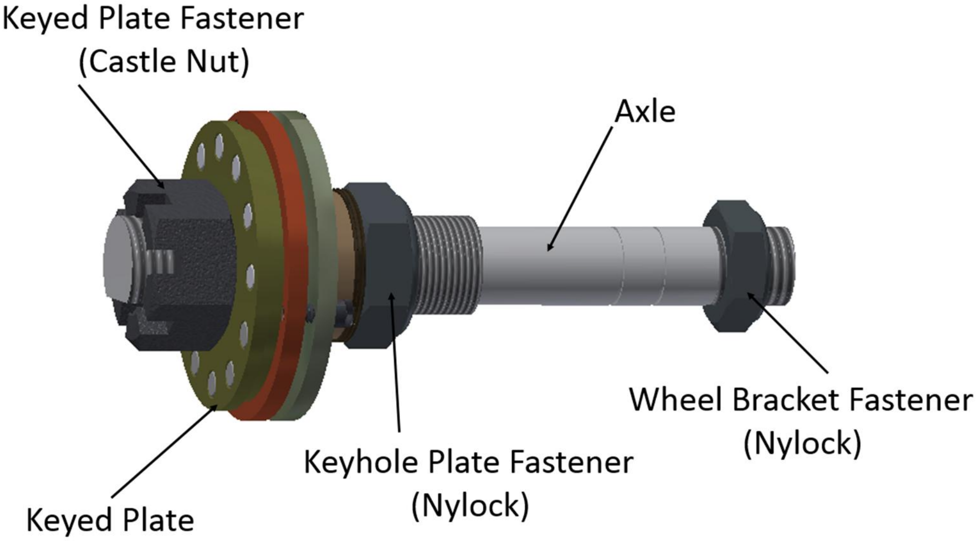

Figure 6. Decoupling Mechanism Components

Caster Wheel

An unpowered caster wheel was built to reduce slip inherent in previous years' skid-steer designs. The caster sits on two roller bearings connected to a dead axle, which is in turn held in place by a welded steel fork. The assembly is unpowered and freely rotates on a large industrial turntable bolted directly to the frame as shown in Figure 6. The wheel is offset from the turntable, rather than directly under it, to induce caster bias and prevent gimbal lock.

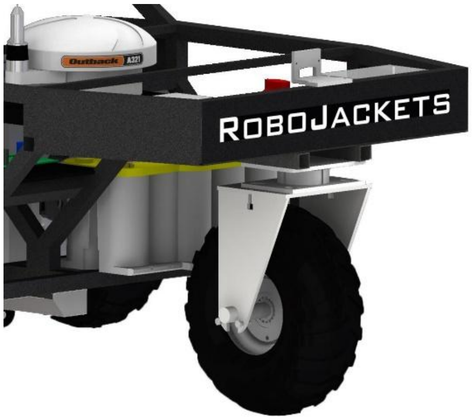

Figure 7. Caster Wheel

Suspension

The suspension on the vehicle borrows elements from previous years, while reducing complexity and tightening tolerances to decrease component wear. The suspension, shown in Figure 7a-c uses a four bar linkage common in many other offroad vehicles. The frame of the vehicle acts essentially as a single bar, holding fixed the endpoints of two ½” diameter control rods that are connected to the wheel bracket assembly that acts as the fourth bar. This assembly is applied twice to each wheel to ensure rigidity, for a total of four control rods per wheel. Each control rod is connected to two opposingly threaded clevis rod ends, one on each side. These rod ends can be simultaneously tightened or loosened by using a wrench to turn the control rod, effectively creating a heavy duty turnbuckle.

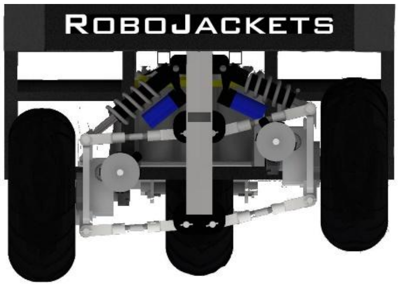

Figure 8a. Independent Compression of Suspension System

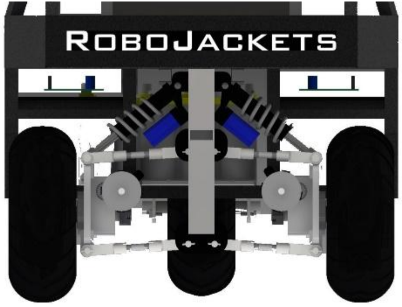

Figure 8b. Neutral Position of Suspension

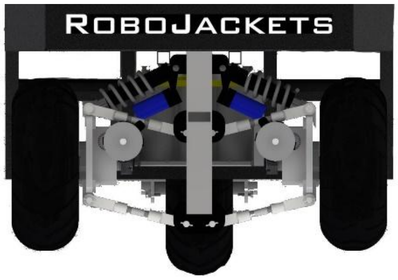

Figure 8c. Maximum Compression of Suspension

Ease of Maintenance and Safety

One of the major goals of the mechanical design is to create a vehicle 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 facilitate maintenance and enhance safety in the overall design:

- Electronics mounted on ESD plastic to prevent accidental electrical discharges. These trays are also removable for easy access.
- LEDs mounted inside the electronics tray to improve internal visibility
- Quick release battery clamps for expedited battery swap and charging
- Wheel decoupling mechanism to ease robot mobility
- Turnbuckle mechanism on suspension to allows easy adjustment of vehicle ride height
- 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 9 gives the layouts used to print our Arduino shields.

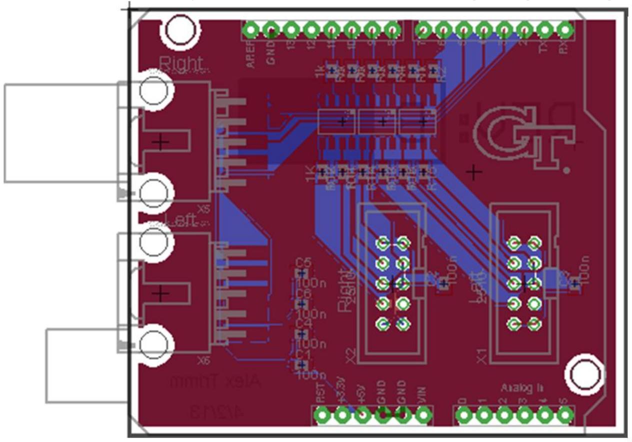

Figure 9a. Arduino Motor Shield

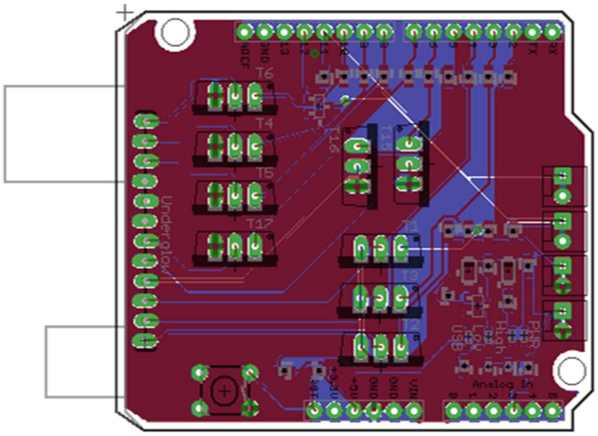

Figure 9b. Arduino Light Shield

LIDAR. Mistii employs a Sick TiM 551 LIDAR to provide convenient and straightforward obstacle detection. The LIDAR operates at 15 Hz, has a 270° field of view and a 10 meter range.

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 communicates over a USB serial connection.

Encoders. Each gearbox is connected to a quadrature wheel encoder, allowing velocity and absolute distance to be calculated. 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 motor control Arduino, which uses this input to implement closed-loop control.

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 Ah of energy, making the robot's total capacity 1052 Wh, and gives a total estimated runtime of approximately 1 hour of driving.

Distribution. The batteries are connected to a power distribution board, fuse-limited to 40 A, which cuts 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 160 A continuous / 300 A 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 19.1 VDC for the other electronics on the robot.

SOFTWARE

The software efforts this year focused on our vision pipeline, position tracking, and a overhaul of our events system. Our code was ported to the Robot Operating System (ROS) to advance the capabilities of our event-based architecture. Our code base is written in C++ using the libraries listed in Table 2. All of our software is open source and available at www.github.com/RoboJackets/igvc-software.

Table 2. Third Party Libraries

Library	Purpose	URL
ROS	Foundation for events-based message passing	www.ros.org
Qt	Graphical interfaces	www.qt-project.org
Point Cloud Library (PCL)	Handling 3-dimensional point cloud data	www.pointclouds.org
OpenCV	Image processing	www.opencv.org

Switching to the Robot Operating System

Since 2013, our code base has been built on an event-based architecture, where each sensor, actuator, and intelligence algorithm ran as its own module, communicating to other modules via events that could be connected and disconnected at runtime. This system allowed us to break free of problems faced by classical loop-based architectures. For example, instead of the entire system being limited by the frame rate of the slowest sensor, each algorithm only has to worry about the speeds of the sensors whose data it actually uses. In our efforts to expand the flexibility of this system, we ran up against limitations of the Qt events API which was originally designed for handling user input in GUI applications.

The ROS core system is a TCP-based message marshalling system that allows for a high degree of flexibility. Events are partitioned into *topics*, whose defining characteristic is the message type, rather than the message source. This allows for more decoupling between individual nodes. In addition, the ROS API exposes more advanced functionality, such as control of message queueing, and comes with a package managing system full of community packages for common sensors.

Specifically for our team, the switch to ROS has accelerated our development by allowing us to easily inject logged data from test runs into an actively running pipeline. This serves as a sort of simulation for how our algorithms respond to real-world data, while still granting us consistency in that data for debugging.

Lane detection

Detecting the boundaries of the lane is an imperative aspect to succeeding in the competition. Thus, we have spent a large amount of our time completely revamping last year's detection code. The main problem with last year's method was that it found not just the lines, but also many blobs and specks from the sun reflecting off of the grass. These extra components cause problems in our path planning algorithm that may lead the robot to run off the track. In order to correct this we have heavily modified the existing code which includes calculating the average brightness of the pixels, blurring the image, and threshold filtering for a color range similar to the color of the lines. The result of this is more stable than last year's but not perfect. In order to further filter out the lines, we first find the Otsu Threshold Value and use it to calculate the high and low threshold limits. With these two limits we apply a Canny Line Detection Filter which returns the edges found in the image. We then apply a Probabilistic Hough Line Transform that calculates the complex spatial derivative-based function of the source image and finds a closer approximation of the lines we want without the smaller edges detected by the Canny Edge Detection. After the filtering is complete, a perspective transform generates a top-down view of the lines, which is converted into a point cloud and broadcasted to other modules.

Mapping

In addition to the vision system, a SICK TiM551 laser range finder is used to detect obstacles that lie out of the plane of the ground. The laser scan data is converted into a point cloud. Both the LIDAR point cloud and vision point cloud are received by our mapping system. This system uses the advanced features of the Open Perception Foundation's Point Cloud Library (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

The path planner used in this year's code, is very similar to the algorithm we described in our 2014 design report. The algorithm is an implementation of the A* graph search algorithm in which we build the graph based on the vehicle's kinematics. The resultant graph sacrifices even, grid-like spacing for paths that are already optimized for the robot's capabilities without any post-processing.

Acknowledgement of Sponsors

This project was made possible through the support of Caterpillar, General Motors, National Instruments, United Technologies Corp., Student Government Association, the George W. Woodruff School of Mechanical Engineering, the Georgia Tech College of Computing, and the Institute for Robotics and Intelligent Machines at Georgia Tech.

BILL OF MATERIALS

Table 3. Bill of Materials

Item	Value ($)	Cost to Team ($)	2015 Cost ($)
Steel Tube	220	220	20
2x Dampers	1190	1190	0
16x Clevis Rod Ends	200	200	125
2x Gearbox	500	500	500
Misc Mechanical	2300	2300	500
Sick TiM 551	1920	1920	1920
Point Grey BumbleBee 2	2495	1380	0
Outback A321 GPS	7000	7000	0
2x Optical Encoder	170	170	0
2x DC Motor	900	900	0
4x Motor Controller	820	820	0
2x Battery	460	460	0
Laptop	1300	1300	0
Laptop Power Converter	50	50	0
24V-12V DC Converter	15	15	15
ArduPilot Mega 2.5 IMU	180	180	0
Arduino Uno	30	30	0
Headlight	250	250	0
Safety Beacon	350	350	0
E-Stop	80	80	0
Wireless E-Stop	50	50	0
USB Hub	5	5	0
Misc Electrical	300	300	15

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Dear IGVC Organizing Committee:

The RoboJackets IGVC team has significantly improved their robot for this year's competition. They transformed current four-wheel skid-steer platform to a three wheeled design with individually powered rear wheels and an unpowered front caster wheel, which involved significant modifications to the drive system and lower chassis of the robot as well as the relocation of sensors.

I certify that the amount of work that the team has spent on this extracurricular project is substantially greater than what is required in a senior design course at the School of Mechanical Engineering.

Sincerely yours,

Jun Ueda

Jun Ueda
Associate Professor
Mechanical Engineering
Georgia Institute of Technology