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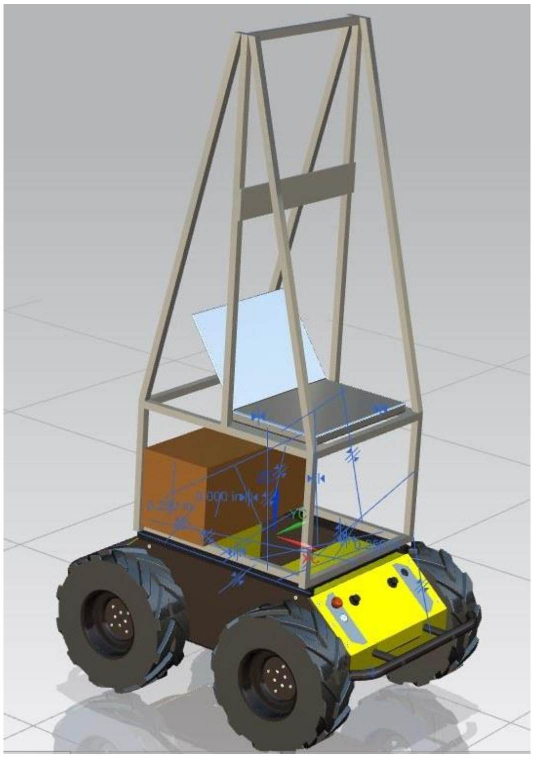

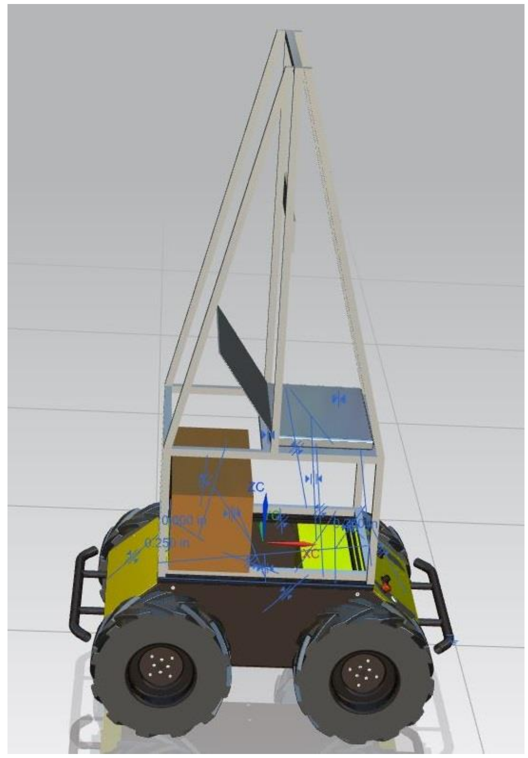

Bigfoot 2

Lawrence Technological University

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Faculty Advisor Statement

We, Dr. CJ Chung and Jonathan Ruszala of the Department of Math and Computer Science at Lawrence Technological University, certify that the design and development on the Bigfoot 2 platform by the individuals on the design team is significant and is either for-credit or equivalent to what might be awarded credit in a senior design course.

Chan Jin Chung

5/15/2016

Signature Date

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DESIGN REPORT FOR THE LAWRENCE TECHNOLOGICAL UNIVERSITY BIGFOOT 2 2016 INTELLIGENT GROUND VEHICLE COMPETITION

Gordon Stein, Yuan Li, Fan Wei, Devson Butani, Nirmit Changani, Nithin Reddy, Dr. CJ Chung, Jonathan Ruszala

INTRODUCTION

The Lawrence Technological University (LTU) Intelligent Ground Vehicle Competition (IGVC) Team has greatly improved upon the design of the previous year, to create a new entry for 2016, Bigfoot 2. The team analyzed the performance and structure of the previous year's entry and determined where it was not performing as well as desired. This led to a totally redesigned tower structure, improved waterproofing, new wheels, improved simulation, new vision code, and new navigation code. The new hardware design of Bigfoot 2 began in the winter, but work on the software began in the fall.

TEAM ORGANIZATION

LTU's IGVC team is split into two portions. One part of the team is focused on hardware, and the other part is focused on software. Due to the small size of the team, a decision was made to not break these portions into further sub-groups, but to instead give each member of the software team at least one focus. These focuses included: navigation, vision/sensors, JAUS, and simulation. All members participated in creating the design report.

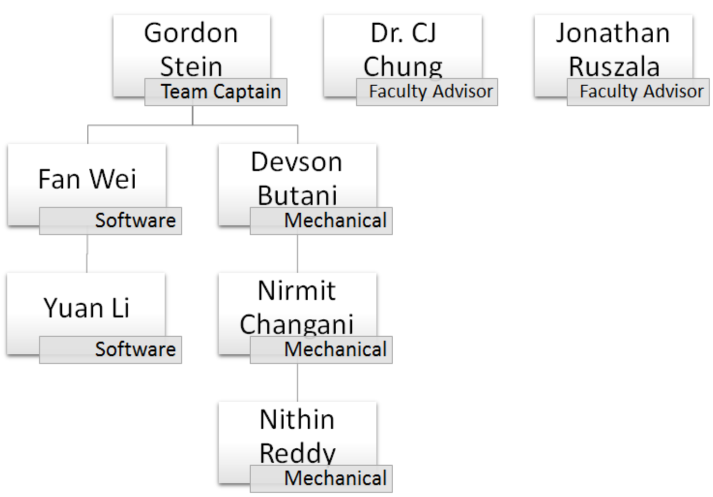

Figure 1. LTU 2016 IGVC Team Organization Chart

Design Concepts and Goals

The main design goal for Bigfoot's hardware was to use low-cost, off the shelf components wherever possible. The reconfigurable extrusion frame furthers this goal by making it simple to attach new parts to the robot. The sensors used were chosen because they were readily available and possible to replace if necessary.

The main design goal for the software was to greatly expand the use of simulations and software-based testing. In previous years, there was difficulty testing with the physical robot because software could not be run until the hardware was complete, and even when the hardware was complete, inclement weather or sunset would prevent the robot's operation outside. In addition, our university campus does not have an area where a proper practice course could be set up, so previous years' teams relied on testing with a small section of path. A simulation allows the team to test the entire circuit at any time and any location.

DESIGN INNOVATIONS

Reinforced frame design

The top of the Bigfoot 1 featured a platform mounted on linear slides for mounting a frame with sensors and other equipment. While this design was intended to allow new parts to be easily added, the team found that new parts were rarely needed and the platform obstructed access to the inside of the robot. To make this design more user friendly, the frame was directly fixed onto the Clearpath Husky removing any movement of wires and adding structural stability. The new frame is raised to fit a laptop at a comfortable working height and constrained by cross-plates to reduce any side to side sway. Using a cuboid frame with triangular corner brackets makes the frame more durable and strong to protect the contents like the payload and the electronics.

Space optimization

Raising the frame using a box structure allowed to organized the payload, laptop, electronics and sensors therefore made them easily accessible. Unlike Bigfoot 1 the electronics are now completely open to the frame giving it extra air circulation for cooling and better wiring space.

Waterproofing

Vinyl sheets are attached to the frame to make it waterproof. The lower parts of the Clearpath Husky are sealed using tape to keep it economical and easily removable for repairs. Moreover the vinyl sheets are clear so that the laptop screen and other LED indicators can be seen from outside to determine faults or keep track of sensor data.

Simulation/Testing/Monitoring Focus

A laptop was mounted on the robot such that the screen is visible for data logging and editing the program on the go. If in case anything in the program goes wrong then instead of connecting the laptop and finding a comfortable place to keep it on, the laptop can be used right away.

MECHANICAL DESIGN

Overview

Bigfoot 2's mechanical design was redesigned based on the performance of the original Bigfoot. The original wheels had caused difficulty turning on many surfaces due to their high traction, so they were replaced. The previous entry was not as fast as the team wanted, so new wheels were selected to also increase the robot's speed. The sensor tower from the previous year had issues with vibration, and did not provided enough room for the laptop, so it was fully redesigned. The sliding baseplate designed for the previous year made maintainance too difficult, so it was replaced with a more open design. Previous years' entries were not water resistant, preventing them from being used during inclement weather at the competition, so steps were taken to weatherproof the robot.

Frame and Chassis Structure

Bigfoot 2 is built on top of a Clearpath Husky platform. This platform includes two motors with rubber lug tread tires, a 24 volt rechargeable battery, and a power distribution system to provide 24 volt, 12 volt, and 5 volt DC current to internal electronics. On the top of the Husky platform are four t-slot rails to allow custom components to be easily attached. The Husky platform also includes an emergency stop button to shut off its motors. An inner compartment provides enough space for computers and other electronic parts.

On top of the Husky platform, the extrusion frame and the sensors are installed. The frame is, 468 mm wide, 550 mm long and 1300 mm tall. This configuration makes it easy to mount the camera right below the height limit and reconfigure the sensor's position on the robot, making this design extremely flexible. The frame includes mounts for the camera, GPS, LIDAR, laptop, and digital compass.

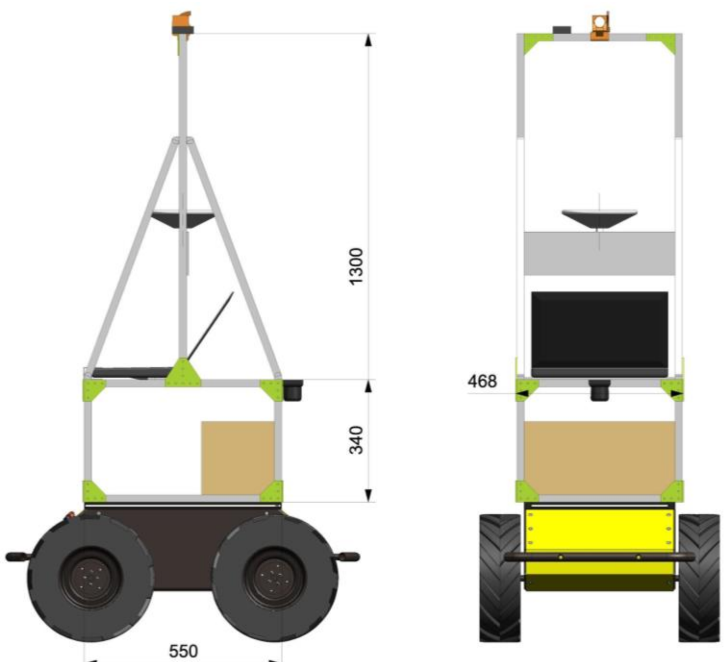

Figure 2. Bigfoot 2 Right Side and Front View

Wheel Adapter

Bigfoot 1 barely passed the speedtest of 1 mph. To increase its speed and allow for improved turns the Clearpath Husky platform's 13" tires/wheels set was replaced with a 16" tires/wheels set. Although the speed the Husky's axles rotate at is locked to prevent it from exceeding 1 mph in a stock configuration, the larger wheels allow it to move faster without requiring new motor controller hardware to override the limit. The new wheel set had a larger bolt pattern hence needed a new wheel adapter to fix with the Husky's axle. The wheel adapter was first designed and 3D printed to verify for perfect size and then waterjet cut out of ¼" thick 6061 Aluminium.

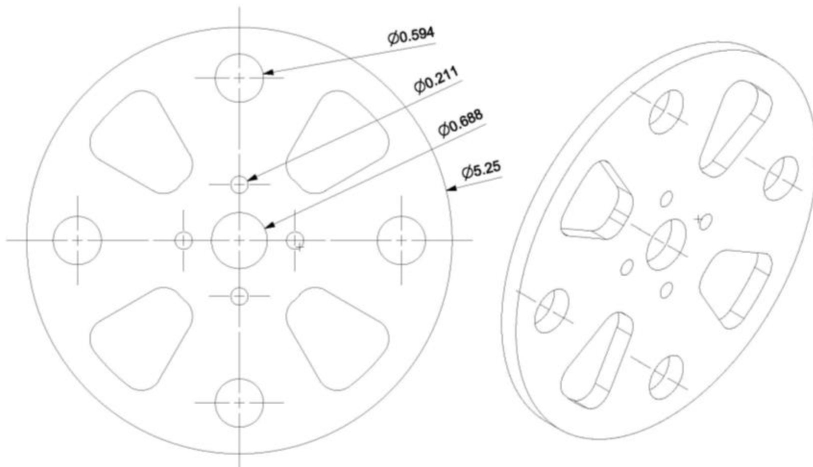

Figure 3. Wheel Adapter

Adjustable Camera Mount

Looking at previous years, to maintain a camera angle and to keep the camera aligned with the robot's horizontal was done by trial and error. To save time and maintain the same accuracy, a new camera mount was designed and 3D printed to snugly fit the Microsoft Lifecam.

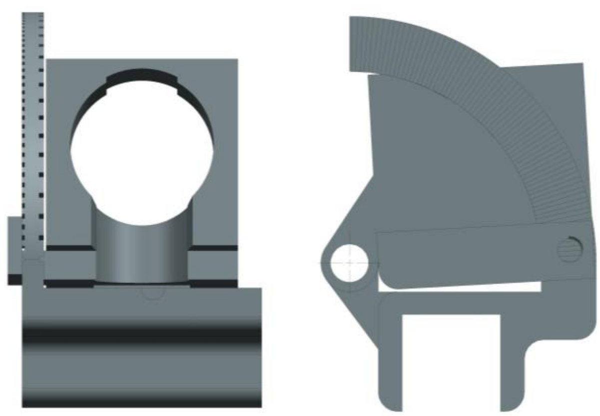

Figure 4. Camera Mount

Suspension

The Husky platform lacks a suspension system. Modifying it to add suspension would not be possible without creating an entirely new platform, so instead shock and vibration resistance must be built into the tower on top of Bigfoot 2. In the previous year, it was noted that the lack of suspension in the chassis caused significant vibration in the upper tower. The new tower is designed to be sturdier and more rigid when the robot is driving on uneven terrain.

Weatherproofing

To reduce the risk of damage due to weather, a vinyl sheet is attached to the frame. The bottom of the tower is sealed using tape to keep it economical and easily removable for repairs. The sheets used are clear so laptop and LED indicators can be seen by the team as the robot runs in the rain.

ELECTRICAL DESIGN

Overview

Bigfoot 2's electrical design was simplified by two factors: the onboard power supply included in the chassis, and the decision to use off-the-shelf modules and components where possible. The communications throughout the robot are handled over USB or Serial connections (which are connected with a USB to Serial adaptor), allowing for standard hubs and cables to be used. This simplified design allowed the team to make the most of the small number of engineers available.

Power Distribution

Primary power for all systems is provided by the integrated Husky power supply board. This board supplies 5, 12 and 24 volt rails at 5 amps per rail from the 24 volt 20 amp hour battery. The laptop used as a computer has its own internal battery, which is augmented with an additional external battery, neither of which rely on the Husky power supply for electricity. Wheel speed is controlled using the integrated wheel encoders with 78,000 ticks per meter. Battery state of charge can be requested from the Husky controller board or read from the LED battery charge display located on the rear of the robot. Communication between the Husky platform, onboard PC, Raspberry Pi and relay board is provided by USB and serial connections. A simplified system diagram of all electrical and communication connections is shown in Figure 5.

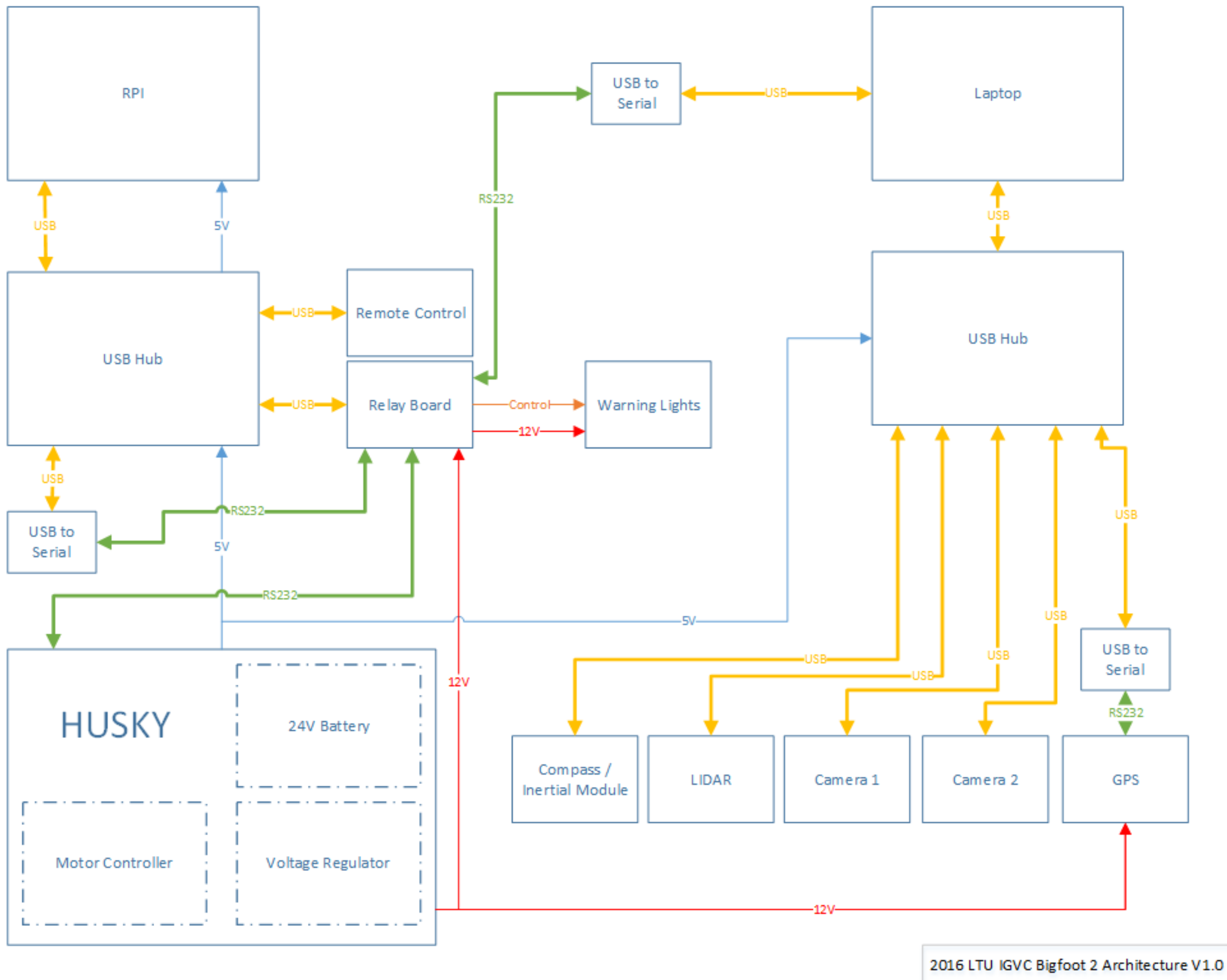

Figure 5. Electrical Connections Within Bigfoot 2

Electronics Suite

CPU

Bigfoot 2's computational power is provided by a HP Z-Book laptop. This laptop has an Intel i7 processor and 16 GB of RAM, along with an Nvidia Quadro GPU with 4 GB of VRAM. The power available in this computer allows for more complex vision and navigation code. The primary storage drive of the laptop is a solid state drive, allowing faster access to files.

Sensors

Camera. Bigfoot 2's vision is provided by a Microsoft LifeCam Studio webcam. This webcam provides a low-cost, off-the-shelf solution with 1080p video at 30 frames per second.3 Focus and color balance controls are provided through a software interface. The LifeCam has been tested extensively in previous IGVC entries, and has been found to be very reliable.

LIDAR. Bigfoot 2 uses a Hokuyo URG-04LX-UG01, a small, low-cost LIDAR able to detect objects within 5600 mm. A scan is completed at 10 Hz with an angular resolution of 0.36 degrees across a detection area of 240 degrees. The LIDAR is powered by 5V DC provided by the USB connection, and its maximum current consumption is 500mA.

GPS. The latitude and longitude are calculated with the help of Novatel ProPak GPS receiver. The ProPak provides reliable data with sub-meter accuracy using the help of differential GPS correction. An external antenna provides GPS signal reception.

Electronic Compass. Heading information is provided by a Sparton GEDC-6E electronic compass. The GEDC-6E provides very accurate and easy to configure readings for pitch, yaw, and roll. Although Bigfoot 2 uses it only as a compass, the GEDC-6E contains a 3-axis gyroscope, magnetometer, and accelerometer, providing an entire suite of inertial measurement unit features.

Safety Devices

Safety Light. A white light has been attached to the rear of the body of the robot to be used as a safety light. The lights are turned on when the robot is power on, and stay in solid mode when the robot is driven manually. When the robot is in autonomous mode, the lights will start to flash.

Mechanical Emergency Stop. Two emergency stop buttons have been attached to the robot. One button came with the robot itself on the back side of the robot's body. However, the placement of this button was too low to be used, so another button has been attached to the Husky platform manually.

Wireless Emergency Stop. The device used for implementing wireless emergency stop functionality is rebuilt from a vehicle remote controller. The robot can be manually stopped by pressing the button on the device within controllable distance.

SOFTWARE DESIGN

Overview

Bigfoot's software architecture was designed with a focus on object-oriented design and flexibility. After the design was conceived, abstract base classes for each object type were created. This included base classes for sensors, motor controllers, and navigation controllers.

The robot's software relies on a navigation controller object to make decisions based on the input from the various sensors, and then send commands to the current motor controller object. The navigation controller can be replaced at runtime to change the robot's current mode of operation. Autonomous navigation, waypoint following, and IOP are all available as navigation controllers.

Obstacle Avoidance and Detection

The camera is used for lane detection. A black paper board with white area is held in front of the vehicle, and set the camera to get the white pixel area as the target area, and crop this area out. Then, count the white pixels number in the target area, and apply the formula threshold = WhiteROI.GetAverage().Intensity * C (C is a coefficient, the default value is 0.75, and can be adjusted based on real environment) to get the current threshold value under current light situation. The reason why the parameter 0.75 is applied is that after multiple test with variety of light situations, the camera can detect the real white lane clearly, and at the same time, filter most of the invalid white pixels which are caused by light reflection. Therefore, once the program is started, the camera will keep detecting and target area, count the current white pixel number that it can see under current light situation and adjust the current threshold value.

LIDAR has been used to implement obstacle detection and avoidance. The LIDAR is a laser sensor used for area scanning. Under the most ideal condition, the scan area is 240º semicircle with 0.36 degree angular resolution and radius range of 20mm to 5600mm. The LIDAR can detect obstacles by processing the data reflected from the obstacles. The LIDAR can be used to collect the distances to obstacles around the robot within the detection range, but cannot help with the course lines detection.

The LIDAR data can be easily converted into local coordinates using trigonometric functions. Visual data requires more processing, due to the perspective of the image received. An interpolation function is used to transform the image space coordinates to approximate local coordinates. With both sets of obstacles in the same coordinate space, the local grid can be assemble.

Software Strategy

The software was created with a modular architecture to allow for easier simulation and modification. There are superclasses for navigation algorithms, motor controllers, and sensors. The sensor and motor controller classes have variations for both the simulated and physical versions, allowing for the software to switch to either the real robot or a simulated one with the click of a button. This switch is not visible to the navigation controller, so it behaves the same in a simulated environment or a real one. Making the code more modular also allows for easier team collaboration using a version control system.

Map Generation

The vision data provides half of the information used to make navigation decisions. The remaining data is received from the LIDAR. The vision supplies reliable information about the lines on the course, but poor information about the obstacles, especially outside of its limited field of view. To overcome the weaknesses of each sensor, their data is combined into a map of the robot's surroundings, the "local grid".

Goal Selection and Path Generation

A path for the robot to follow is chosen by testing multiple potential paths against the known obstacles on the local grid. Each turn is tested by drawing a curve in the local grid space, representing the turning curve of the robot for the potential input, and testing for known obstacles along the robot's positions along that path.

The goal is selected using a system of waypoints. Approximate waypoints of the corners of the field (and the provided waypoints for the competition field) are given to the navigation code to find an initial direction. If the turn that would lead the robot in the direction of that waypoint is available, it will move in that direction. The current goal waypoint is switched to the next waypoint when the robot comes within a certain threshold distance. This waypoint system is also used during the qualification run.

FAILURE POINTS AND MODES

Hardware failure points

Raspberry Pi

The Raspberry Pi controlling the relay board and non-autonomous motor control could fail. If this occurs, the board will need to be replaced. As it is available off-the-shelf, a new board would be easy to obtain quickly, and the code would be restored from a backup. In the event that a new board cannot be obtained in time, the relay board could be rewired to give the laptop control of the motors. The lights could also be re-wired to be controlled through an alternative method.

Relay Board

In the event that a single relay becomes stuck or unresponsive, its function can be moved to a different relay. The code running on the Raspberry Pi would be modified to command the new relay.

If the entire relay board fails, or too many relays fail to allow wires to be moved to working relays, the relay board will need to be replaced. The board is available off-the-shelf, and extra boards will be brought to the competition to be used in the event of a failure.

Motors

The Husky platform's motors are a potential failure point. The windings in the motor could become damaged, causing a cascade failure limiting the robot's mobility. However, the only known case of this happening was due to modifications made to the drivetrain of another team's robot and is very unlikely to occur in Bigfoot. In the event that the motors do fail, the Husky platform will need to be returned to Clearpath for repairs and an alternate platform will need to be sourced. The modular design of the reconfigurable top panel means that it would be easy to separate the chassis from the other parts of the robot for repairs.

Sensors

All of Bigfoot's sensors are reliable and available off-the-shelf. If a sensor fails, it will simply be replaced with a compatible part. The reconfigurable design allows for any of the sensors to be easily detached and replaced.

Main Computer

Bigfoot's main computer is easily replaceable. The software is stored on a remote Git repository, allowing it to be transferred to any computer over the internet. In the event that the laptop fails completely, its USB ports fail, or it becomes damaged in some other way that prevents it from being used, the laptop can be switched out for any other laptop with sufficient USB ports to connect to all of Bigfoot's sensors and sufficient computing power to perform the necessary calculations.

Battery

The battery used to power Bigfoot could become damaged and lose its ability to store a charge. If the battery becomes damaged, it will be replaced with the extra battery that was purchased with the Husky platform.

Wiring

In the event that the wiring inside Bigfoot becomes damaged, the hardware sub-team will focus on finding the damaged wire and replace it with new wiring.

Software Failure Points

In Bigfoot's testing, it was found that dead or dormant grass can sometimes be light enough for the vision processing software to classify it as white area from a line or pothole. However, this is not expected to be a major issue during the competition due to the time of year and weather expected. Although making a stricter filter for finding visual obstacles could result in the robot not seeing a line, additional filtering will be added if deemed necessary at the competition.

Failure Prevention Strategy

Our failure prevention strategy is to keep the robot's design as simple and as modular as possible. Fewer parts on the robot mean that there are fewer parts to break. A modular design means that failures in one portion of the robot are less likely to affect other parts.

Testing

Testing work has been separated to two major parts, hardware and software. For hardware part, each component has been checked before being assembled to the robot. And then, functional test will be conducted to check if the vehicle can perform all the required functions. For software part,unit test has been conducted first, and after being integrated into the main program, integration test will be conducted to make sure nothing will be incompatible. After the combination of hardware and software parts, run and test the vehicle in real environment and check it follow the competition requirements.

Safety Design Concepts

The Safety Design Concepts have been kept from last year. All safety devices that are based on hardware including: one Safety Light, which is turned on while the vehicle is running; Mechanical Emergency Stop, which is activated by a red button and has been moved lower to be easily reached; and Wireless E-Stop Device, which can stop the robot remotely within the controllable distance. By adding these safety equipments, people can get alert while the vehicle is running, and prevent danger from happening. Once a failure occurs, it will be stopped immediately.

TESTING AND SIMULATION

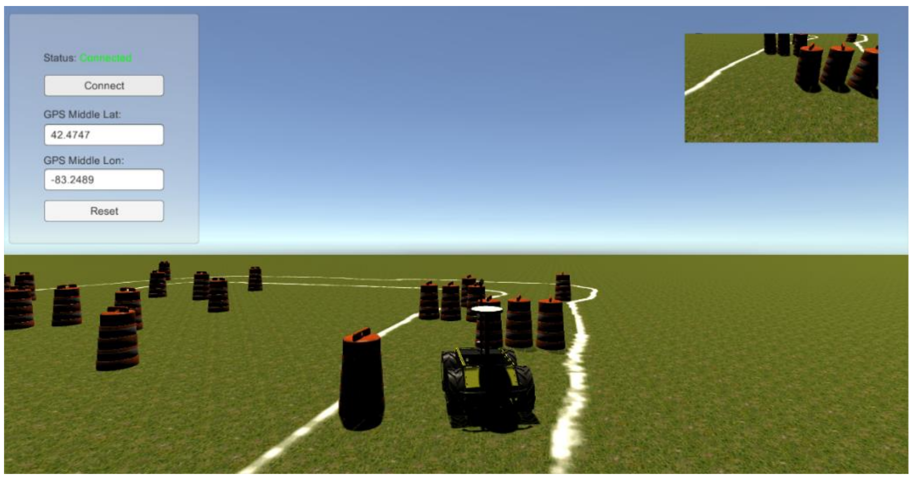

Figure 6. Screenshot of Simulator Running and Connected to Robot Software

Simulation for the platform was done using an upgraded version of the simulator created for the previous year. This simulator communicates over a network with the robot software, sending updates of the robot’s state to simulated sensors, and receiving commands to be sent to a simulation of the real platform’s motor controller.

To improve the simulator for this year, many new features were added. In the previous year, we noticed that the simulator only included a constant daytime light, and our vision code needed improvement in the situation where the lighting is changing due to clouds. To allow for testing in changing and different conditions, a slider was added for manually controlling the lighting in the scene. To allow for navigation code to be tested before the updated vision code is complete, a new feature was added to replace the grass textures with an unshaded black texture. The simulated LIDAR was optimized to use half as many raycasts. The modelled robot in the simulation was modified to reflect the proposed structure of the new platform. The simulated IGVC auto-nav course was updated to include a ramp, an obstacle that proved difficult in the previous year.

This simulation was used for both the auto-nav code and the IOP code. This allowed the team to have access to a robot and a field to test in, even when the weather was not good or the robot was not possible to use.

PERFORMANCE TESTING

Travel Speed

The Husky robotic platform has a maximum speed of 1 meter per second. However, because this limit is implemented through software instead of being a physical limitation of the motors or electrical systems, the platform is able to reach this speed even with the additional mass of the modifications.

Incline Climbing

The Husky robotics platform is specified as being able to climb a 45 degree incline and drive laterally on a 30 degree incline. The modifications made to the platform have moved the center of gravity. Additional testing was required to ensure Bigfoot would be able to handle the approximately 10 degree inclines potentially included as obstacles on the course.

Using the terrain available on the Lawrence Tech campus, Bigfoot was tested on inclines exceeding 20 degrees. While the robot was able to both climb and descend the hills without issue, braking is required for the robot to stay at a position on the hill.

Ramps on campus, measured at approximately 10 degrees were also used. The ramps had no significant impact on the performance of the robot.

Reaction Time and High Speed Operations

The navigation controller is limited to running no faster than the camera updates, at approximately 30 frames per second. However, the processing required may take slightly longer than one thirtieth of a second, resulting in a new decision not being made for up to one fifteenth of a second. The motor controller updates the requested speed every 20 milliseconds.

The LIDAR completes a scan ten times a second, so obstacles not detectable with vision or seen in previous LIDAR data may not be reacted to for 100 milliseconds. However, this is not likely to be an issue for autonomous navigation because the obstacles not already seen are most likely at the maximum range of the lidar, giving the robot several seconds to react.

Battery Life

Clearpath specifies that the Husky platform's lead-acid battery is capable of providing power for 8 hours of standby or 3 hours of heavy use.

The computer used has been upgraded with an external extended battery, which will more than double its battery life. The extended battery is rechargeable and swappable, so it can be replaced with another battery after it runs out.

Tests of the Husky battery found that it could be used for approximately 5 hours for our use. The laptop battery is able to be used for over 10 hours of light use without replacing the external battery.

Obstacle Detection Distance

The angle of the camera allows Bigfoot to see approximately 4 meters in front of it, with a diagonal field of view of 75 degrees. There is a small blind spot very close to the robot, within the nearest 10 centimeters, due to the body of the robot blocking the camera's view. However, this blind spot usually does not prevent obstacle detection because the robot avoids situations where the front of the robot is that close to a line, and the LIDAR would detect a physical obstacle within that range.

The LIDAR sensor we are using is Hokuyo URG-04LX-UG01, of which the detection area is 240°, with a 0.36° angular resolution. The specified detection range of the LIDAR is from 20 millimeters to 5600 millimeters. However, the sensor is designed for indoor use only and bright sunlight may have some influence on the maximum detection distance of the sensor. In addition, the detection distance of the LIDAR sensor may also vary with different objects. This bigger the object is, the easier the LIDAR will detect it at a long distance.

Complex Obstacles

When facing a switchback, the robot will treat it like any other turn on the course. It will attempt to find the best available path through the detected obstacles, which should lead it safely around the turn. Center islands will also be detected like any other obstacle, and the robot will navigate around the island. Potholes will be detected by the vision code looking for the lines, which will also place the pothole on the local grid. Dashed lines are detected by the software like other lines, and will definitely be avoided as long as the hole is not significantly larger than the robot.

Failure Point Identification

Most of the components used in Bigfoot are available off-the-shelf and compatible with alternative parts. The failure points found are largely total failures of each component, which would require a quick replacement with a compatible part.

Parts using USB to communicate were chosen for greater compatibility with different computers and to remove adaptors as a failure point. The main software is able to run on any Windows computer with the processing power required to make decisions in a timely matter.

Location Accuracy

The DGPS data available through the Novatel GPS receiver can determine its location with sub-meter accuracy. Tests using known waypoints found that the GPS sensor could position the robot within 1 meter of the desired waypoint.

INITIAL PERFORMANCE ASSESSMENTS

In our initial tests, the robot was able to navigate easily around barrels and other obstacles while navigating. We noticed that the turning and stability of the tower are greatly improved from the previous year. In addition, the new design of the tower allows for easy access to the control laptop, which proved to be very useful during our tests.