Little Mac

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Faculty Statement: I certify that the vehicle has been significantly modified for this year's competition.

INTRODUCTION

The Robotics Club at UCF presents Little Mac, our entry in the 2015 International Ground Vehicle Competition. Our dedicated team members consist of undergraduate engineering and computer science students. Together we have successfully upgraded the autonomous ground vehicle with a brand new body and completely reorganized schematics. Little Mac has been designed to be optimally lightweight and durable. It integrates the Robotic Operating System (ROS) into our software and utilizes 80/20 T-slotted framing for an exceptionally customizable platform. Our interdisciplinary team has worked hard to build upon past experience and develop an impressive system that can operate fluently and precisely.

ORGANIZATION

Overall club leadership is elected democratically and each individual project team lead is appointed by the club officers. Teams of all-undergraduate student volunteers are responsible for scheduling and hosting professional meetings and events in order to optimally collaborate and best interact with club and project sponsors. Regularly scheduled IGVC design requirement meetings began in the Fall 2014 semester, allowing for vehicle fabrication to be completed in the spring semester. The project personnel is organized into mechanical, electrical, and software teams, each responsible for providing the other disciplines with regular updates and keeping open communication throughout the multidisciplinary engineering process.

MECHANICAL

Chassis Design

Little MAC's frame is constructed of primarily 15 series (1.5 in2) T-slotted anodized aluminum for its structural rigidity and robust, modular nature. The frame has three central sections: front, back, and mast. The front of the vehicle's structure tapers down to allow for the cameras atop the sensor mast to view the lane lines directly in front of the swivel casters. The section underneath the curve at the front contains the platform's computer. The back has an orthogonal (rectangular) profile to optimally house batteries, support the payload, and squarely mount the sensor mast. The sensor mast is a 3030 (3.0 in2) T-slotted structure selected based on its ability to mount any of the sensors required for autonomous capabilities plus an E-stop button and centralized USB hub.

Figure 1. Render of Chassis

The paneling for Little Mac is comprised of three layers attached to the main frame. On the outside is black and gold anodized aluminum. Underneath, it is reinforced with black, impact-resistant ABS plastic. Finally, between the ABS and the main frame is orange weather stripping to reduce any remaining impact forces and distribute the compressive forces of mounting into the frame. This paneling is implemented on the top, back, and both sides of the vehicle. This configuration has been chosen to optimize protection from any kind of impact while maintaining a sleek and professional aesthetic design.

Drive Configuration

The vehicle exhibits a single axis differential skid drive while resting on four pneumatically supported ground contact points. Two 13" OD heavy-duty lug tread tires directly driven by electric wheelchair motors are mounted along the same horizontal drive axis in order for the vehicle to achieve a smooth zero radius turn. The drive axis lies slightly behind the batteries, the vehicle's heaviest components, to allow for a low rotational inertia about the vehicle's center of mass. The front of the vehicle is supported by two pneumatically supported industrial-grade swivel casters, which minimize overall inertia while maintaining extraordinary multi directional capabilities.

The vehicle's off-the-shelf brushed DC wheelchair motors were selected for their power output, integrated 32:1 gear reduction, and shaft accessibility for encoder mounting. Custom aluminum brackets were machined in order to mount the motor's gearboxes flush to the bottom of the 80/20 while giving them the ability to be adjusted along the frame's T-slots from the side.

Electronics Packaging

The main electronics compartments of Little MAC are enclosed within an array of panels securely fastened to the main frame, which is covered in adhesive-backed extreme-temperature silicon rubber strips for impact resistance and waterproofing (weather stripping). The vehicle's main electronics bays are accessible via two untethered, fully removable ceiling panels. Static-

Dissipative polycarbonate is used as the mounting base for all electronic devices sensitive to static discharge. Plastic “T-Strips” are used to run wires through the interior T-slots to organize routing and enhance aesthetics.

Sensor Mounting

Several custom sensor mounting solutions were developed in order to allow Little MAC to optimally survey its environment and self simultaneously. Most of these mounts including the antenna, cameras, Sparton, Hokuyo, and GPS mounts were designed in Solidworks 2015. Three Logitech c930e web cameras are mounted at the top of the sensor mast using a custom double-nested 3-D printed part that allows for a primary global yaw and secondary local pitch adjustment in order to optimally view approaching lane lines. A Hokuyo UTM-30LX is mounted just below the front of the vehicle to allow for a 270 degree planar laser scan accurate up to 30m using a custom 3-D printed part with an integrated heat sink and rain shield. Quadrature optical encoders are mounted on the non-geared motor shaft to precisely capture motor shaft movement. Mounted adjacent to the computer in the front electronics bay is the system’s global positioning unit, the Hemisphere MiniMAX dGPS. To obtain accurate inertial measurements while avoiding magnetic interference from the motors, the system’s Sparton Altitude Heading and Reference System 8 is mounted midway up the sensor mast. Finally, both the Ubiquiti networking and Hemisphere GPS antennas are mounted on the sensor mast using custom 3-D printed adapters.

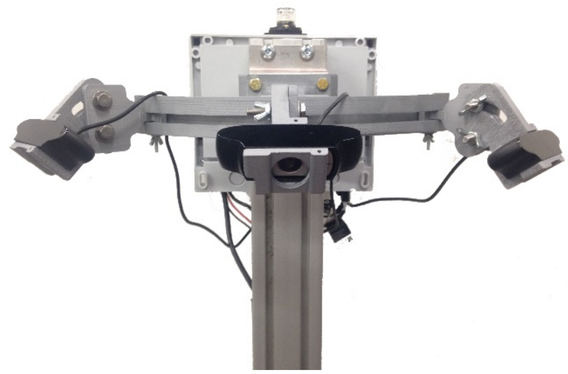

Figure 2. Camera Mount

ELECTRICAL

Overview

The power distribution system of the Little Mac was meticulously planned to encompass safety, capacity, functionality, efficiency, and ease of use. In the following segments of the document the various considerations and sub-systems of the power distribution system will be discussed.

The function of the power system on Little Mac is to separate and distribute the appropriate values of electrical power to each subsystem within the robot. The power system is divided into two main subsystems, the motor drive system and the logic system. These two systems are separated within the robot and are capable of being activated independently. As is the function of the power system, the power distribution within the two main subsystems is divided and distributed into separate voltage levels, +24V, +12V, and +5V. A high level diagram of the power system is shown below in Figure 1.

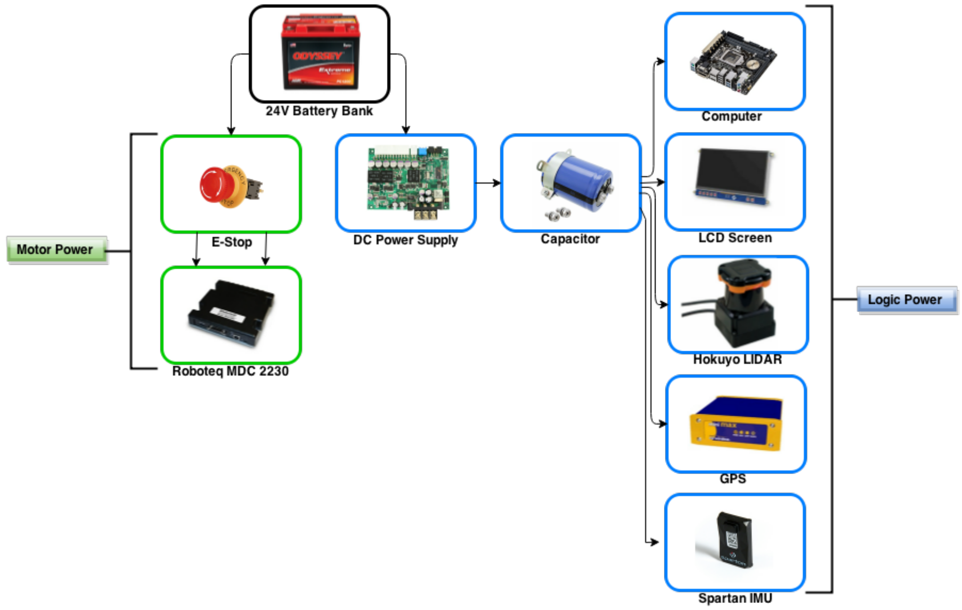

Figure 3. Power System Distribution Block Diagram

Batteries

Figure 4. Power Source

The batteries that were selected for use in the ground vehicle are the Odyssey PC1200. The Odyssey PC1200 batteries were chosen for the following reasons: deep cycle discharging capability to get the highest run time possible without damaging the batteries; sealed absorbed glass mat form factor prevents any spillage of battery contents; highly durable casing prevents hazardous fault conditions such as explosions; military grade performance for ultimate reliability. Two 12 VDC PC1200 batteries connected in series are utilized to accommodate the 24VDC drive system as stepping up to 24 VDC from a 12 VDC source would be much less efficient than a 24 VDC series configuration. Utilizing the 24 VDC series configuration yields a capacity of 44 amp hours and an approximate run time of 1-2 hours depending on the power consumption conditions. To allow for quick swapping between sets of batteries Anderson power pole connectors were implemented. The Anderson power pole connectors not only provide a quick disconnect but also ensure a reliable low resistance connection which is very important consideration of the vehicle. To ensure a low resistance/low loss connection with the batteries to the power distribution system, Stinger 4 gauge oxygen free hyper twist tinned wire was utilized. In addition to having a higher stand count than average wire, Stinger 4 gauge hyper twist wire is also tinned to prevent corrosion from exposure to oxygen. This ensures a solid low resistance connection to peripherals.

Safety

Safety of the ground vehicle was a very important consideration important when designing the vehicle. To ensure the safety of the vehicle operators and observers alike, numerous safety systems and features were implemented on the vehicle. The following segments of the document will explain these safety features and their significance.

Fuses and breakers were used extensively in the power distribution system design of the ground vehicle. For the higher current segments of the power distribution system such as the power feeds going to the Roboteq motor controller, the Logic relay, the battery charging feeds, and the AC-DC inverter feeds, manually resettable 24 VDC automotive breakers were used. This ensures that should an over current condition arise such that more current is being drawn than the power wires can handle, the breakers interrupt the circuit to prevent the power wires from overheating and causing a fire, a short, or any other type of damage to the power distribution circuit. For the lower amperage peripherals of the power distribution circuit, ATC fuses were utilized. ATC fuses are cheap and readily available automotive fuses that provide tried and true circuit protection. To facilitate a consolidated fusing configuration, one to one fuse blocks were utilized in conjunction with terminal blocks. This allows for circuits of various voltages to be fed though the fuse block. This is not possible with a "ganged" fuse block.

For the purposes of this project relays were also used extensively. The main purpose of the relay is to ensure safe switching of the high power circuits by isolating the end user from the high voltage/amperage circuits. This is facilitated by utilizing a relatively lower voltage circuit to connect and disconnect the high voltage/amperage circuits. Relays were utilized to switch the motor controller power feeds as well as the charging feeds, logic circuit feeds, and the AC-DC inverter feeds. To consolidate and reduce the number of relay contactors in the circuit double pole double throw relays were implemented. In the strobe switching circuitry a solid state relay was used to eliminate the constant clicking noise that would have been created by a mechanical relay. In addition, the solid state relay is also more suitable for a rapid switching scenario as mechanical relays typically have a limited number of switching cycles before they fail. To ensure safe operation during the software development process an additional two relays were implemented which allow the microcontroller portion of the Roboteq motor controller to run during development while also disabling the high current motor power output terminals. This is a critical safety consideration which prevents the vehicle from moving during the development process during which the vehicle is programmed.

Strobe System

The strobe system of the ground vehicle is yet another important safety feature. The strobe system provides visual feedback of the current operational state of the ground vehicle to observers and bystanders. The flashing state of the strobe indicates autonomous operation, while the solid state of the strobe indicates manual operation via radio control. The flashing of the strobe is facilitated by the switching action of a solid state relay. The switching rate of the solid state relay is controlled by an Atmega 328p microcontroller. The microcontroller determines the strobe pattern based on the data passed from the Roboteq controller from the DOUT 1 pin. A "1" tells the microcontroller that the vehicle is in the manually operated state (strobe solid) while a "0" from the DOUT 1 pin of the Roboteq tells the microcontroller that the vehicle is in the autonomous state (strobe flashing).

E-Stop

The E-Stop of the ground vehicle is intended to bring the vehicle to a complete halt immediately in the event of a malfunction or bystander injury. To ensure that the vehicle does come to a complete stop, the two V-Mot power terminals of the Roboteq motor controller are fed through a double pole double throw relay which shorts the V-Mot terminals to ground when the E-Stop button is pressed. In addition, the microcontroller portion of the Roboteq motor controller remains on while the E-Stop is activated. This ensures that data can still be sent to and from the motor controller during the E-Stop condition.

High Current Diodes

High current diodes were utilized in the ground vehicle to control the current flow in certain circuits. In order to ensure that there is always a return path to the battery during a regenerative breaking state (even when the master fuse has popped), high current diodes were utilized to facilitate a current path directly from the V-Mot power terminals to the positive terminal of the battery assembly. Without these diodes in place the motor controller could fail if the regenerated current has no return path to the battery. To ensure that only the computer and the sensors can draw power from the capacitor in the uninterruptible power supply high current diodes were also utilized. This prevents the motor controller from drawing power from said capacitor.

DC-DC Conversion

The DC-DC conversion of the ground vehicle consists of a 12 volt isolated regulator, and an M4-ATX computer power supply that also has a 5 volt and 12 volt rail. The standalone 12 volt regulator drives the 12 volt relays that control the switching states of the power circuits. 12 volts relays were chosen to ensure that even if the series battery assembly drops to 9 volts the relays will remain in their intended states. To power the 5 volt peripherals such as the Ethernet switch, the USB hub and the beagle bone/touch screen the 5 volt rail of the M4-ATX power supply was utilized. To power the Hokuyo Lidar range finding laser the 12 volt rail of the M4-ATX power supply was utilized.

External Switches

In order to toggle the various circuits of the vehicle four switches were implemented. The switches include the main power switch, the logic power switch, the motor power switch, and the RC/autonomous state toggle switch. The main power switch is used to connect or disconnect the main power from the vehicle. The logic power switch controls the power state of the computer, sensors, the Beaglebone LCD capacitive touchscreen, and the USB hub. The motor power switch toggles the power state of the microcontroller in the Roboteq motor controller via a relay and the power enable pin. The motor power switch will not allow the vehicle to move if the E-Stop switch is activated. The RC/autonomous toggle switch allows the operator to force radio control of the vehicle via a remote control.

Charging System and Uninterruptible Power Supply

The charging system of the ground vehicle is the NOCO Genius G2600. The G2600 has the capability to charge both batteries in series at 24 VDC with a current of 14 Amps. In addition, a 600 watt AC-DC inverter is utilized to run all of the on board peripherals including the computer while the batteries are charging. This allows the developers to work on the ground vehicle while the batteries are charging without the vehicle leaching power from the battery system. Both the inverter and the battery charger will be housed in an off vehicle portable charging case. In order to ensure that the computer and sensors can remain on without an interruption of their power sources a large capacitor was put in parallel with the power terminal block coming off the relay that switches between wall power and battery power.

SOFTWARE

Robot Operating System (ROS)

This year marks the switch for all platforms operated by the UCF Robotics Club from a complete in-house codebase to an architecture built on the Robot Operating System (ROS). ROS provides significant benefits through easily integrated custom solutions with the wealth of well-tested solutions developed throughout the ROS community. This rich ecosystem provides options for configurable implementations of common robotics software functionality including sensor interfacing, 2D navigation, and data logging.

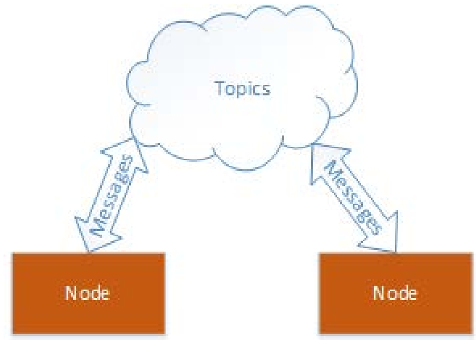

Figure 5. ROS Communications

ROS itself is essentially a message handling architecture built on XML-RPC (Remote Procedure Call). This architecture provides for communication between modular software components called *nodes* by subscription to and publishing of *messages* on named *topics* using well-defined message types. This message handling affords ROS its modular nature, allowing nodes to fulfill their intended purpose without direct awareness of any implementation deeper than this message interface.

ROS Development Toolset

Community developed packages are not the only advantages provided by ROS over previous in-house solutions. Several tools exist as part of larger ROS support for simulation of entire robot systems and visualization of both simulated and real sensor data. The two most frequently used tools in our development process are the Gazebo simulation suite and the visualization tool rviz.

Gazebo

Gazebo is a general purpose robotics simulator including full graphical presentation, customizable physics simulation, and extension of its feature set through user-made plugins. As with ROS itself, many plugins are available throughout the ROS and Gazebo communities. The Gazebo development team provides a set of packages for wrapping ROS features and providing an interface for communication with a simulated robot using ROS messages.

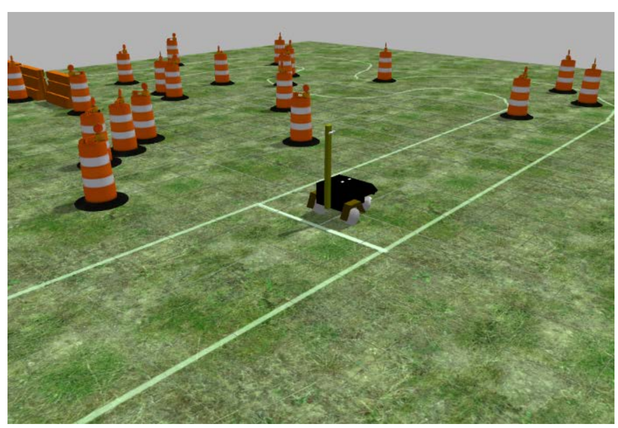

Figure 6. IGVC Gazebo Simulation

ROS Visualization

ROS visualization (rviz) is a ROS package that provides for visualization of a large variety of sensor data and other robot state information. Important in development of this year's platform were the ability to view LIDAR scans, raw camera feeds, and real-time views of many data structures used by the robot's navigation systems. These data structures include the current map being used, several different paths generated by the path-planning systems, and the current navigation goal or waypoint.

Course Navigation

This year's entry uses many pre-existing ROS packages. Packages providing sensor interfacing, mapping, path planning, localization, sensor fusion, and complex coordinate frame transformations, are readily available as part of the core ROS distribution. These packages are integrated into the platform with custom image processing nodes to complete course navigation goals.

Lane Detection Pipeline

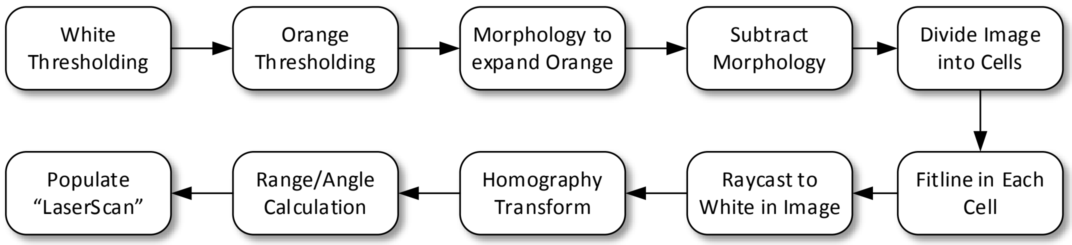

Figure 7. Image Processing Pipeline

Lane detection is accomplished using three Logitech c930 webcams positioned at the top of the vehicle sensor mast. The cameras are tilted downward and placed to capture lane lines within several meters of the vehicle's footprint. Incoming images are put through a processing pipeline using the OpenCV libraries to obtain an image containing only best-fit approximations to lane lines in the image. The resultant images are then analyzed to produce spoofed LIDAR scans containing the ranges to lane lines detected in each camera's field of view. Figure (7) shows an overview of this pipeline.

Figure 8. IGVC Course Image

First, thresholding is applied on white and orange to obtain two binary images. The image obtained via white thresholding contains the location of potential lane lines as well as white components of course obstacles such as barrels. The image obtained via orange thresholding contains parts of the image containing obstacles. Figure (8) shows the binary images obtained via each threshold application. This second image is then transformed using the OpenCV morphology open operation, expanding the detected orange areas to fill in detected white space like barrel lines between orange obstacle components. By subtracting the morphed image from the white thresholded image, a binary image containing only lane lines is obtained.

Lane line approximations are then obtained from the filtered image. The image is first split into a grid of uniform cells. In practice grid sizes of 4x4 to 8x8 function adequately with the available computing resources. The OpenCV fitLine function is then applied to each cell. This function applies a weighted least-squares algorithm to generate a straight-line approximation fitting the line detected in the supplied dataset. The straight line approximation replaces the data in the cell, and the cell is inserted back into the image. By applying the fitline approximation on individual cells in the image, potential gaps hidden by obstacles or poor quality of incoming images are bridged. Applying this technique to each cell in the image yields an image with piecewise approximations of the complete lane lines detected. Figure (10) shows an example of the process operating on the log data shown in Figure (8) from a previous competition year.

Figure 9. White Threshold (left) and Orange Threshold (right)

Raycasting is then performed from the bottom center of the image at incremental angles. Bright blobs in the binary image that are encountered are considered lane lines. Pixel (x,y) coordinates are obtained and converted to distances from the camera using a homography transformation and the camera's known orientation. Each detection's range and the angle along the camera's field of view, taking the origin as the center of the image, is recorded for map population in a faked LIDAR scan. This process allows treating lane lines in the mapping and path planning services as if they were any other course obstacle.

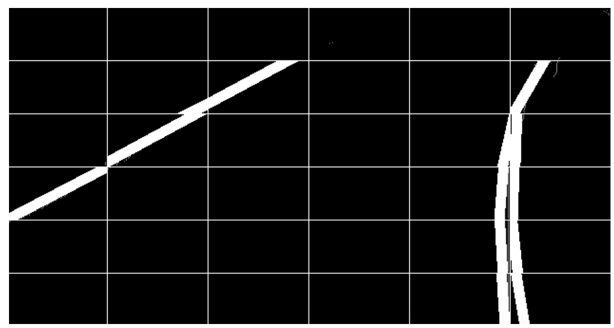

Figure 10. Fitline Result

Mapping

Map building is accomplished by use of the ROS *gmapping* package. This package provides an implementation of the SLAM algorithm, which both continuously builds and updates the current map and serves as a primary means of localization. The laser scan generated from the vehicle's LIDAR is merged with the three faked laser scans generated by the lane detection cameras. The resulting scan is transformed to a new coordinate frame at the center of the frames where the LIDAR and camera scan origins lie. The ranges reported in the merged scan, the robot's current orientation, and the transform between the merged scan's coordinate frame and the map are then used to populate obstacles.

Path Planning and Obstacle Avoidance

General navigation tasks such as path planning and local obstacle avoidance are accomplished by use of the ROS Navigation Stack. At the highest level, the Navigation Stack uses incoming LIDAR scans, the current map, robot odometry information, and geometric transforms between coordinate frames to produce velocity commands for local navigation. Internally, this is accomplished by separate local and global path planning and generic recovery behaviors for when path planning fails. Both planners are reconfigurable at runtime through a large number of parameters for tuning navigation performance.

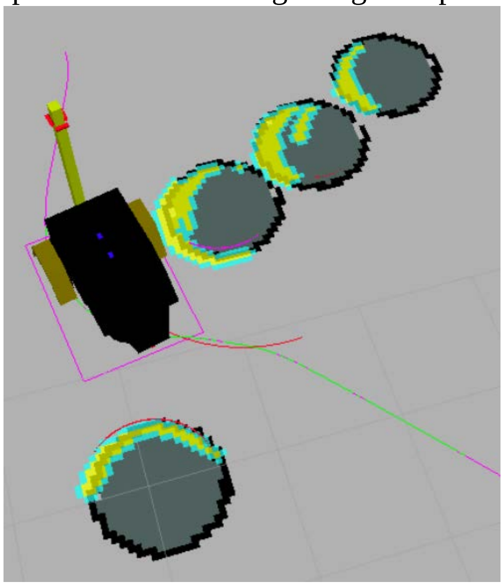

Figure 11. Path Planning in Rviz

The global path planner (*navfn/NavfnROS)* generates paths from the current robot location to an arbitrary waypoint supplied to the Navigation Stack using Dijkstra's algorithm. This path avoids known obstacles between the current location and destination and is regenerated if new map information is discovered between these points. An important capability of the global planner is that movement goals can be set for any frame that has a transform path from itself to the map's coordinate frame. The goal's frame is specified in the call to the Navigation Stack's path planning services, and the goal coordinates are then always transformed to map coordinates. This allows waypoints to be specified in the map itself, relative to the robot's current location, and (as detailed in the Localization and Waypoints section) even indirectly from GPS coordinates. Figure (11) shows the complete global path in purple, the recently recalculated global path in green, and the local path in red.

The local path planner uses incoming LIDAR scan ranges to determine where obstacles are located within a definable range from the robot. The local planner (*base_local_planner/TrajectoryPlannerROS)* uses this information to generate paths adhering as closely as possible to the global path while avoiding the locally detected obstacles. In the event all local paths result in collision with detected obstacles, the local path planner is able to initiate the Navigation Stack's recovery behaviors in an effort to yield valid local paths.

Localization and Waypoints

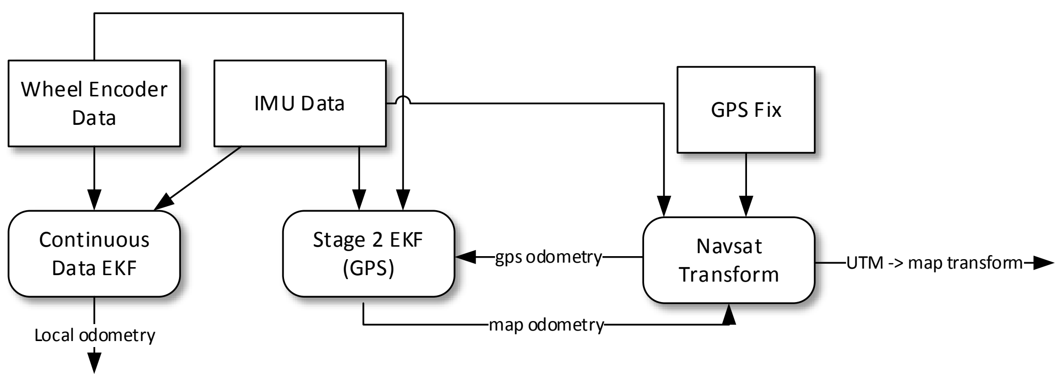

Figure 12. Localization Data Flow

Three separate sources of odometry information are generated using the ROS *robot_localization* package. Two key nodes are used from this package, *robot_localization_ekf* and *navsat_transform_node*.

The *robot_localization_ekf* node uses an extended Kalman filter (EKF) to fuse robot state measurements obtained from odometry sensors into a single robot state estimate in the robot's world (or map) frame. Two of these nodes are used. The first fuses only continuous sensor data consisting of wheel encoder data and IMU measurements to provide an odometry estimate that is not subject to the discrete jumps possible when using GPS data. The second incorporates continuous sensor data as well as the discrete measurements obtained from the GPS unit, providing the best estimate possible of the robot's odometry at any instant. Figure (12) shows an overview of the flow of various important measurements and node outputs in obtaining these odometry sources.

The *navsat_transform_node* uses a GPS fix and the robot state estimate from the second EKF result to produce an odometry source using primarily the GPS data. This node also publishes a transform between the robot's map frame and the Universal Transverse Mercator (UTM) frame, which is a method of representing locations on the Earth (as reported in the GPS fix) in a 2D cartesian coordinate system.

This transform between the map frame and UTM frame allows navigation waypoints to be specified easily as UTM grid coordinates, which can be obtained from supplied lat/lon GPS coordinates. Figure (13) shows the important transforms necessary for this use.

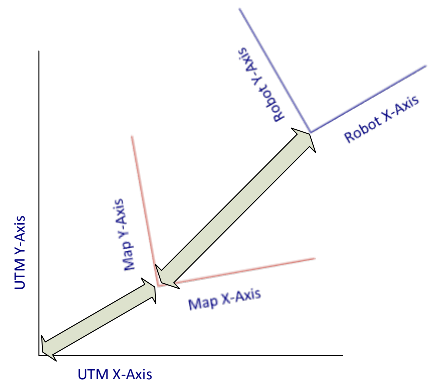

Figure 13. Navigation Transforms

Network Communication

Point-to-point wireless communication for data communication is handled by using two Ubiquiti Rocket M5 BaseStations. Both ends are equipped with a 13dBi omnidirectional antenna. The IP network will be using a standard class-C subnet with a network address of 192.168.1.0/24. The setup has been tested using JPerf to provide a throughput of 75 Mb/s with a latency averaging 1-5ms across approximately 100ft. We believe that this setup can provide a reliable consistent connection for the scope of the project. Due to the nature of the course, interference is projected to be minimal. With other teams on the field, there may be a possibility of degraded performance due to channel overlap within the 5 GHz spectrum but the system is capable of multiple interference mitigation techniques to minimize this issue if necessary.

TOTAL COST ESTIMATION

The total retail cost of all the vehicle's components is approximately $14,000. The most expensive components were the AHRS-8 and Hokyuo LRF, both of which were donated to the club's project effort. The total cost for the club to construct Little MAC was approximately $7000.

Table 1. Cost Estimation

Sensors	$8,304.65
Power Distribution	$1,507.72
Mechanical Supplies	$2,127.56
Electrical Supplies	$980.83
Total	**$12,920.76**