Stony Brook University
Stony Brook Robot Design Team

Project Tina

2014 IGVC Competition

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I hereby declare that the mechanical and software changes implemented in the design and engineering of the vehicle by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

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Professor David Westerfeld
Department of Electrical Engineering
Stony Brook University

Date:______________________

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I. Overview

The Stony Brook Robot Design Team is led by an Executive Board consisting of five administrative positions and three engineering team leaders, all undergraduate students. The president, vice president, secretary, treasurer and public relations officer collaborate to take care of the team logistics while the mechanical, electrical and software engineering team leaders oversee the design, fabrication and testing of the competition vehicle. The team leaders report directly to the vice president. The overall hierarchy is shown in Figure 1.

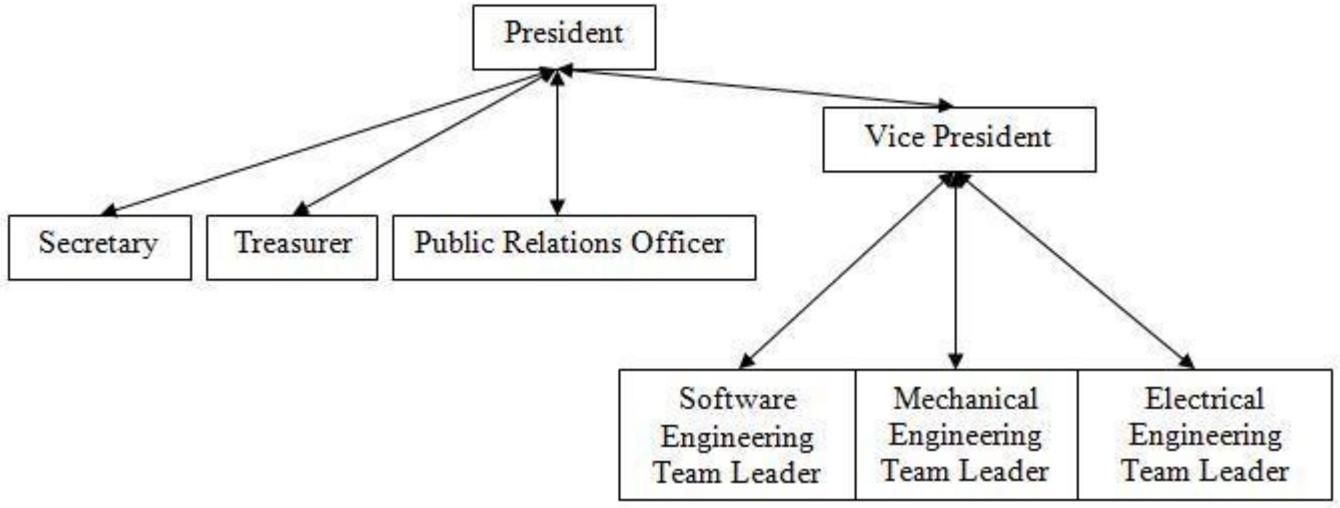

Figure 1: Team leadership structure.

Each vehicle prepared for competition is a collaborative effort. Although Project Tina was entered into the 2012 competition as P15, a senior design project from the Department of Mechanical Engineering at Stony Brook University, we have rebuilt some parts and completely retrofitted its interior.

II. Mechanical Design

1. Chassis

The chassis of the robot is built from extruded aluminum. The extruded aluminum is easily assembled using right angle brackets, this makes the robot more modular and easy to change or add parts. For the more sturdy parts of the robot (battery holder, load shelf) the aluminum was tapped and milled to have notches which fit into other pieces of extrusion.

2. Drivetrain

Our drive train contains a sprocket ratio of 15:12 which gives us a top speed of approximately 7 mph. This sprocket system drives the center wheels of the robot to create a six wheeled skid steering system for the robot. Skid steering allows us to perform turns that have an almost 0 degree radius; these turns are made easier with the help of the mecanum wheels which have rollers angled at 45 degrees in order to decrease the shear stress on the wheels when turning.

3. Weatherproofing

Our weatherproofing system includes a canvas treated with a hydrophobic spray, and a rear and front panel. In the event of rain the droplets will roll off the canvas instead of saturating and running through it. Not only do the front and back panels serve to enclose the electronics of our robot, they serve as the mounting points for fans that will provide airflow and cooling to our electronic components that will inevitably generate heat. Through the use of a foam meshing, the openings for the fans have been made water resistant. These fans are oriented so that the flow moves from the front of the robot to the back, the front fans move air in while the back move air out.

4. Rear Mount

For components that need to be away from electronic/magnetic interference, such as the compass and gps, and for the cameras which needed to see the front of the robot a tower was assembled. The tower reaches a height of 5 feet which allows the cameras to see not only what is in front of the robot but also the front of the chassis in order to see its position. In order to minimize the vibrations on the mount the gps and compass are mounted lower.

5. Suspension

In order to minimize vibrations throughout the robot, air shocks are used as suspension. The air shocks are mounted to the chassis of the robot and an arm which holds the front mecanum wheels of the robot. The air shocks can be calibrated for the amount of play wanted by the knobs on the shocks and also by the amount of air added. This year to give the shocks more play we mounted them high and also angled them.

III. Electrical Design

The electrical portion of Project Tina can be summarized by the power source, devices and the design decisions made behind everything.

1. Power source and distribution

The robot's main power source is two 12V marine batteries wired in series. These marine batteries are capable of providing 67Ah each. The decision to put them in series as opposed to parallel was due to the motors drawing 960W at most and in order to keep the current down, the voltage was increased. The drawback of these batteries is their weight of 50 lb each and their size. However, the larger energy storage potential and stability of the voltage on a marine deep cycle battery was enough to use these batteries over lighter and smaller Li-Ion batteries.

The two 12V batteries are used to create a roughly 24V source. All the power for the robot is fed through a 100A circuit breaker and into a breaker box for distribution to all the subsystems. Each of the subsystems is fed 24V, but if a particular subsystem needs a lower voltage, the voltage is converted by the subsystem from 24V into the appropriate voltage using either internal or external power regulations. Figure #A1 shows a basic breakdown of how power is distributed within Project Tina.

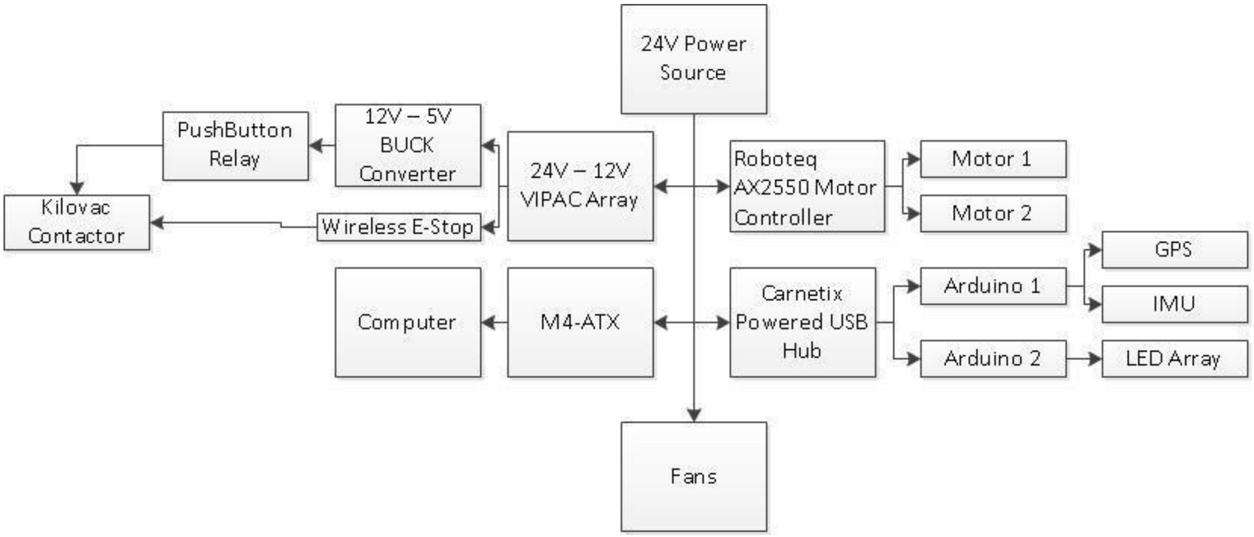

Figure #A1. Diagram showing distribution of power between components

There are only two subsystems which requires external power regulation: the Arduino subsystem and the Emergency-Stop subsystem. The Arduino subsystem receives a regulated 5V from the Carnetix 24V powered USB Hub. This is due to the capability of the Arduino to be powered just via USB. The Emergency Stop subsystem uses 12V and 5V of which are regulated by a VICOR 24V to 12V DC/DC converter and a 12V to 5V Buck Converter respectively.

2. Devices

There are various electrical devices utilized in the robot. These devices are mostly commercial off the shelf components. The most important systems formed by the devices are described below.

2.1 Roboteq AX2550 Motor Controller

This motor controller directly drives the two brushed DC motors that provide the locomotion for the robot. The motor controller accepts the raw 24V input for the two motors independently. Additionally, the motor controller's brain is also activated by having 24V applied to a control line. The use of this particular motor controller gives us variety of features and configurability that also add to the safety to this design.

All power management to the motors is performed directly by the motor controller. The device has the ability to handle currents up to 120A on each motor in the worst case. There are also programmable current limits that can be set to limit the current draw. During testing, the motors were measured to draw approximately 20A each under load and so the current limits were set to 40A for each motor. Another safety feature is the ability to constantly require pinging by the computer to remain in motion, otherwise the controller will shut down.

2.2 Emergency Stop

The emergency stop system is implemented as required by IGVC competition rules, and for the general safety of the team and public. It is implemented using 2 relays, a pushbutton and a flip flop (which simulate a third relay), and a Darlington transistor as shown in Figure #A2

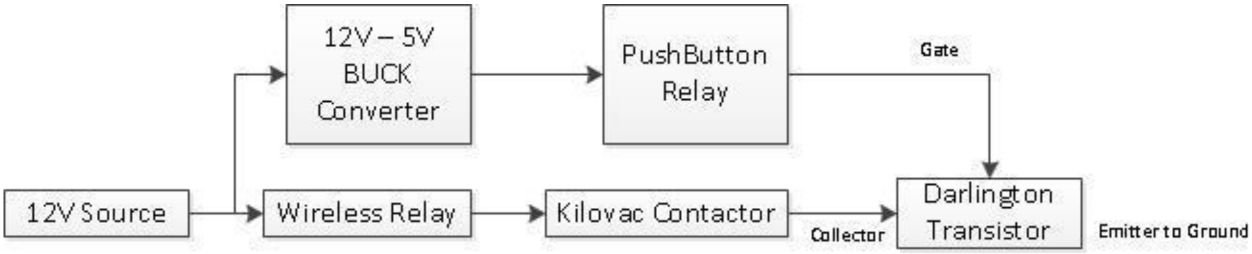

Figure #A2. Emergency stop flow diagram

The kilovac contactor is a relay in a normally "off" state until energized by a 12V source. The 12V source is directly controlled by the wireless relay. The transistor is wired in an electronic switch configuration where the flip flop switches whether or not current is allowed to flow through the kilovac contactor. If either the pushbutton relay or the wireless relay are tripped, the robot will lose power to its motors immediately. If the pushbutton relay is pressed, the flop flop changes state which results in the transistor “shutting off” the power to the kilovac contactor. In both cases, the robot will lose all power to its motors immediately and will stay as such until the “on” wireless signal is received if the wireless relay was tripped or a software or hard reset on the system occurs if the pushbutton relay was pressed. For safety, the wireless relay is “off” by default and power to both the motor circuit and emergency stop circuit must be on in order for the robot to move. These circuits are on separate breakers in the breaker box.

2.2.1 Wireless Relay Module

The wirelessly controlled relay is part of a device called the “Relay Function Module 2” manufactured by Linx Technologies. It is a box that essentially contains 4 independent relays that can be wirelessly controlled by a remote. One of the available relays is used in the emergency stop module. The relay can be toggled between an “on” and “off” state on demand. Additionally, the relay defaults to the “off” state.

2.2.2 Pushbutton Reset Module

In order to have a physical pushbutton to act as a emergency stop on the robot itself, a circuit was designed and built to act as a triggerable relay circuit. It was made to be reusable with any kind of pushbutton. The module uses no programmable elements as required by the IGVC rules and instead utilizes a simple D-flop flop to switch the Darlington transistor on or off. One designed feature of the module is a permanent shut off of the relay until the module receives an electrical reset.

2.2.3 Kilovac Contactor

The Kilovac LEV200 series contactor is the biggest relay used in the emergency stop circuit. The motor power travels through the relay before it is fed into the motor controller. It is capable of handling up to 500A and its switched by a 12V source.

2.3 On-board Computer

From previous entries in the IGVC, we found a onboard computer was more reliable than the previous designs using just a laptop. Two of the major issues that the laptop had were power draw and overheating in the summer. The integration of a standard computer motherboard and components has allowed us to build a more reliable computing system.

2.3.1 M4-ATX Power Supply

The most important component for the onboard computer is the power supply without which the computer would not have the various regulated voltages needed for proper functionality. This is an off the shelf power supply meant for powering ATX standard motherboards from a DC supply. It has all the connectors required for the motherboard ATX and CPU connectors, as well as 4-pin MOLEX and SATA power connectors. The power supply is capable of delivering up to 250W at max load and handles all power management of the connected components making it an perfect component to have been integrated into the design.

2.3.2 Motherboard

The motherboard is the heart of any computer and the one chosen is an ITX desktop motherboard. It has 16GB of memory installed and an i5 processor. The upside of these choices is evident in speed and power, but at the cost of more power consumption. Due to the risk of overrunning the 250W supplied by the power supply, we decided that an ITX motherboard which has a smaller footprint and is more energy efficient than its ATX counterparts is the better option. After testing we found that we were also able to add an additional Nvidia GT 630 graphics card with a low power consumption for more efficient image manipulation.

2.3.3 Solid State Drive

A Solid State Drive(SSD) is utilized due to the immediate benefit of not having spinning disks. An issue that exists when using conventional hard drives is the need to be relatively stable while writing or reading data or else mechanical problems may occur internally. Hard drives are not meant to be in use in environments with many predictable vibrations. The solid state drive is for the most part unaffected by the movement of the robot and thus a logical choice since it’s available and we do not need a large amount of storage.

2.4 Arduino Subsystem

Due to ease of use and high IO operability, two Arduino Mega 2560's are utilized on Project Tina. These particular models were chosen for their greater IO support and the 16MHz microprocessor. They communicate to the computer and receive their power through a USB connection to the Carnetix powered USB Hub.

2.4.1 GPS

We elected to use 3 MTK3339 GPS' due to their extremely small footprint. We decided that 3 GPS modules would be used so that we could achieve a slightly more accurate reading by averaging each of the locations reported together. Each of the 3 GPS modules communicate with Arduino-1 which then relays the information to the computer. Figure #A3 demonstrates how Arduino-1 is wired with the three GPS modules.

2.4.2 IMU

An IMU is an Inertial Measurement Unit. The particular one chosen for Project Tina has a 3 axis accelerometer, a magnetometer, and a gyroscope on chip. This allows us to receive information about what direction we are moving, if we are on an incline, and in what directions we are accelerating. The use of this chip is for feedback to the computer to know how movement actually compares with how the computer "thinks" it is moving. The IMU communicates with Arduino-1 which then relays the information to the computer.

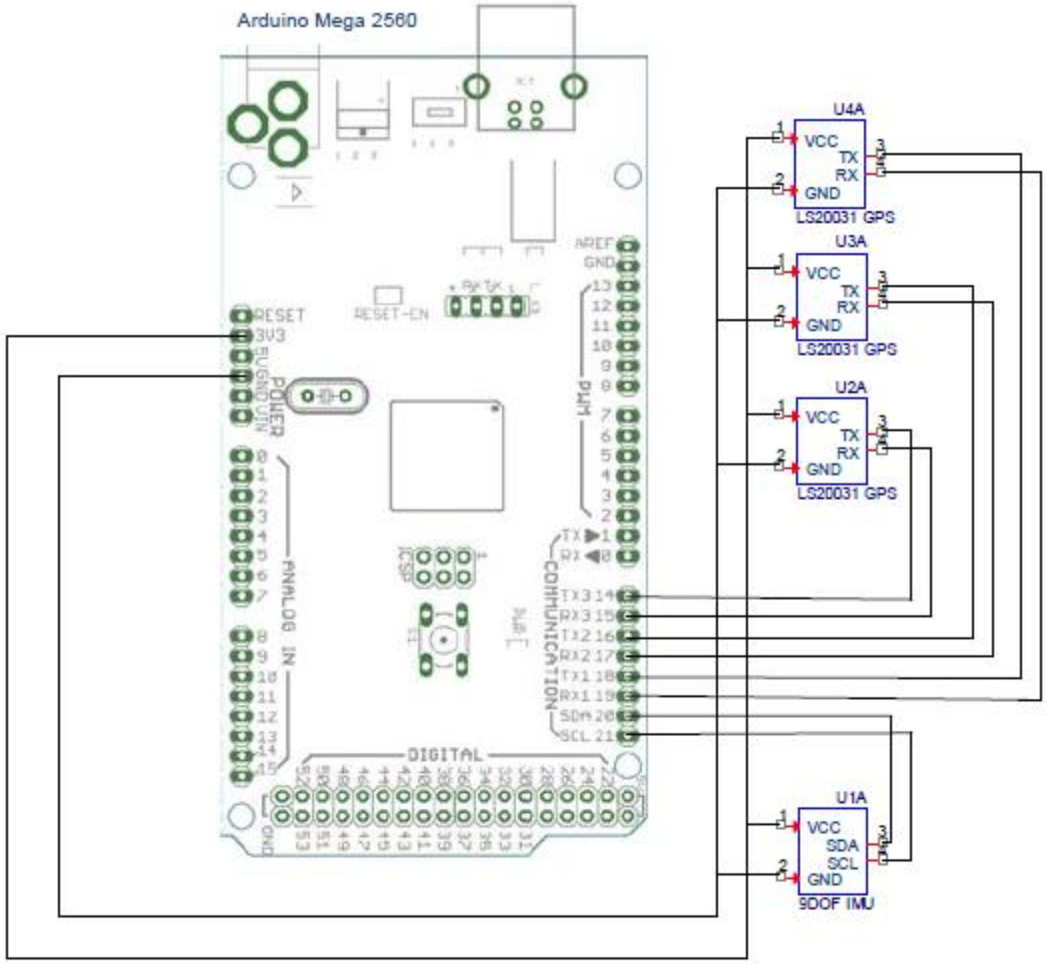

Figure #A3. Arduino-1 Wiring Diagram

2.4.3 LED's

Three ultrabright LED's are installed on Project Tina as per the IGVC rules. These are to be solid when the robot is on and blinking when the robot enters autonomous mode. The LED's are driven by Arduino-2 which receives commands from the computer whether the LED's are to be solid or blinking.

2.5 User Interfaces

An IO panel was integrated into Project Tina to provide an easy place to perform various debugging processes but also to provide a home for the integrated charging port. The use of a charging port was decided due to ease of charging the batteries during the competition but also to protect the batteries from damage due to reversed polarity. The use of a circuit breaker box was to provide an easy way of shutting down individual subsystems on the robot without shutting down every system. The breaker box also protects each of the subsystems individually and the batteries from short circuits or over current draw.

3. Overall Design Decisions

There were a few electrical design decisions made in Project Tina. They consisted of component layout, power distribution, and components used.

3.1 Layout

The component layout on the robot is potentially suboptimal but was decided on as shown in Figure #A4. The space between related components was minimized for the E-STOP and computer system. Additionally, the circuit breaker box and switches were put as close to the batteries as possible. One reason the layout is suboptimal is because the Kilovac Contactor is placed so far away from the Motor Controller. This was done so that there would be decent air flow to the motor controller as we are worried about potential overheating. The entire Arduino subsystem is located on the rear boom of the robot and therefore is not on Figure #A4 since Figure #A4 only shows placements of components on the base of Project Tina. The fans are placed throughout the robot and were not placed on the figure to simplify it.

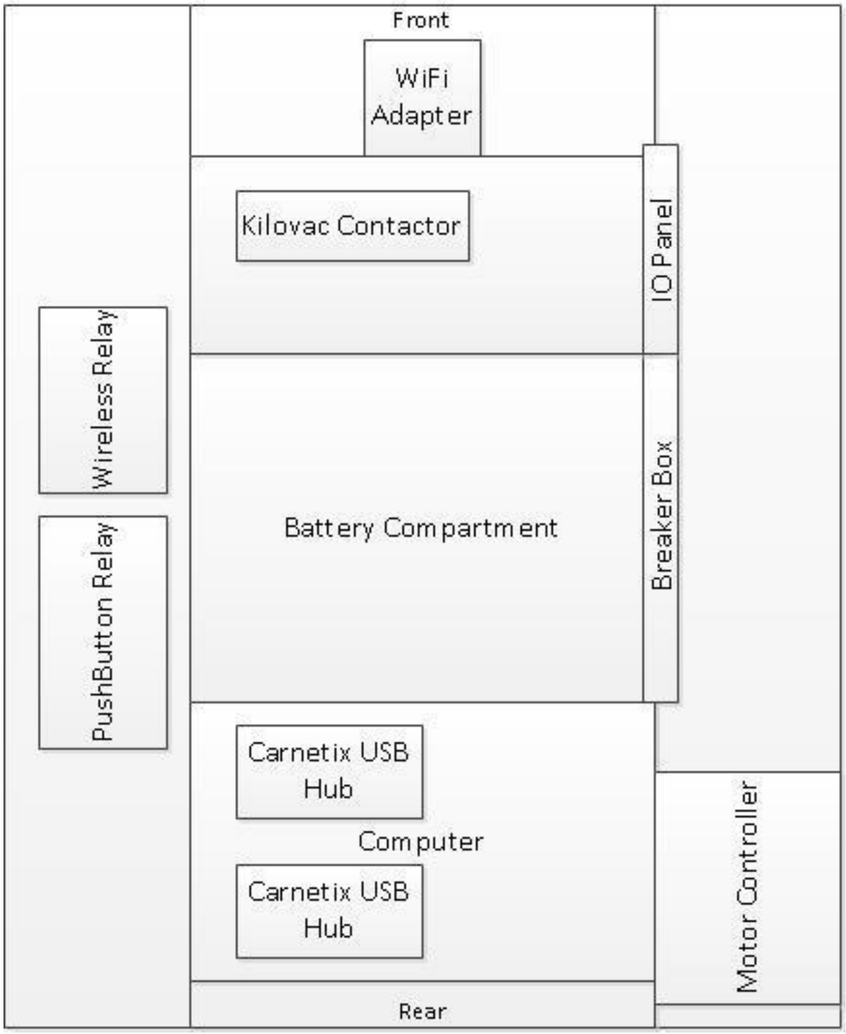

Figure #A4. Component Layout

3.2 Power distribution

The power source created by using the two 12V marine batteries was fed through a 100A circuit breaker and then into the circuit breaker box. The 100A circuit breaker provided protection to the batteries but also provided an easy way to shut down the entire robot in case of an emergency. The 24V coming out of the circuit breaker box for each individual subsystem was not regulated as all the subsystems have voltage regulation. The direct result of not regulating the voltage was space saving because a large 24V, high power regulator was not needed. The E-Stop system required the use of both 12V and 5V which were generated using DC/DC converters. The E-Stop was the only subsystem that required the use of extra converters.

3.3 Component Usage

The usage of off the shelf components while not as in depth in engineering enabled a faster build of the robot. Additionally, the components have more features than would be possible if for example the motor controller was self built. The AX2550 has a full feature programmable system capable of various operating modes and data responses that would not be possible by a small team of engineers. Finally, a cost saving is incurred by using components without having to waste money on prototyping and implementation.

IV. Software

1. Overview

The software system from previous years has been completely redesigned and recoded from the ground up with an event driven architecture as the primary system. This system allows for highly modular design which in turn allows for a sensor fusion with plug and play aspects of sensors. Modules are registered in a base module loader, however modules have no knowledge of each other. They communicate over a bus of events which fosters highly modular and safe coding which decreases the chance of complete failure of any one module. This concept was chosen as a failsafe for ensuring the effectiveness of the robot's navigation system as the complexity of the algorithms utilized increased during development. In order to accomplish the concurrent usage of multiple sensors, an onboard computer system was implemented. The embedded system consisted of one high end desktop motherboard with a high performance quad core processor, and ample RAM. The specific system chosen was MIL-SPEC rated for long term use, solid state components (included hard drive) and overall durability in the most demanding of environments. Each device had event-driven connection and data management processes which allowed for worry-free connectivity and data visibility. These new features also provided safety checkpoints during the robot's initialization and autonomous states. Each component was configured so that in case of a disconnection, the robot stops any dangerous actions and displays the state of every part of the robot platform for debugging.

2. Sensors

2.1 Camera

The computer vision system is comprised of two Microsoft LifeCam Cinema cameras placed at a known distance apart on a five foot boom in the rear of the robot. The cameras faced downward at a specific angle so that the furthermost edge of the robot is the only portion of the chassis visible in the camera systems field of view. This placement allows for the detection of obstacles in and around the robot with a focus on its blind spots.

2.2 IMU

An IMU with 3 axis accelerometer(ADXL345), gyroscope(ITG-3200) and magnetometer(HMC5883L) was embedded in the system. The accuracy of the gyroscope and the magnetometer is useful for highly precise calculations of heading. The accelerometer also allows provides a rudimentary position estimate for use with dead reckoning.

2.3 GPS

For GPS, 3 inexpensive MTK3339 units are used in conjunction to come up with an estimate for position. This absolute position is used in conjunction with our IMU position to get a more accurate estimate of our absolute coordinates.

2.4 Long Range IR Sensors

An Array of 1 meter IR sensors are used as an emergency stop system to detect any obstacles that our optical imaging systems might have missed. This is to prevent damage to the robot and the obstacle in the path. It's sensor information is also used in ordinary navigation algorithm.

3. Program Hierarchy

3.1 Base System

The base system of the software is tasked with managing communication between modules. It also defines the interface between modules. Modules have the responsibility of responding appropriately to certain command flags like STARTUP, SHUTDOWN, and STATUS. Once sensor modules start up they are supposed to broadcast information such as GPS coordinates or other information. This information is wrapped in a common interface such as a state estimation structure. This estimate structure denotes what aspects of state it estimates such as position, velocity, or heading. It also provides what kind of error is associated with this estimate and whether the error is relative or absolute. Knowing this information our system can implement an arbitrarily sized kalman filter with adjustable values for each module in state estimation. Sensors can also publish obstacle information. This information would comprise of the shape of the obstacle (plane/line, point, cuboid, or circular), the position of the obstacle relative to a fixed point on the robot, and any error in size or position of the obstacle. Then finally there are general status update events which denote module status (on, off, error), status changes, and other things. The one exception to this modularization is the linkage of the navigation module to the motor module. These modules are built simultaneously with the other's capabilities in mind in order to reduce algorithm complexity. There exists a set of auxiliary modules whose purpose is to monitor event logging, computer status, and power information in order to debug any issues.

3.2 Sensor System

The Camera system performs its basic function and obtains images of the course in front of the robot. The images are blurred to create a more uniform distribution of color on the floor in front of the robot. The system then performs a Hough Transformation to detect lines on the ground. Initial Camera Data Manager creates an array of points from the images that contain the x and y position of each pixel detected by the Hough Transformation. The RGB-D images obtained from our stereoscopic setup allows us to do object detection and recognition on obstacles. With this we can compute the homography of our known obstacle with our unknown. Then, through homography decomposition we can determine its relative location orientation and size.

The GPS unit obtains state data like position, velocity, and heading. This information is fed into a kalman filter along with our accelerometer data in order to come up with accurate estimations of state. The heading of the GPS is weighted very low as the accuracy of our IMU heading is much higher.

The IMU system computes a dead reckoning based on previous “absolute” estimates of position. The heading information provided by our IMU is very accurate so it is weighted very high.

3.3 Navigation System

The navigation system works by building a map of obstacles. The map is actually a graph of obstacles relative to the robot. GPS waypoints are also added to the map as objectives. The goal is to reach each objective choosing the objectives with the shortest path. The robot calculates shortest path by doing a lot of preprocessing on obstacle graph. Convex hulls (for obstacle point sets) are calculated and the minkowski sum of the robot’s geometry is added to the set of polygons created by the obstacles. This map is then decomposed to find navigation waypoints by choosing the minimum set of points that see every vertex (includes obstacles, robot, and gps waypoints), that bisect line segments between vertices. Line segments that the robot cannot pass through (too small) are not checked. This provides a set of waypoints that the robot can navigate to and through based on current information available. These waypoints are then traversed using a shortest path algorithm like Dijkstra's.