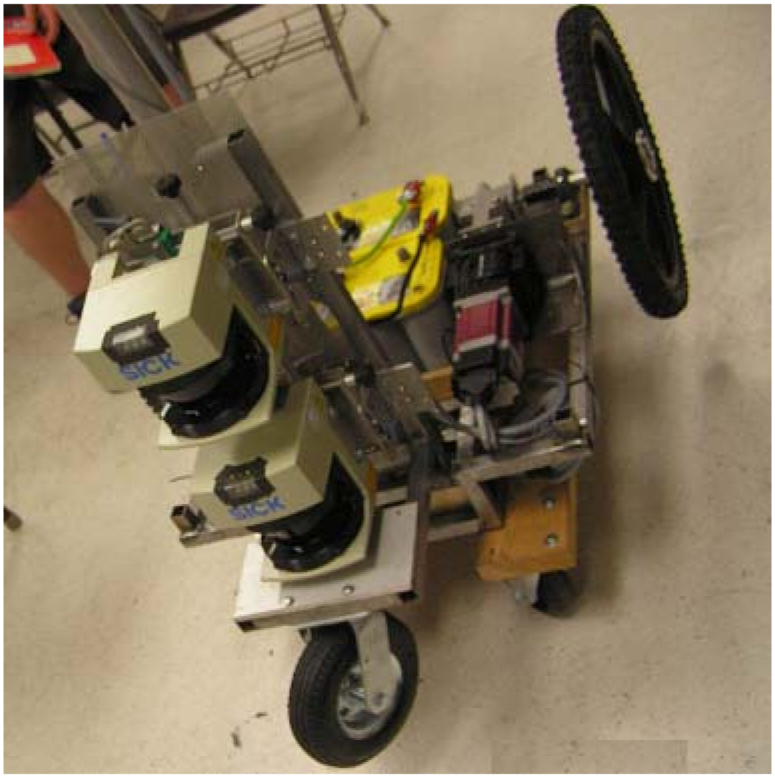
LinBot

California State University
Northridge



Team Members

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Cerna, Napolean
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Coreas, Luis
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Required Faculty Advisor Statement:

I certify that the engineering design of the vehicle described in this report, LinBot, has been significant and that each team member has earned four semester hours, of senior design credit for their work on this project.

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1 Introduction

The Intelligent ground vehicle team of California State University, Northridge (CSUN) is proud to present LinBot for entry into the 15th Annual Intelligent Ground Vehicle Competition. This is the second year that CSUN will be competing. The current team took over the project in September 2006 with fresh idea and new innovations. After ten months of designing, testing and programming, we have fabricated a robot that is ready for competition.

1.1 Team Organization

Our team was divided into three sub-teams each with a team leader as well as three project overseers as shown in Figure 1.

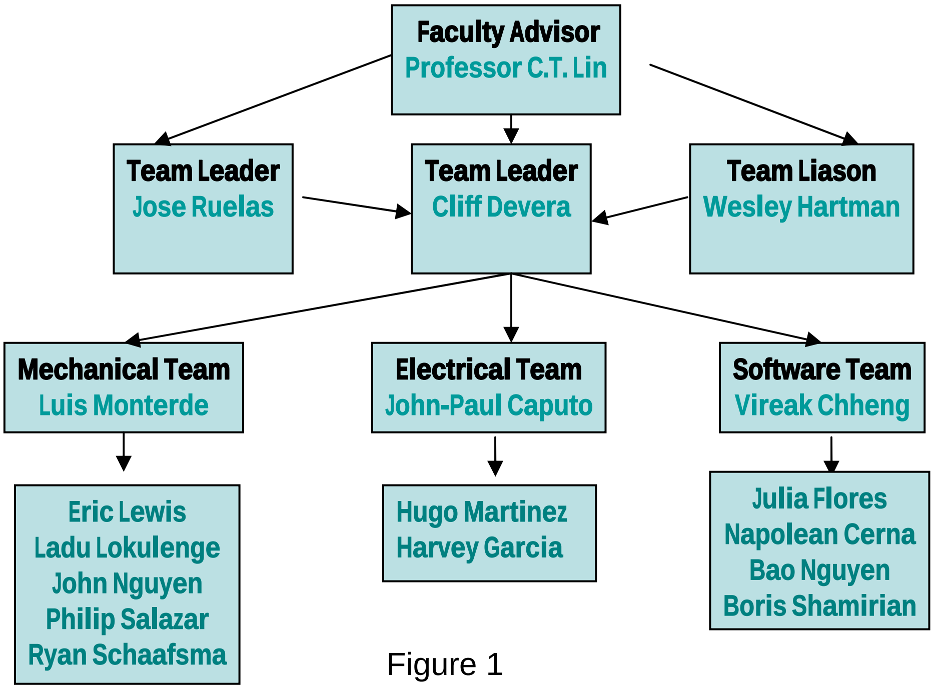


Figure 1

The project overseers help facilitate communication with the different groups as well as keep the project as a whole in perspective and on track.

1.2 Design Innovations

With the second year of the team, we have brought new innovations to the design of our vehicle. The first is the micro network. This network uses a Linksys router to facilitate the communications between our multiple computers. The second is the use of a laptop for all vision processing. This frees the PXI from having to spend significant clock cycles on vision processing. The third is the shared variable engine. Using shared variables in Labview, we shared data across the micro network from the laptop to the PXI. Using this system provides true parallel processing. The fourth is the sensor fusion. We combine the data from the camera and the laser range finder to create a single map. The fifth is vision filtering using all chromakey. Last is the Power distribution panel. Every sensor has a switch creating a modular electrical system that can be easily fixed.

2 Mechanical Systems

2.1 Mechanical Development

The development of the vehicle went through 4 stages. These stages are illustrated in figure 2:

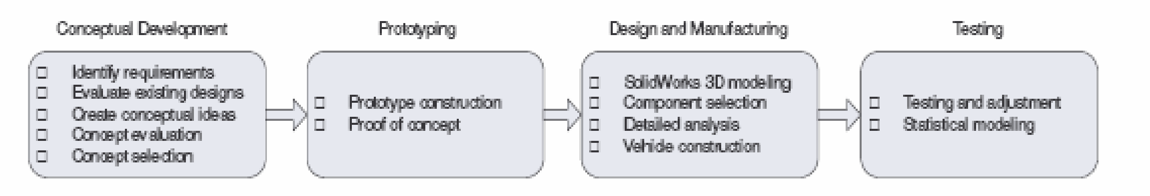


Figure 2

2.2 Chassis

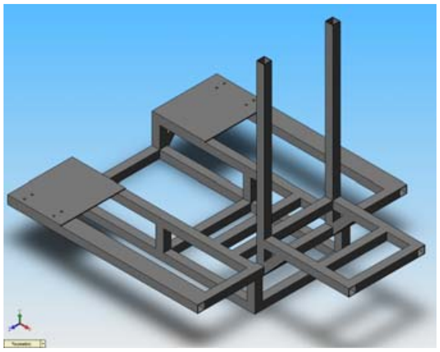


Figure 3

The chassis for LinBot was designed to have a lower center of gravity and a strong frame (Figure 3). Size, position and weight of all components were taken into consideration and were design with this in mind. The frame is constructed of square steel tubing that has been welded together and polished. This structure has been designed to support and evenly distribute a load of up to 1000 pounds.

2.3 Wheel Configuration

The choice of differential drive set the base point of the wheel configuration. For higher stability, a three wheel configuration was chosen having the drive wheels located in the back with one pneumatic castor wheel for support in the front of the vehicle.

2.4 Mobility

A differential drive robot such as LinBot has only on kinematical restraint on robot mobility. That restraint limits lateral motion of the drive wheels and makes the problem of vehicle control much simpler.

2.5 Drive train

Two Quicksilver 34HC-2 motors were selected to power the drive train. They are connected to Bison gearboxes having a gear ratio of approximately 21:1. In order to reduce the width of the vehicle, it was decided to right angle gearboxes for achieve a right angle configuration as shown in Figure 4. Couplers are used to connect the gearboxes and the wheels.

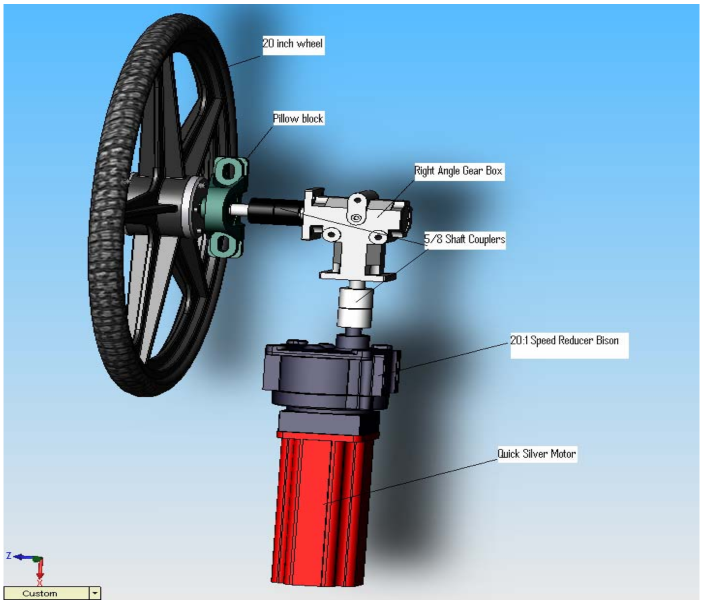


Figure 4

2.6 Shell

The design requirements took into account the frame and the placement of the internal components. The shell fabricated of fiberglass with structural reinforcements. The shell is designed to be weatherproof, dustproof, and able to take high amounts of high stresses. One sheet of 4 millimeter thick Nomex honeycomb core was used as reinforcement to support the payload. Figure 5 shows the mold for the shell split into 7 pieces. These pieces were produced for our NC Code which was used for and placed into the CNC machine. Figure 6 shows an isometric view of our final product of shell design. The resin and fiberglass set to cure. The shell was then removed from the mold and then cut to specification.

The shell has doors installed into them for easy access to the electrical components

Figure 5

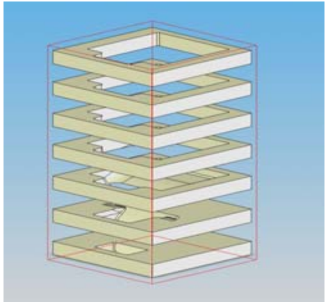
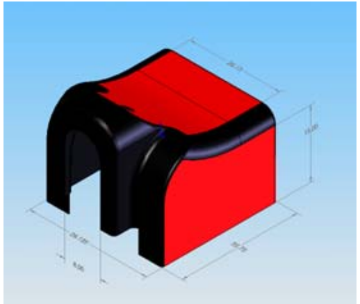


Figure 6



3 Electrical System

3.1 System Layout

Figure 7 is the design of our electrical system layout. Green blocks represent high power outputs, red and blue circles are switches, dark orange rectangles are output power, light green rectangles are the backing for the fuse holders and the light blue is AC power supply input.

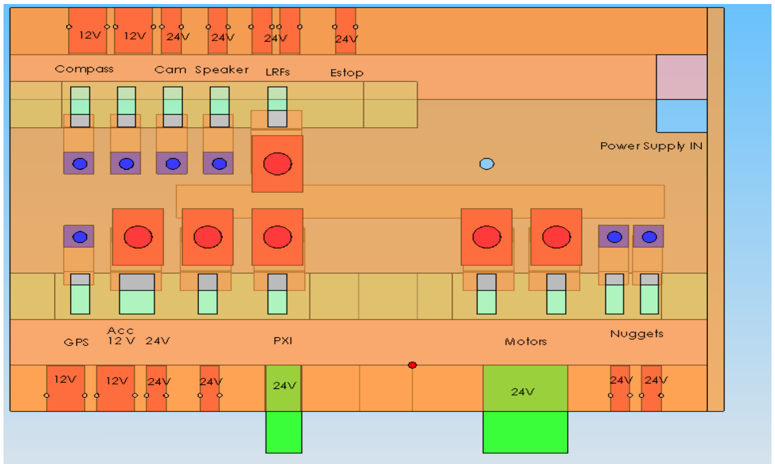
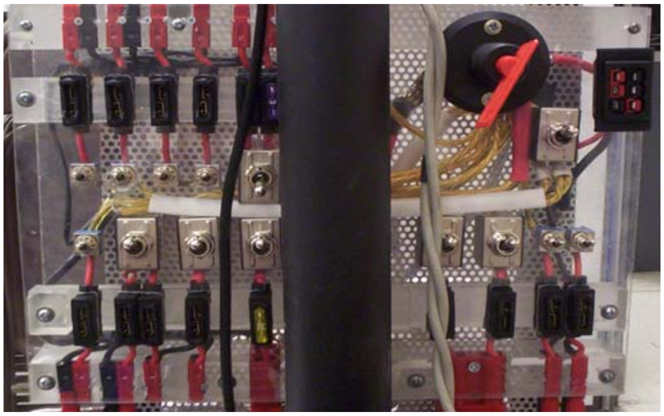


Figure 7

3.2 Power Distribution

Figure 8



Two 12 volt batteries are connected in series to provide 24 volts of power. These batteries are connected to each other and to the main switch board (Figure 8) using oversized power cables for low voltage drop at peak current. These cables were also chosen to handle our nominal current need of 30 and the maximum current need of 57 amps under extreme motor conditions. All systems have been setup to run on DC power of 24 volts, or 12 volts. The power distribution box is custom made with Anderson connectors, switches, and fuses for every sensor. A remote control system is implemented using standard remote control car/airplane parts. All sensors are set to run on DC sources. The laser range finder, camera, PXI, and motors are 24 volts; and the digital compass, remote control, router, and GPS use 12 volts.

3.3 Batteries

Figure 9

LinBot is powered by 24 volts system using two SVR 12 volt batteries (Figure 9) connected in series. These batteries are lighter than the previous Optima batteries. Each battery provides 28 amp hours giving us approximately one hour of power.

4 Sensors

4.1 System Integration

All sensors and the remote terminal laptop computer are used to control and provide feedback to a central National Instruments PXI 8187 main computer using a Pentium 4 M processor with 1GB of RAM. The robot has an onboard computer network that uses a Linksys Wireless-G Router to enable both data packet forwarding and allow for the use of wireless remote control access to the programs that run on the PXI. The PXI 8187 main computer uses a combination of different types of interfaces which include RS-232, RS-422, Fire Wire, Ethernet TCP/IP, 802.11g, and motion controller card to provide maximum interface flexibility. The main controller interfaces with the

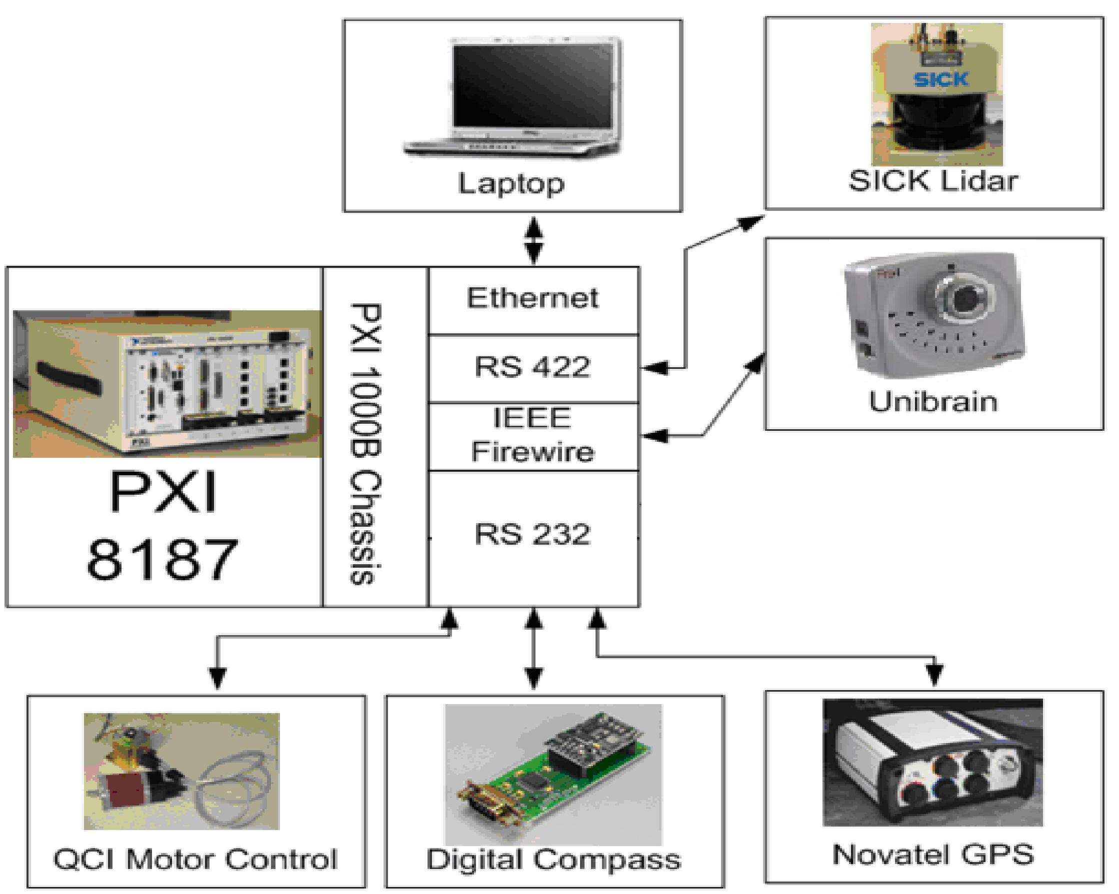


Figure 10

expansion cards using the PXI 1000B chassis. The diagram (Figure 10) provides a summary of the interfaces for each individual subsystem.

4.2 Digital Camera

LinBot's vision system consists of a digital camera created by the Unibrain company as seen in Figure 11. The UniBrain has resolution capabilities of up to 640X480, selectable frame rates of up to 30fps, IEEE 1394 and USB data interface along with a 2.5mm Focal lens. The vision system will detect and process the necessary data of the lines which the robot is specified to stay within. The UniBrain is then used in conjunction with a linear polarized lens along with a neutral color filter. The vision program is processed on a separate laptop and the result is passed onto the main algorithm through the onboard computer network via the shared variables engine.

Figure 11

4.3 GPS

The GPS system used in LinBot is the Novatel Pro-Pak LBplus system seen in Figure 12. It is shock, water, and dust resistant. It can provide position accuracy of 1.5 meters CEP (Circular Error Probable) without a correction signal. The system uses Omnistar HP differential corrections to achieve an accuracy of .10 meters CEP. CDGPS and WAAS corrections can also be acquired to improve positioning. The system communicates with the PXI onboard computer through an RS-232 port. It can be powered by +7 to +15 VDC and it consumes 3.7W of power (typical). The system will be used in the navigation challenge to localize the vehicle and guide it towards the waypoints.

Figure 12

4.4 Laser Rangefinder

LinBot's main source of obstacle detection is a SICK LMS291-SO4 laser rangefinder seen in Figure 13. This device is capable of scanning a range of 180º in 0.25º increments, measuring distances up to 80m away. The settings used for LinBot make the device scan a range of 180º in 1º increments, measuring distances up to 8m away and returning values in mm. Anything further than 1.5m will not be considered by the obstacle avoidance algorithm, and 1º increments are sufficient at this distance. An RS-422 serial interface was used in order to obtain a data transfer rate of 500kbaud.


Figure 13

4.5 Digital Compass

Using the Honeywell HMR3300 digital compass as seen in Figure 14, LinBot's heading is determined relative to the Earth's magnetic field and is accurate to within ±1 degrees. The compass connects to the main computer by way of an RS-232 serial connection. The compass is mounted on the mast in a plastic, weather resistant enclosure to reduce any interference.

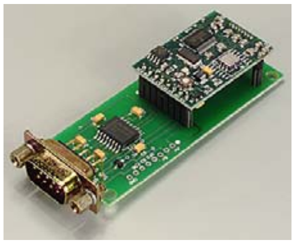


Figure 14

As a failsafe device for both testing purposes and redundancy during competition, we are also using a True North digital compass. This device has an accuracy of 0.3 degrees and can be updated frequency of 12Hz. It also uses an RS-232 serial communication interface for data transmission.

4.6 Motor Controller

The motor controllers used are the Silver Nugget N3 M-Grade controller/drivers seen in Figure 15. They have an input voltage of 24V and run on 18 amps continuously. The controllers have an RS-232 serial input for connection to the computer. The controllers function as a relay between the computer and the motors by taking a low voltage digital signal from the computer and boosting it to a high voltage signal to be read by the motors.

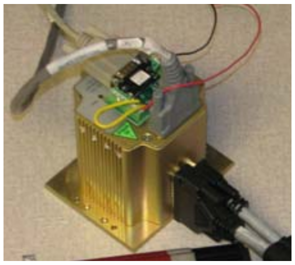


Figure 15

5 Software

5.1 Device Communication Software

The software of choice for LinBot was National Instrument's LabView 8.2.0 and Real Time 8.2.0 operating system. This software made the subsystem communication possible through the use of a global shared variables engine. These variables are an efficient way to code separate portions of code while maintaining the top-down modeling approach. Each subsystem on the robot such as the camera, motion control, and data acquisition software was developed by separate teams and later combined into the main algorithm. In addition the graphical programming environment made it much easier for novice programmers on our team to use and create code.

5.2 Vision Software

The process for detecting the boundary lines of the track is executed through LabView 8.2.0 and the Labview 8.2.0 Vision Assistant. The camera has a linear polarizer that is placed in front of the lens. The purpose of this lens is to eliminate unwanted glare that may enter the camera lens. In addition, a neutral color lens is then added to further reduce the amount of unwanted glare that is entering the camera lens. When the image is acquired by the Unibrain camera, the image undergoes the perspective correction algorithm and the image is split in half so that each side of the image contains either the left or right boundary line. The green is then removed from the image through a chromakeying process. A Hough Line Transform (HLT) algorithm then processes the filtered image and generates the best fit equation of the line for both lines. From the two lines, the trajectory of the robot is calculated and used for path planning. The location of boundary lines is also fed to the global robot map to be used as obstacles. This process can be seen in the following Figures 16 and 17:

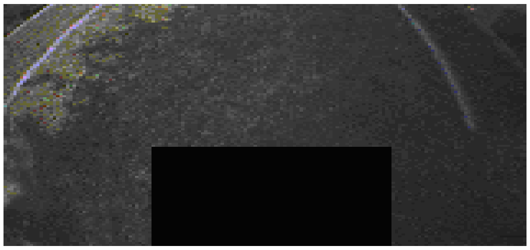


Figure 15: Before Line Detection

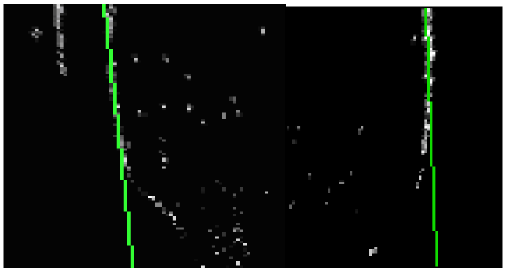


Figure 16: Split Images After Line Detection

The image filtering algorithm has a portion of code that will eliminate orange barrels and highlight white or yellow lines.

5.3 Behavior Algorithm

This portion of the code moved away from the closed loop algorithm that was used in previous years. This year the program focused on an open loop control system. The open loop control system simulates a predefined reaction while entering a preconceived set of conditions. The general programming methodology consisted of create a priority list of conditions that would be processed to determine the robots need to turn left, right or to continue to move forward. The obstacle array is the sole input that is required for the obstacle avoidance program. In addition, the array is also compiled from data acquired from each sensor. The final result of Boolean procedures is a combined polar array of obstacles from the camera and the laser range finder.

5.3.1 Obstacle detection

LinBot uses a laser range finder to scan in data for the use of obstacle avoidance code. The Laser Range Finder will output into a polar array of obstacles within a 180 degree sweep and within a distance of 8 meters. The data is then passed into our obstacle avoidance code. LinBot is heavily reliant upon the data received from the LRF to interpret obstacles within the robot's range of interest.

5.3.2 Scenario and decisions making

The decision making program requires an array of 180 items that refer to obstacle distances.   The polar array is divided into two subsets and then processed. Each half will be processed in our case statements within the program. Based on the region and distance in which object is located within the robot's frame, the command to move left, right, forward or reversed is issued to the motor.

An example of such a case statement is that of the turn left or right algorithm. If there is an object directly to the left or right of the object (within 0 – 20 or 160 -180 degrees) of the robot, the motors can only perform the move forward or backwards commands in-order to avoid a collision with an obstacle. This obstacle can be a barrel or a wall; however, the algorithm does not distinguish between the two. Overall, it is only seen as an object that must be avoided.

5.4 Autonomous Challenge

LinBot uses a behavior based solution to complete the autonomous challenge. From the highest level perspective, the main algorithm consists of gathering sensor data from all the sensors. The approach of this challenge is the behavior algorithm to make all of the decisions for the motion of the robot. The primary sensors used in the autonomous challenge are the laser ranger finder and the digital camera. LinBot integrates the vision input into the obstacle array created by the LRF. The two sensors will feed into a resultant array of combined obstacles and line data. This is achieved through the use of two independent computers that are using the shared variable engine which allows sensor values to be passed between multiple computers or virtual instrument files.

This approach improves the efficiency of the development process. The obstacle avoidance and vision algorithms occur in parallel during the development process and testing phase. These portions are combined after the specifications are met.

The purpose of the vision is to track the course boundary lines and use the data to create a virtual wall that the robot can use as boundaries within the virtually mapped course. In this process the robot cannot distinguish the difference between a real wall and a painted white line that is located on the floor. Each item will be considered impassable boundaries and guide the robot through the autonomous course.

5.5 Navigation Challenge

In order to complete the navigation challenge, LinBot relies heavily on another set of sensors. The role of the DGPS and digital compass unit will play a larger role in this portion of challenge. The LRF will continue to be used as the primary sensor for obstacle avoidance. In using the idea of modules, the navigation code will use the same obstacle avoidance module that was seen in the autonomous challenge. With an exception, the data from the camera has been removed from the processing queue.

The obstacle avoidance algorithm will be instantiated if an object is detected within our threshold limits. The goal is to get the robot into a position that will allow the robot to realize a direct path to its goal. If a direct path does not exist, the robot will continue to probe the area until a path is found.

The approach to this challenge is based on a difference between the two algorithms. The vision system is removed from the program and the GPS unit will be responsible for a significant portion of the outputted motion. First we input the waypoints in the order that we would like to reach first. Then using the DGPS, digital compass, and motor encoder feedback, LinBot localizes and finds the direction to the first waypoint. While moving, LinBot uses the DGPS and compass feedback to localize itself on the planet. Once the DGPS and compass have given their respective position and heading estimates, this information is used to orient the robot with the final goal bearing of the robot. This may only be bypassed if an object exists within the threshold range of the robot. This process allows LinBot to localize with very high accuracy.

6 Predicted Vehicle Performance

6.1 Speed

The motors are capable of outputting a combined peak power of 0.76HP at 24 volts and run at an optimal speed of about 1200 RPM. This translates to an optimal vehicle speed of 3.4 mph, which gives the greatest motor efficiency. The robot has the ability to travel faster, but it is programmed to travel at a maximum speed of 5 mph.

6.2 Ramp Clearing

LinBot has the ability to climb an incline of up to 30 degrees. The motors are capable of driving the vehicle up a 30 degree incline at 1.3 mph.

6.3 Reaction time

LinBot's reaction time to situations is almost instant. This amount of time has been estimated to be approximately .1 second. Motion can be interrupted by our sensors that run parallel to our main program. These sensors consist of our compass, camera and laser range finder. At 5 mph the robot will move slightly over .7 feet before reacting.

6.4 Battery Life

The robot requires and average of 28 amps of continuous power. Two SVR batteries are used providing 28 amp hours allowing the use of approximately one hour of operating time.

6.5 Obstacle Avoidance

The laser range finder, which outputs polar coordinates, is used as our main obstacle sensor. The points are observed and have various math functions applied to the data. The results of the functions are then applied to a case statement. This case statement will determine the behavior of the robot.

6.6 Waypoint navigation

LinBot uses differential GPS during the navigation challenge to achieve an accuracy of at least .1 meters while localizing. In combination with the encoder feedback from both servo drive motors and the digital compass, the waypoint accuracy is less than .1 meters.

7 Safety Configuration

When creating any autonomous vehicle it is very important to take safety into account. A careful safety analysis is essential to ensure that no one will be harmed while operating, observing, or working on the vehicle. Safety considerations have been of the utmost importance when designing LinBot. LinBot includes two forms of emergency stopping, wireless and manual. For the wireless e-stop, a Radio Shack 61-2667A, used to wirelessly interrupt power to the motors. Whenever the “ON” button is pressed on the remote control of the Radio Shack unit, AC power to the motors is interrupted. The mechanical switch, Mouser 653-A22E-MP-01, is connected to the DC power to the motors as well. Another consideration of safety for LinBot was that no one would be injured while working on the vehicle. All connections that pose an electrical shock hazard have been covered in non-conductive material. In addition to this all sharp edges were de-burred during assembly.

8 Cost

Throughout the design and development of LinBot there was an effort made to reduce cost without sacrificing sensor accuracy or vehicle performance. This was accomplished with the help of industry sponsors. Many of the component costs were eliminated or reduced due to the generous donations received by our sponsors. A full analysis of component and material costs can be seen in the following Figure 18:

Item	Quantity	List Cost	Cost to Team
NI PXI-1000B Chassis	1	3,173.50	2,856.15
NI PXI-8187 Controller	1	5,640.26	5,076.23
NI PXI-8252 IEEE1394 Interface Board	1	544.5	490.05
NI PXI-8430/4 RS232 Serial Interface	2	709.5	638.55
NI PXI-8430/4 RS485 Serial Interface	2	764.5	688.05
SCB-68 I/O Connector Block and Cable	1	385	346.5
Quicksilver Motors and Controllers	2	4,040.00	1,743.94
Gear Boxes	2	1009	759
Novatel DGPS Unit	1	5,942.93	2,922.75
SICK Laser Rangefinder	1	7,675.00	4,891.00
Honeywell Digital Compass	1	540.17	540.17
UNIBrain Digital Camera	1	120.00	120.00
Mechanical Drivewheels and Chassis	N/A	782.27	782.27
AVR 12V Batteries	2	279.18	279.18
Electrical Components	N/A	253	253
LMS Driver	1	720	0
Total			22,386.84

Figure 18

9 Conclusion

LinBot is an autonomous ground vehicle designed, built, and tested by the students of the CSUN IGV Team. We believe that with our simple yet refined mechanical design, our dependable electronic layout, and our sophisticated sensors and programming, LinBot will be very successful in this year's Intelligent Ground Vehicle Competition. We also believe that our design innovations, especially the "Shared Variable Engine", will set LinBot apart and establish new standards in the field of autonomous robotics.