Team Land ROOver: The University of Akron

Team Members:

(All Team Members are Senior Electrical Engineering Students)

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Faculty adviser statement:

I certify that the engineering design in 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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Land ROOver

1. Introduction

Land ROOver is the University of Akron's first vehicle entry for the Intelligent Ground Vehicle Competition. Akron's eight-person team was formed through the combination of two sub-groups of The Electrical and Computer Engineering Department's senior design program. The motor group focused on the power system, motor control gateway, and navigation algorithms; the sensors group gathered the information of Land ROOver's surroundings for vehicle navigation.

2. Vehicle Architecture

The team began with a pre-fabricated vehicle base. The motor group developed a controller gateway that used encoders and communicated with the stock motor controller. The students also utilized two power systems: one to power the vehicle motors and the other for sensors and components. The sensors group used a camera, a differential global positioning system (DGPS), a digital compass, as well as a scanning distance measurement system (SDMS) to determine the vehicle's environment. A laptop running LabVIEW was shared by both groups to perform the required information processing and vehicle control.

2.1 Hardware Design

The students received a pre-fabricated wheelchair from Invacare, which minimized the project's mechanical design and left sufficient time for software development and testing. In addition, using a manufactured base greatly improved the reliability and durability of the vehicle drive train on outdoor terrain. The minimal amount of hardware that was required included a steel frame and PVC mounting structure to hold and enclose the components and wiring. The frame was designed with a shelf system to allow for easy access of components in order to quickly make modifications. The shelving and steel frame was bolted to T-nuts that were supplied with the wheelchair. Angle iron was used to secure a place for the payload as well as the component batteries underneath of the vehicle.

The laptop sits on the top shelf so that it can be easily opened to make software adjustments. The bottom shelf holds the power system components as well as the DGPS receiver. The rest of the components lie on the outside of this steel frame. The two microprocessors (one each for the SDMS and motor controller gateway) lie inside a box on the front of the vehicle, which also holds the SDMS components for object detection. The camera, DGPS antenna, and digital compass are situated on the PVC structure to receive the best sensor data. Figure 2.1 is the overall block diagram for the Land ROOver. One may notice in this figure the two separate power systems. The team chose this approach in order to maintain the integrity of the existing wheelchair electronics. In addition, this separation ensured that noise from the motor power system would be isolated from the sensitive sensors and components.

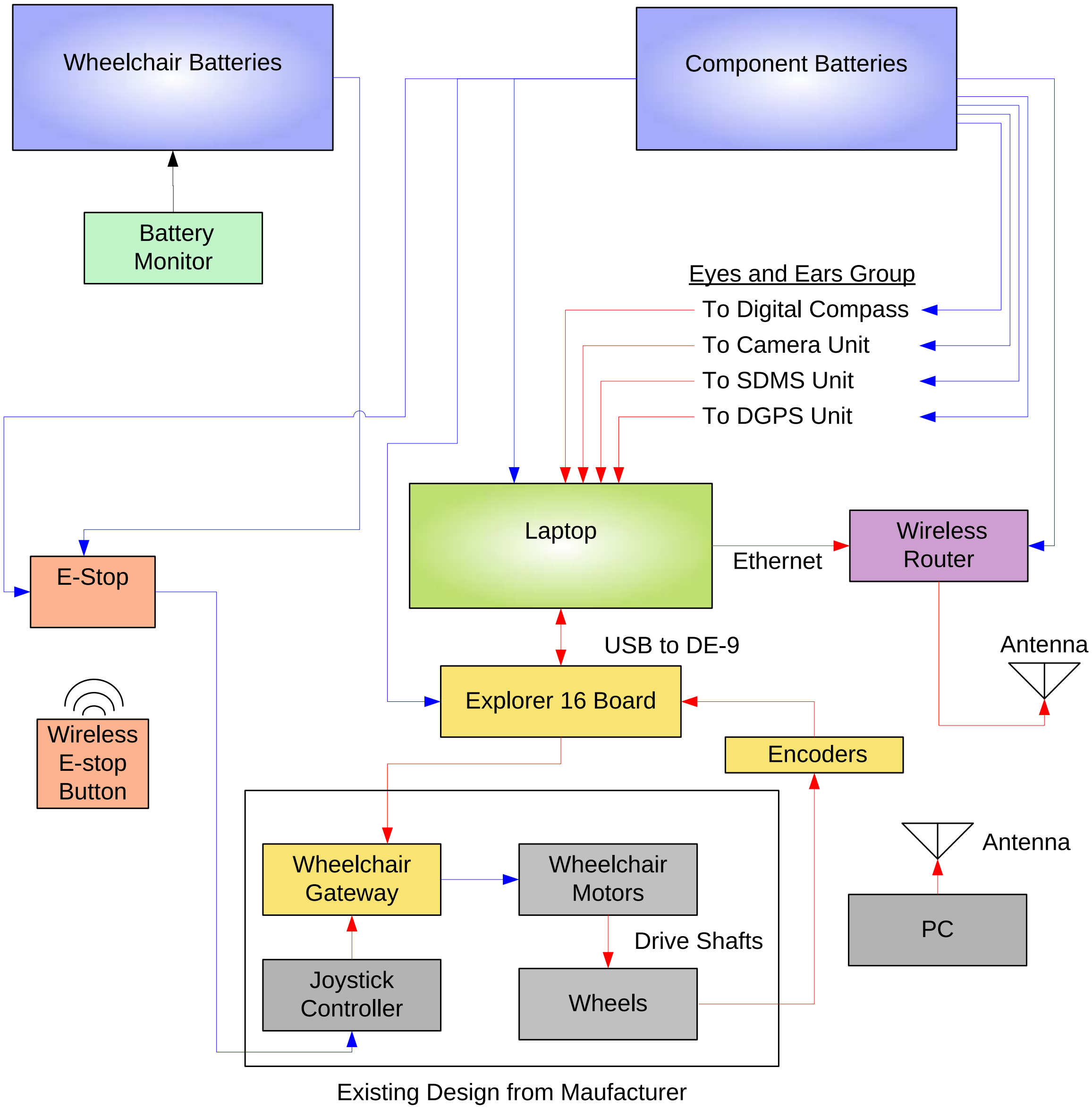


Figure 2.1: Overall Block Diagram for the Vehicle

2.2 Software Design

The computing for the Land ROOver was written in two different languages. The competition algorithms, most sensor data, and user interface have been programmed using

LabVIEW. However, the motor controller, SDMS and camera use C for their individual component programs. The motor controller and SDMS code is programmed on two PIC24 microprocessors and communicates with LabVIEW on the laptop via UART. The camera code is contained on the laptop and passes information to LabVIEW through file I/O. Figure 2.2 is the system software flow diagram and the order in which each device is called upon, as well as their initialization pattern. In the figure, the block labeled autonomous algorithm contains the code for both competition courses, and these are explained in further detail below.

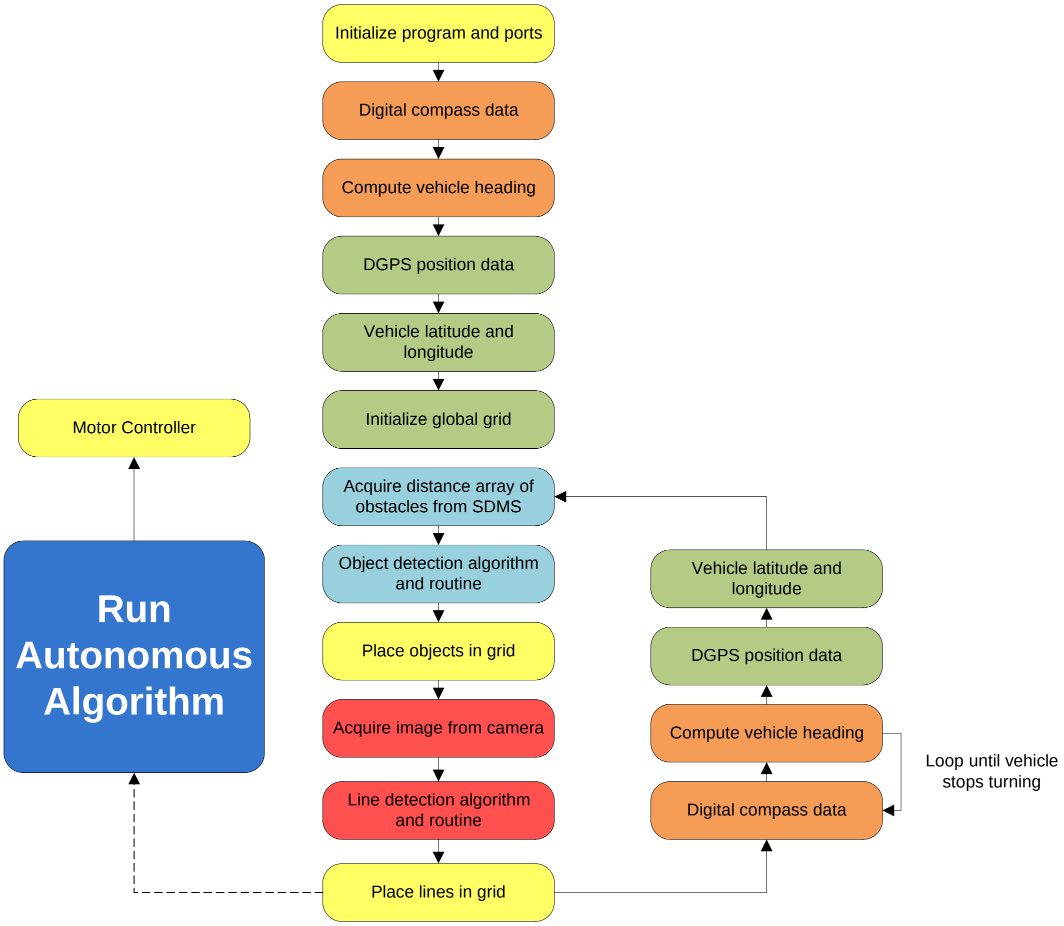
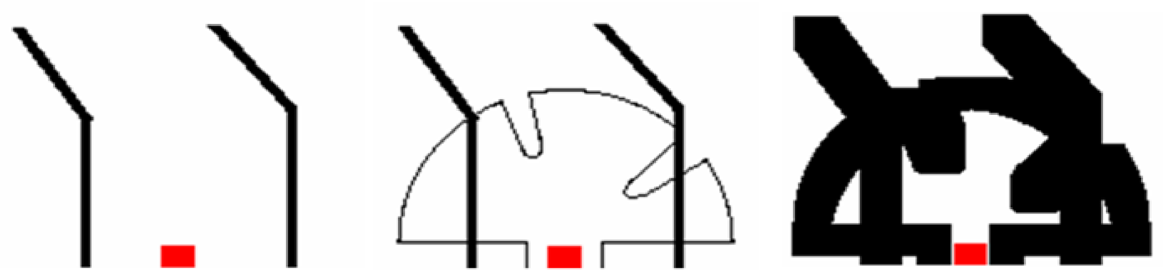


Figure 2.2: Overall System Software Block Diagram

3. Lane Following

3.1 Pathfinder Algorithm

In order for the autonomous vehicle to navigate around the course, an algorithm was created to tell the vehicle where to go. There were many different ways to accomplish this. To keep the amount of data being transferred between the two teams to a minimum, the “picture” of what is in front of the vehicle was saved as a global binary array. This will contain the compiled information from the camera, Scanning Distance Measurement Sensor (SDMS), Global Positioning System (GPS), and digital compass. A ‘1’ will represent an obstacle or a line on the course, and a ‘0’ will represent clear space. The grid’s direction is fixed based on the direction the vehicle is facing. Figure 3.1 shows the algorithm sequence in graphical form.



1: Input Lines

2: Input SDMS and ‘OR’ with Lines

3: Stretch by a factor of 8

4: Move forward 20cm

5: Check Angles

6: Find center of widest arc

7: Move 50cm towards the center of the longest arc

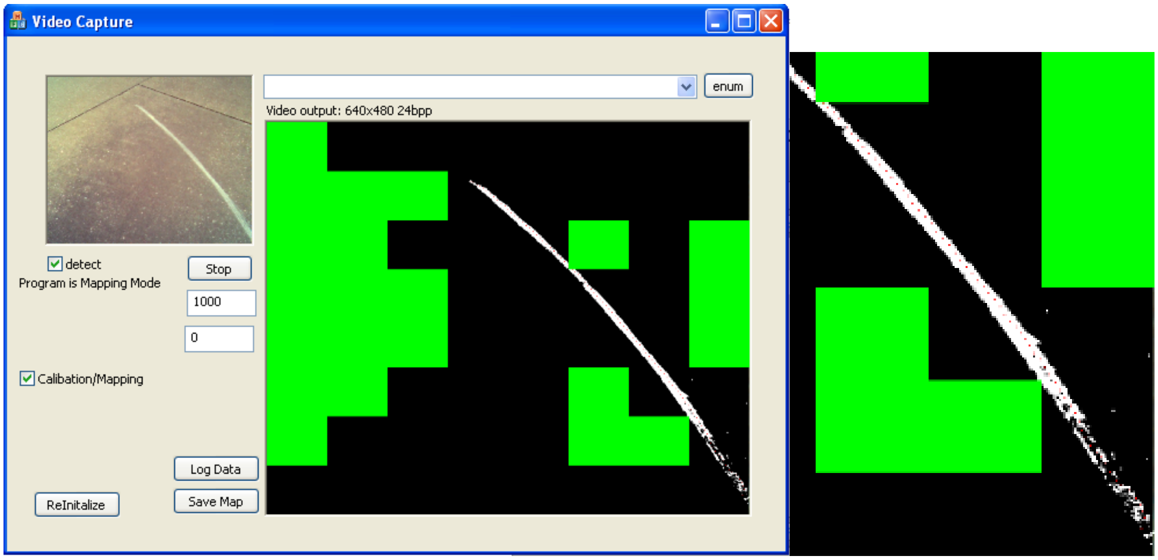
Figure 3.1: Progression of the Pathfinder Algorithm

The design algorithm works as follows: First the program checks to see if it can move forward 50cm, and then it moves forward if possible. Starting at the new vehicle location on the grid map, the program will draw lines at angles ranging from the start angle minus 70 degrees to the start angle plus 70 degrees. When the path reaches a cell that has an obstacle in it, the distance at that angle will be recorded in a 2D array. After combining the array, all the angles that have a corresponding distance less then 100cm are removed. The remaining angles are then compared to see how many grid spaces in a row it can travel. This generates another array containing the length of the arc and the start point.

The center of the longest arc is then selected as the best path. A distance of 20cm is then sent to the gateway at the corresponding angle. If all distances happen to be less than 100cm, then the greatest distance would be chosen as the correct path to take. As soon as the global array is updated, the new path instructions are sent to the gateway updating the previous instructions.

3.2 Image Processing

To identify the image, a center of mass approach was used. Every pixel of interest (white and yellow) has a mass and all other pixels have no mass. In order to find the first point in the line segment in the image, the code starts at the bottom of the image and looks for a white line. When the code finds a white pixel, it uses a search-box to see if the pixel is actually a line (number of white pixels in the search box). If the pixel is not a line, the search-box is masked out and the search continues. Once the first point in the line is found, a search-box checks for the center of mass of the pixels in the search-box. Once the center of mass is calculated, the code moves to the pixel that is the center of mass. The code keeps going to the next center of mass until the code moves up the whole image. This technique allows for the direct following of the lines. Looking at Figure 3.2, the red dots show all of the center of mass pixels used for the line analysis.



Video output: 640x480 24bpp

☑ detect

Program is Mapping Mode

1000

0

☑ Calibration/Mapping

Figure 3.2: Video Capture Interface of Line Detection

Now that the lines have been identified in the image, using the focal length of the camera, the line's length and orientation can be calculated. The lines found will be stored in the computer's memory as points. The points are all connected together in a list to create a long line. As more of the lines are captured, more points are added to the list. There will be two lists of points: one is the left line and one is the right line. The updated course points will be connected to the previously found path on the grid to determine where the vehicle can travel. Checking the found line segment's angle with respect to previous lines and if it is close to the left or right line helps to create a continuous path.

4. Waypoint Navigation

To compete in the navigation challenge, the team's algorithm takes the eight GPS waypoints and chooses the shortest distance to travel to each of the waypoints. Inputs to the system include current GPS coordinates, current desired waypoint coordinates, and heading information. The output solely includes grid coordinates in X and Y directions to send to the motor controller. In order to attain information about obstacles in the path between two points, this algorithm determines the straight-line approximation between the two waypoints in question. It will then iterate through and compare all of these locations to the array of known obstacles. Also, information about the course perimeter and starting box are appended to the end of the known obstacle array. If no obstacles fall within the range of these values, then the GPS waypoint grid coordinate will be returned as the output to the motor controller. When an obstacle is encountered, a degree shift will be added to the current direct path and then another check will determine if any obstacles are present using the new straight line. If no obstacles are found, the shifted GPS waypoint grid coordinate will be returned as the output to the motor controller. Once the vehicle has entered into the range around the desired waypoint, it will continue on to the next waypoint and eventually end up at the starting box. This program structure can be seen in Figure 4.1. The GPS program arrives at the waypoints within a 70 cm diameter range of the waypoint, which is well within the smaller Mesa radius of two meters.

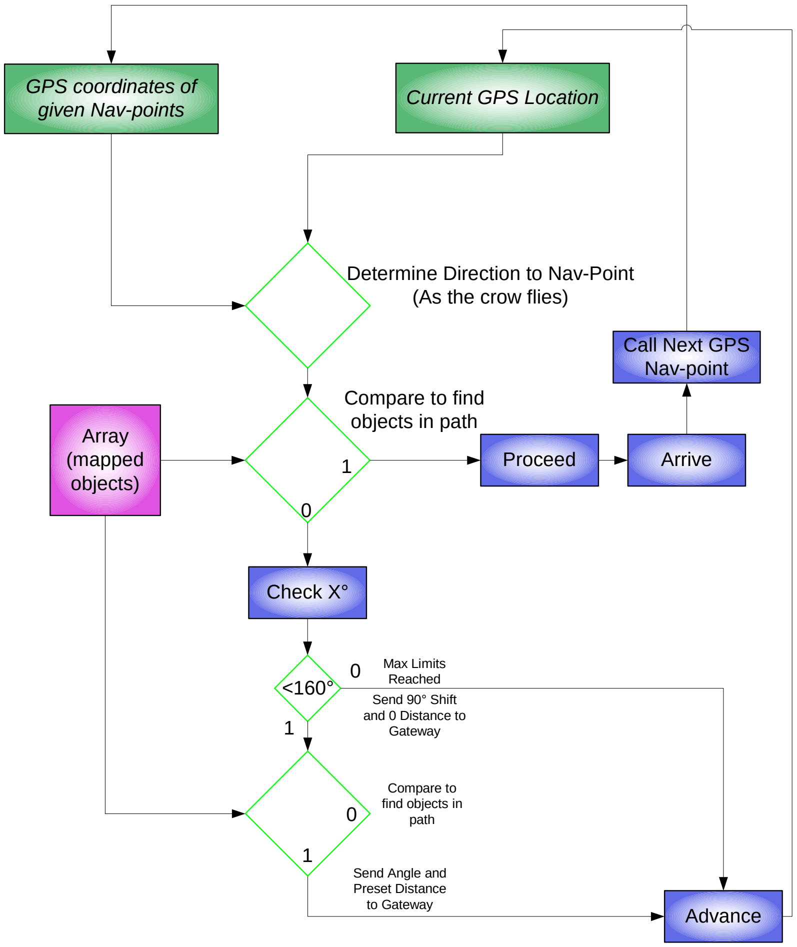


Figure 4.1: GPS Control Algorithm

5. Innovation

Since this is the first year The University of Akron has ever submitted a vehicle to the IGVC, the entire vehicle is in itself an innovation. However, after noticing several trends from previous years competitions, the U of A team has implemented one major innovation separate from most teams. Instead of using a laser range-finder or similar means for obstacle detection, the team has designed and implemented a scanning distance measurement sensor (SDMS). The SDMS is basically two IR sensors mounted atop a servomotor which rotates the two sensors to take distance measurements at angular positions along the rotated path. The servomotor rotates these IR sensors through an angular field of 180° in order for the sensor to take distance measurements.

The Sharp 2Y0A02 IR sensors yield information about the distance to an object off which the sensor has pulsed infrared radiation. The sensor provides this information in the form of an analog voltage that can be cross-referenced with a corresponding distance. The maximum distance that these IR sensors can detect obstacles is three meters (9.84 ft.). The two IR sensors are positioned 90º apart so that cross talk between sensors does not occur. The servomotor and sensors are controlled and sampled through a microprocessor, which builds the measurements taken from the IR sensors into an array to be sent later to the central processing unit. The data is then transmitted via UART into a LabVIEW virtual instrument.

Once the array describing distances to obstacles has been sent to the computer, LabVIEW translates the distances and their corresponding angular positions into Cartesian coordinates. The Cartesian coordinates are then connected together using a point to line algorithm. A grid of 5x5 sq. cm is then created from the information returned from the SDMS that describes an area void of obstacles in the field measured in front of the vehicle. The control algorithm is then able to make driving decisions based on this grid.

After extensive testing of the SDMS, it was determined that the refresh rate of the unit is nearly 0.8 seconds. Also, the amount of filtering required for the device to operate in direct sunlight attenuates the infrared radiation signal so greatly that the sensors are only accurate to within approximately 1.52 meters (5 ft.) of the vehicle. Moreover, as testing proved, the SDMS is quite susceptible to plant life, which confuses the sensor’s data measurements.

The physical structure that the SDMS utilizes can be seen in Figure 5.1. The figure shows that the SDMS is covered by a metal structure covered with black matte paper, which helps to decrease erroneous infrared radiation into the sensors, and blocks direct sunlight from the sensors. Also, Figure 5.1 shows that the sensors utilize an IR filter from a VCR receiver head.

For illustration purposes, a setup of a test field for measurement was made and the test field can be seen in Figure 5.2.

Figure 5.1: Mounting of SDMS

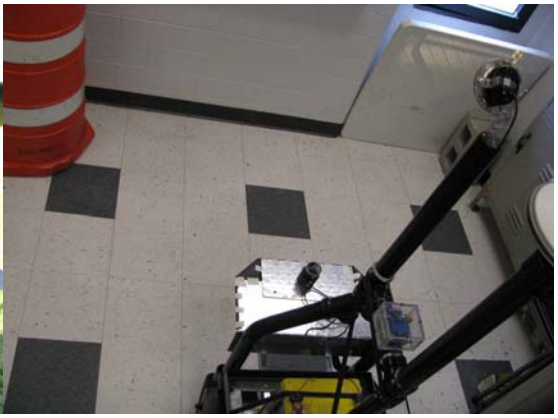


Figure 5.2: SDMS Test Field

The floor tiles seen in the test field in Figure 5.2 are ten-inch square tiles. The voltage returned from the IR sensors can be seen in Figure 5.3. The figure shows that the sensors readings are periodic and that the time it takes the SDMS to measure one entire field is approximately 0.8 seconds.

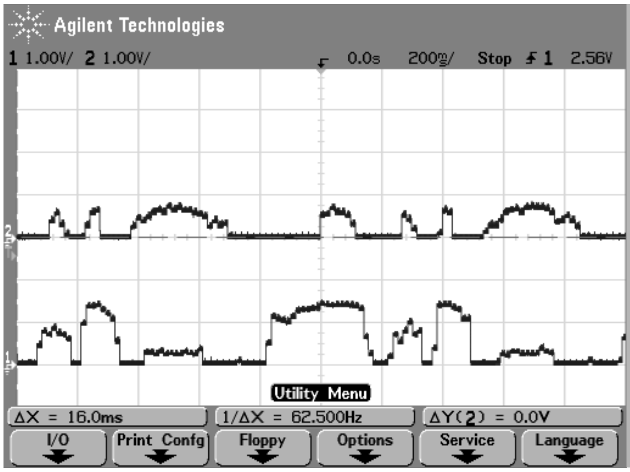


Figure 5.3:
SDMS IR Sensor Measurements

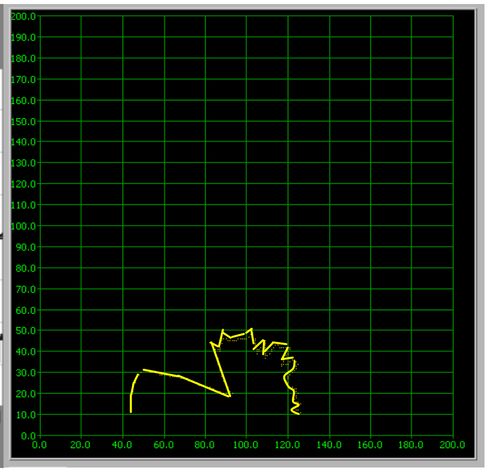


Figure 5.4:
LabVIEW GUI Illustrating Test Measurements

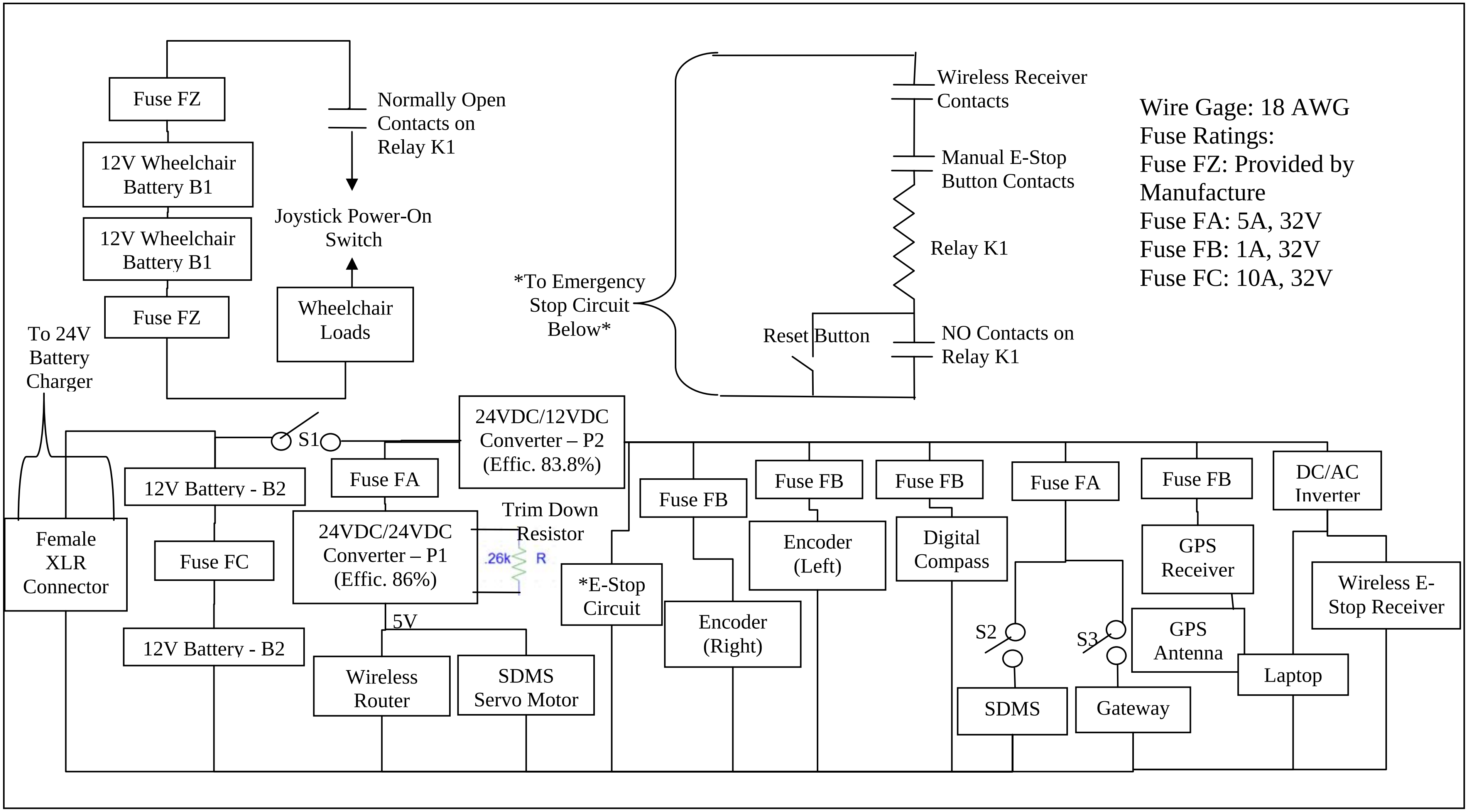
The LabVIEW GUI used to illustrate the measurements taken from the IR sensors and sent over the UART peripheral can be seen in Figure 5.4. In this figure, the SDMS system is measuring the location to obstacles in terms of five-centimeter blocks. If one were to evaluate closely the test field, they would see that the measurements taken are quite close to the actual field setup. In general, the SDMS is accurate to within 20cm.

6. Power System

Two separate power systems have been implemented for the Land ROOver vehicle. The first is the original wheelchair power system, which is 24V system supplied by two 12V series connected batteries. The wheelchair electronics have only been adjusted for the emergency stop circuit and motor controller. These have both been implemented on the joystick of the wheelchair. The second power system consists of two smaller 12V batteries in series, for 24 volts total, and contains two Vicor DC/DC converters to take the voltage down to 12 and 5VDC. The 24-12VDC converter is rated for 300W at 87% efficiency and the 24-5VDC is rated for 100W at 86% efficiency. Also, a 12VDC to 115VAC inverter is onboard to supply power to the wireless receiver and laptop to extend testing times. Figure 6.1 is the schematic for both power systems and a list of the fuse values. The wheelchair came with an XLR connector for easy charging of the batteries, so the team installed an identical connector that would be appropriate for charging the additional component batteries.

To make sure safe operation of the vehicle is maintained, an emergency stop button has been implemented on the wheelchair joystick. This emergency stop circuit can be seen in the top middle section of the power system schematic shown in Figure 6.1. When either the wireless or manual e-stop button is pushed, a relay coil is de-energized. Once this relay is de-energized, its contacts open which are in series with the joystick power-on circuit. The joystick power-on circuit removes power from the motors and motor controller and the vehicle comes to a quick and complete stop. Our initial design had specified a wireless receiver evaluation board from Radiotronix to act as our wireless emergency stop system. Due to numerous electromagnetic compatibility issues, including impedance line mismatches, poor positioning of the receiver, as well as conducted emissions from the emergency stop lines, the team decided to use an off the shelf garage door opener, which requires the use of our DC/AC inverter.

The additional component batteries are 10.5 A-Hrs and the current draw without the DC/AC inverter connected is roughly two amps. The wheelchair batteries are rated at 40A-Hr. When testing, the inverter is connected to an extra battery that rests where the payload will be positioned; combining these three power systems has allowed the team to test for greater than four hours at a time. During the competition, the inverter will be connected to the additional component batteries and will last approximately a half an hour.



Wire Gage: 18 AWG
Fuse Ratings:
Fuse FZ: Provided by Manufacture
Fuse FA: 5A, 32V
Fuse FB: 1A, 32V
Fuse FC: 10A, 32V

Figure 6.1: Schematic for Wheelchair Power System, Additional Component Power System and E-Stop Circuit

7. System Integration

7.1 Design Process

Since The University of Akron's Electrical and Computer Engineering Department has a strenuous senior design class, both the competition and this program governed the design and implementation process. The team and preliminary block diagrams were organized in the spring semester of 2007. The design portion of the project was completed in the fall of 2008 and implementation and testing occurred in the last semester, which was spring 2008. The team visited last year's competition and determined we needed numerous hours of testing as well as prefabricated or off-the-shelf components to minimize implementation time. Due to the nature of our team make up, being split into two sub-teams, integration was complicated but steady. Overall, the eight-person team spent approximately 2800 hours designing, constructing, and testing the Land ROOver. At first, we tested each component individually for functionality, and this turned out to be excellent. However when the time came for full integration, some unforeseen environmental factors set the team back and limited testing time.

7.2 Performance

The speed of the wheelchair is hardware governed at 5MPH, and testing speeds have reached approximately 4.5 MPH on grass. The manufactured wheelchair also has the ability to climb ramps well over 15º, which is the highest slope of a ramp in the competition. Testing proved that the vehicle could climb a 30º slope. Wireless emergency stop activation has been tested at 70 feet and found to function properly.

Additionally, testing has been performed for both the autonomous and navigation challenges and will continue until the competition. The team has constructed a mock autonomous challenge course and can demonstrate limited lane following and obstacle avoidance capabilities. The team has also been testing the navigation challenge on an additional mock course, shown in Figure 7.1, which is approximately one-ninth the size of the actual competition course. Tests led the team to develop a more fluid-motion control strategy in order to cover more area in less time.

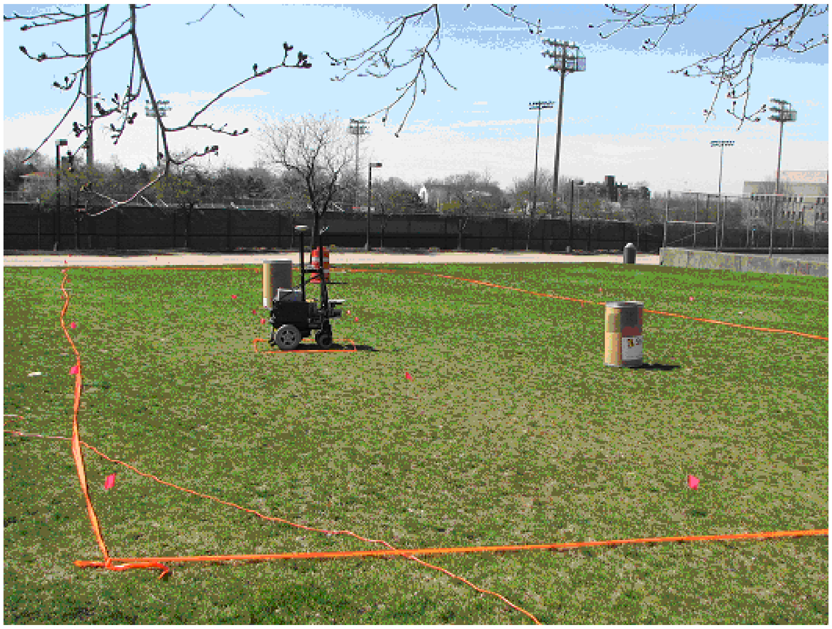


Figure 7.1: Navigation Challenge Test Course

7.3 Budget

As a first year team, many expenses were incurred to develop the Land ROOver. A detailed list of these expenses is given in Table 7.1. Additional components that are not included in the table below are A/D Converters, Ethernet Cable, Emergency Stop Button, Insurance Coverage, Terminal Blocks, DIN Mounting Rail, 16” Drawer Slides, Female XLR Connector, Fuse Block. Each of these components were donated to the team and therefore were no cost, however their duplication cost was unknown so it was not included in the budget. Similarly, any price that has $0 under the “cost to team” was donated.

Table 7.1: Land ROOver Vehicle Budget

Qty.	Item	Duplication Cost	Cost to Team
5	Sharp GP2Y0A02YK IR Sensor	$33.00	$165.00
1	Sensor Housing Unit	$5.00	$0.00
2	Standard Servo	$30.00	$30.00
4	IR Sensor Wiring Harness	$16.00	$16.00
2	PIC24 Explorer 16 development board	$700.00	$0.00
1	Differential Global Positioning System (DGPS)	$13,500.00	$2,700.00
1	OmniSTAR HP service	$2,000.00	$0.00
2	Sparton Electronics Digital Compass	$850.00	$0.00
2	4-port RS-232 to USB Hub Bus/Self Powered for Notebooks	$13.98	$13.98
1	Creative LivePro Digital Camera	$50.00	$0.00
1	Diamond Plate Aluminum Sheet	$35.00	$35.00
2	Black PVC Spray Paint	$6.00	$6.00
4	PVC Caps	$3.96	$3.96
2	Y Connection PVC Tube Connectors	$5.96	$5.96
1	20 ft. of PVC Tubing	$30.00	$30.00
48	“Fear The Roo-Bots” T-Shirts	$602.11	$602.11
1	Wheelchair Base	$6,829.00	$0.00
1	Laptop	$1,067.00	$0.00
1	Wireless Router	$44.99	$0.00
2	Optima Batteries	$347.60	$0.00
2	Lead Acid Batteries	$158.62	$0.00
1	USB Extension	$9.99	$9.99
1	USB to Serial Adaptor	$12.20	$12.20
2	Angular Encoder	$1,060.00	$1,060.00
1	Paired Unshielded Cable	$170.92	$170.92
1	Relay	$3.77	$3.77
1	Wireless Receiver	$71.43	$71.43
1	12VDC/115VAC Inverter	$40.00	$0.00
2	Travel Expense: Gasoline	$117.64	$117.64
8	Travel Expense: Board	$504.00	$504.00
4	Travel Expense: Hotel	$725.98	$725.98
1	Competition Entry Fee	$250.00	$250.00
1	11 Gauge Sheet Steel	$49.63	$0.00
2	22 Gauge Sheet Steel	$20.98	$0.00
1	8-32 Machine Screws	$2.48	$2.48
1	10-32 Machine Screws	$2.88	$2.88
2	11 Gauge 2” Angle Iron	$20.74	$20.74
1	Power Box Enclosure	$63.62	$63.62
1	PIC Box Enclosure	$38.54	$38.54
10	Fuse 32V, 5A	$3.92	$3.92
10	Fuse 32V, 1A	$4.30	$4.30
3	Rustoleum Paint	$13.50	$0.00
1	RP-SMA Extension Cable	$6.99	$6.99
	Total	**$ 29,521.73**	**$ 6,677.41**

8. Conclusion

Since the University of Akron’s Land ROOver is a first time entry and everything but vehicle chassis was built from the ground up, more testing and many adjustments are needed. The team expected that a large amount of time would be needed for testing, but due to the senior design process through the school, the team’s progress was impeded. Construction of the vehicle did not begin until January 2008 and poor weather conditions in Ohio severely decreased testing time. Furthermore, the students did not expect unforeseen problems like electromagnetic compatibility or environmental issues. Additional resources for image processing and obstacle detection would have also been helpful and key for optimal performance. The complexity of these aspects was unexpected and the senior design process limited the allocation of additional resources. By the time of competition, the team expects Land ROOver to qualify and be competitive in both the autonomous and navigation challenges.