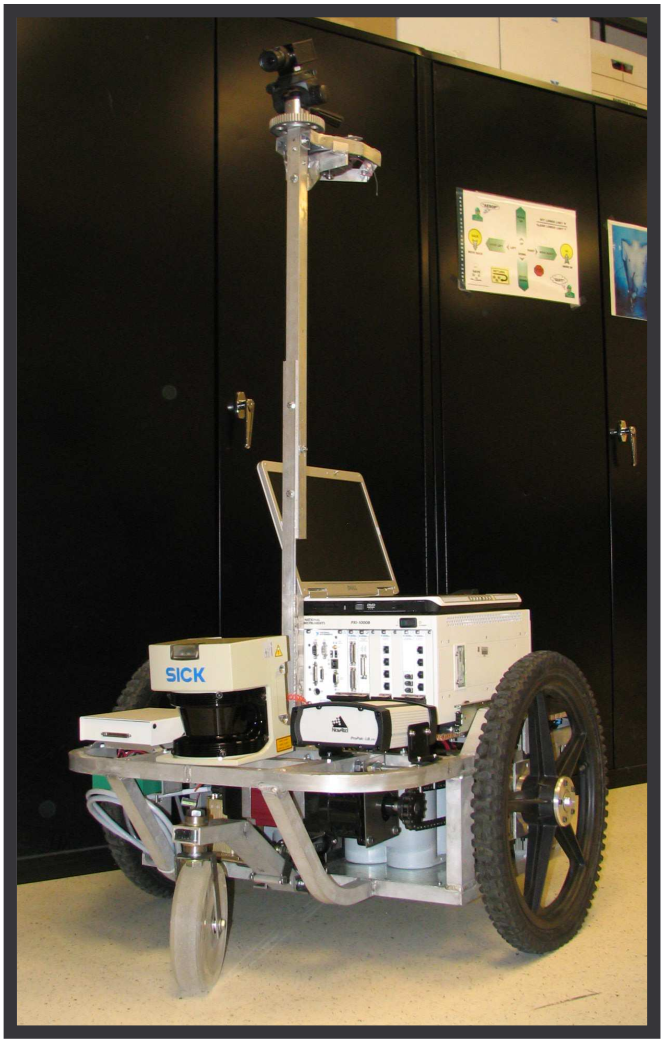
MI-1

California State University
Northridge



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Required Faculty Advisor Statement:

I certify that the engineering design of the vehicle described in this report, MI-1, 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 Cal State University, Northridge is proud to present Mobile Intelligence 1 (MI-1) for entry into the 14th Annual Intelligent Ground Vehicle Competition. We are excited to be a part of the first team from CSUN to enter into this competition. Our logo, seen on the right in Figure 1 and at the bottom corner of each page, is a brain with wheels as a symbol for Mobile Intelligence.

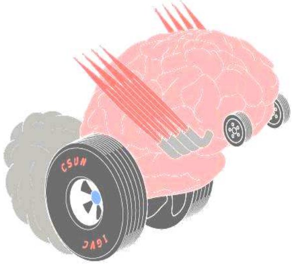

Figure 1: Brain Logo

We began this project about one year ago with great ambitions of having a fully functional robot for the competition in June of 2006. Being that this was CSUN's first attempt at building, programming, testing, and refining a fully autonomous robot, we had a lot of ground to cover. So, after twelve months of hard work, the CSUN IGV Team would like to introduce MI-1.

1.1 TEAM ORGANIZATION

Our team was divided into three sub-teams which can be seen in Figure 2:

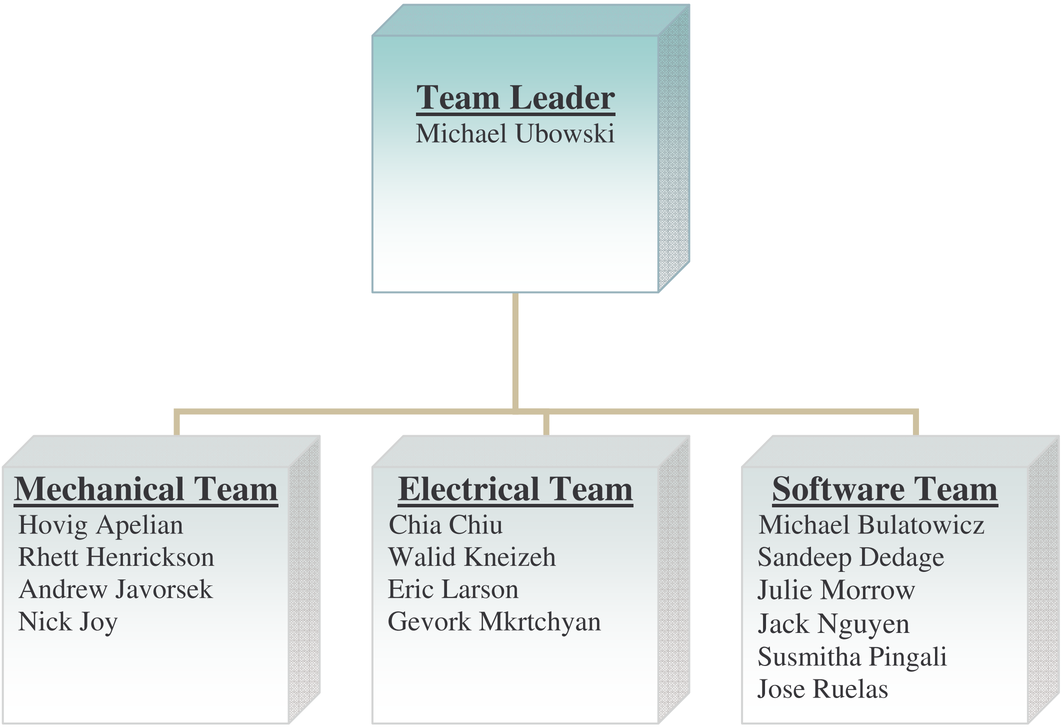

Figure 2: Team Structure

As the mechanical and electrical components were completed, some students switched to the software team to complete the code writing for the various sensors.

1.2 DESIGN INNOVATIONS

Even though this is CSUN's first attempt at an autonomous vehicle, we strove to have a design that was both innovative and functional. The first innovation is the unique mobile robot intelligence software. All of the software was designed and created specifically for this competition within a time span of 9 months. This software includes all of the motion control, sensor communication, vision perception, obstacle avoidance, and path planning for both the autonomous and navigation challenges.

The second innovation is a camera that is capable of panning to maintain a view upstream the course during the autonomous challenge. This allows the camera to always maintain a visual lock on the course boundary lines and sustain its desired heading.

The third innovation is a quick-connect coupler which allows the sprocket to easily disengage from the axle for transporting the vehicle and for testing the motors without turning the wheels.

2 MECHANICAL SYSTEM

2.1 MECHANICAL DEVELOPMENT

The mechanical development of the vehicle went through 4 distinct stages which are illustrated in Figure 3:

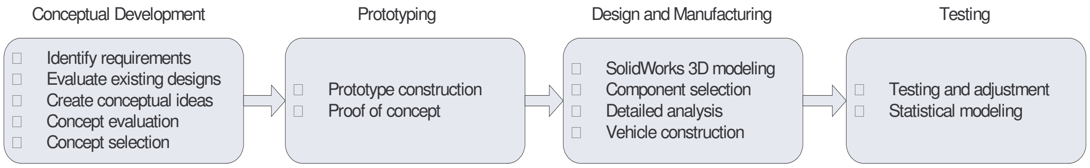

Figure 3: Mechanical Design Flow

2.2 CHASSIS

The chassis for MI-1 was designed to keep a low center of gravity. The size and position of the components were all taken into consideration and were designed around. The frame is constructed of 6063 T52 square aluminum tubing which has been welded together and then heat treated. This can be seen in Figure 4. The structure has been designed to support an evenly distributed load of up to 400 lbs.

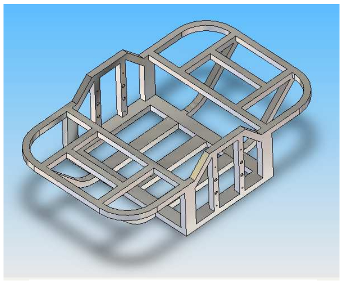

Figure 4: Chassis

2.3 WHEEL CONFIGURATION

The wheel configuration was also taken into consideration in the design of the chassis. The choice of differential drive set the base point for the wheel configuration. For higher stability, a four wheel configuration was chosen having the drive wheels located in the center with two castor wheels for support, one in the front and one in back.

2.4 MOBILITY

A differential-drive robot such as MI-1 has only one kinematic restraint on robot mobility. That restraint limits lateral motion of the drive wheels and makes the problem of vehicle control much simpler. A zero point turn radius is possible by driving the wheels in opposite directions at the same speed, and the sweep radius was reduced further by placing the drive wheels at the center of the vehicle.

2.5 DRIVETRAIN

Two Quicksilver 34HC-2 motors were selected to power the drive-train as shown in Figure 5. They are connected to Bison gearboxes having a gear ratio of 21:1. In order to reduce the width of the vehicle, it was decided to offset the motors from the drive wheels and use a chain to connect the gearboxes to the axle. This method allowed a reduction in the overall width by approximately six inches. In addition, it allowed the batteries to be mounted directly in the center which has the benefit of reducing rotational inertia during turns. Another benefit of this drive system was the ability to design in the quick-connect coupler shown in Figure 6. This allows the sprocket to easily disengage from the axle for transporting the vehicle and for testing the motors without turning the wheels.

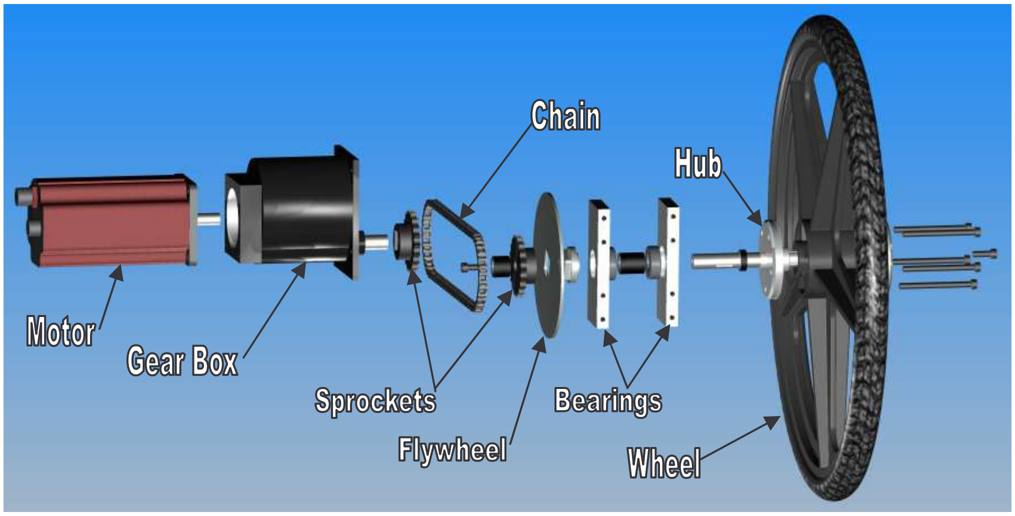

Figure 5: Drivetrain

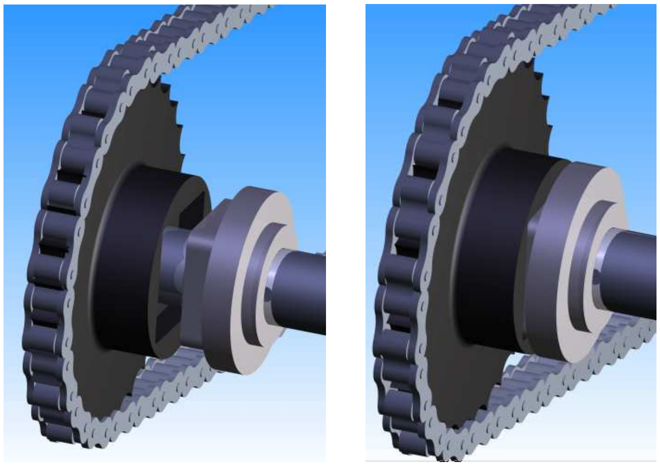

Figure 6: Quick-Connect Coupler disengaged (left) and engaged (right)

3 ELECTRICAL SYSTEM

3.1 SYSTEM LAYOUT

The following Figure 7 is a layout of the electrical system. The red lines represent +12 volts DC, the black lines represent the DC ground circuit, and the green lines represent 110 volts AC.

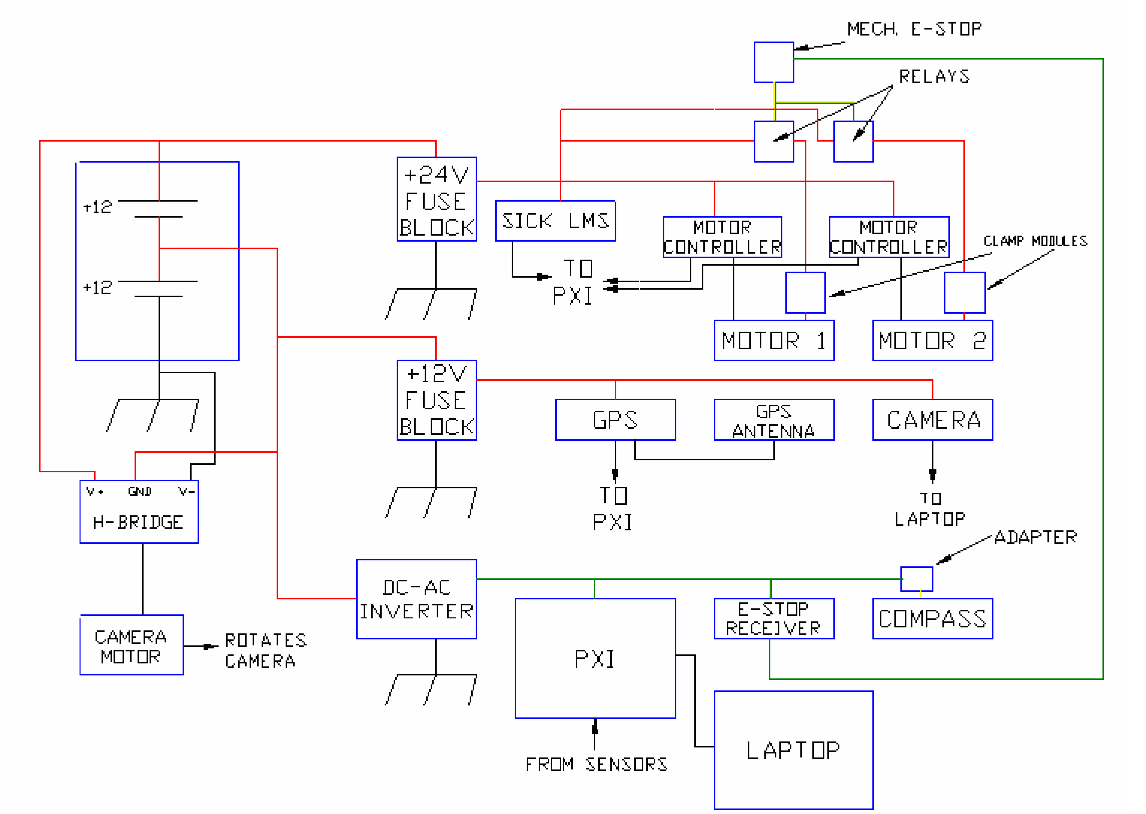

Figure 7: Electrical Layout

3.2 POWER DISTRIBUTION

The wiring of the vehicle was done with 4 different wire sizes: 24 AWG, 16 AWG, 12 AWG, and 8 AWG. Wiring from the batteries to the fuse-block was done with 8 AWG. This size wire was chosen because this is where the highest current would flow. It can easily handle 26A since it is a short run from the battery to the fuse-block.

The motors were wired with 12 AWG; this size wire is capable of handling the nominal 3A that the motors will draw. Furthermore, this size wire can handle the short period of 16.5A that will be drawn by each motor during acceleration. For components that draw 1A to 3A, such as the Laser Range Finder, 16 AWG wire will be used to supply power to them. Finally, for components that draw less than 1A of current, such as the GPS, 24 AWG wire is used.

In the IGV, there are components that require AC power, such as the Wireless E-stop, the PXI 8187 controller, and the laptop computer (whenever its battery is not charged). In order to provide power to these components, a DC to AC inverter, model number PW900-12, was installed. The inverter is capable of providing 900W of continuous power and 1800W of peak power, which is sufficient for the operation of MI-1. The laptop computer requires 150W of power, the Wireless E-stop requires less that 20W, while the PXI Controller needs 100W of power to operate. However, when the sensors are connected to the PXI controller, the power required by it increases. It can have a maximum output of 300W. Hence, the PXI controller is going to require a total 400W maximum to run it and the connected components/sensors. Therefore, the total AC power required is 570W, which is well below the 900W continuous power rating of the power inverter.

3.3 BATTERIES

MI-1 is powered by a 24V system. Two Optima D34 batteries, seen in Figure 8, connected in series create the required 24V system. These batteries were chosen due to their high current capacity, relatively light weight, and their ability to start vehicles with large accessory loads. Each battery has a capacity of 55 A-h. Since the IGV will be drawing 26A nominally, the batteries are able to provide approximately 2 hours and 7 minutes of power.

Figure 8: Batteries

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 256MB of RAM. The PXI 8187 main computer uses a combination of different types of interfaces which include RS-232, RS-422, Fire Wire, Ethernet TCP/IP, and motion controller card to provide maximum interface flexibility. The main controller itself interfaces with the expansion cards using the PXI 1000B chassis. Figure 9 (below) provides a summary of the interfaces for each individual subsystem.

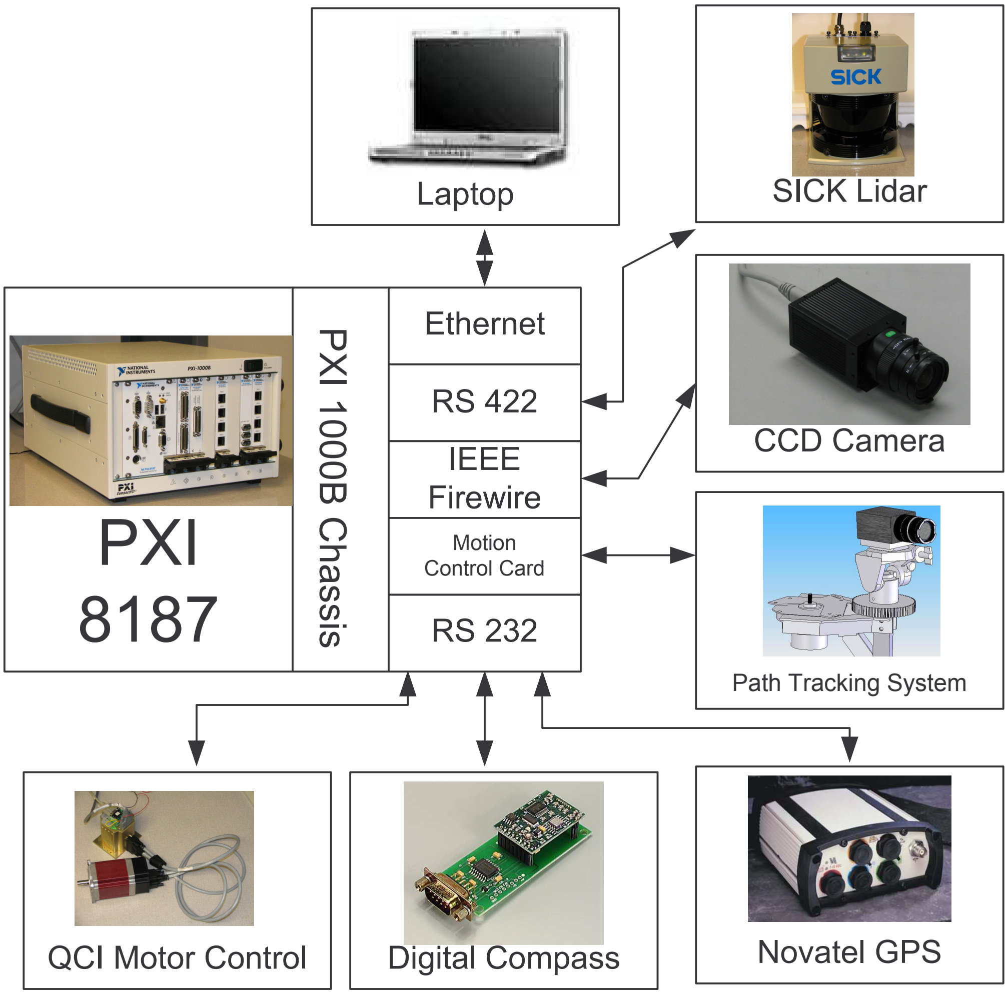

Figure 9: Interface Layout

4.2 DIGITAL CAMERA

Figure 10: Camera

MI-1's vision system consists of a high-resolution digital camera by Imaging Solutions Groups seen in Figure 10. This is a high performance unit with a 1.3 mega pixel CMOS image sensor. The ISG LW1.3 has resolution capabilities of up to 1280X1024, selectable frame rates of up to 30fps, IEEE 1394 data interface and a 4.5-12.5mm Vari-Focal lens. The vision system will detect and process the necessary data of the lines which the robot is specified to stay within.

4.3 GPS

The GPS system used in MI-1 is the Novatel Pro-Pak LBplus system seen in Figure 11. 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 11: GPS

4.4 LASER RANGEFINDER

MI-1's main source of obstacle detection is a SICK LMS291-SO4 laser rangefinder seen in Figure 12. This device is capable of scanning a range of 180º in 0.25º increments, measuring distances up to 80m away. The settings used for MI-1 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 8m will not be considered by the path-planning 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. The path-planning program requires an x, y array

Figure 12: Laser Rangefinder

of obstacle points, offset away from the actual location of the obstacle the radius of the vehicle. This is managed by turning each obstacle point into eight points circling the original point.

4.5 DIGITAL COMPASS

Using the Honeywell HMR3300 digital compass seen in Figure 13 MI-1'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.

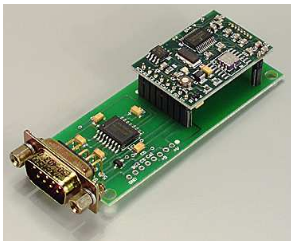

Figure 13: Compass

4.6 MOTOR CONTROLLER

The motor controllers used are the Silver Nugget N3 M-Grade controller/drivers seen in Figure 14. 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.

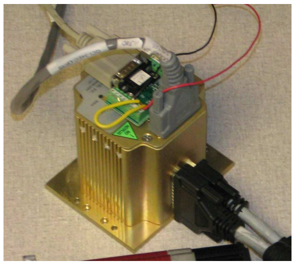

Figure 14: Motor Controller

5 SOFTWARE

5.1 DEVICE COMMUNICATION SOFTWARE

All software for MI-1 was developed using National Instruments LabView 7.1. This software made subsystem communication much easier to develop using the built in functions. All of the camera, serial communications, motion control, and data acquisition software was quickly developed using the built in functions. 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. When the image is first acquired by the ISG Firewire camera, the image is split in half so that each side of the image contains either the left or right boundary line. It then passes through a threshold filter which separates the lines from the grass and other noises. 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 15 and 16:

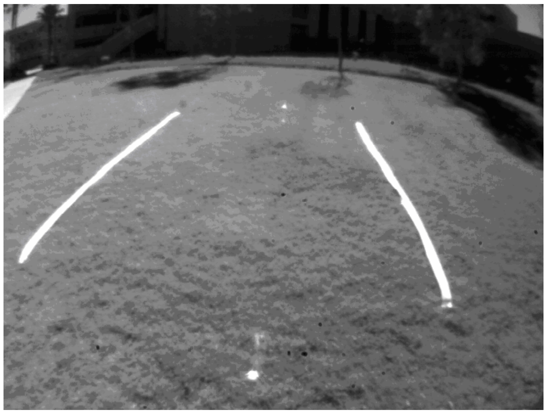

Figure 15: Before Line Detection

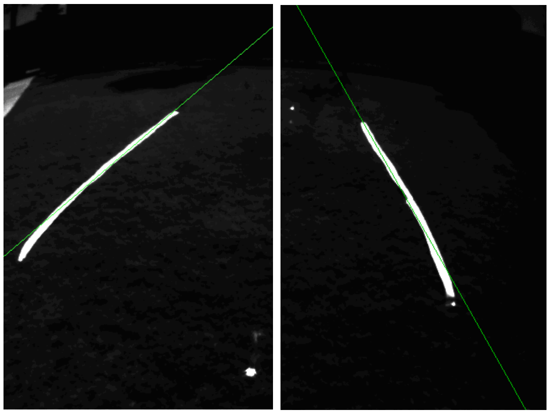

Figure 16: Split Images After Line Detection

During the section of the course where dashed lines occur, MI-1 will use the solid line that is visible to predict the location of the missing line. An algorithm will create a line offset 10 feet away from the solid line. The direction to offset will be determined from what side of the camera the solid line is located. For example, if the solid line is on the left the new line will be offset to the right.

One of the issues that were seen from previous robots was their ability to track the boundary lines when it is not pointed in the direction of the path. The "Path Tracking System" (PTS) was developed to keep the course path in the camera's line of sight at all times. The PTS uses LabView in conjunction with the NI PXI 7350 motion controller to control a servomotor and pan the camera continuously, allowing the camera to always be pointing down the trajectory path. The integrated encoder in the servomotor enabled for

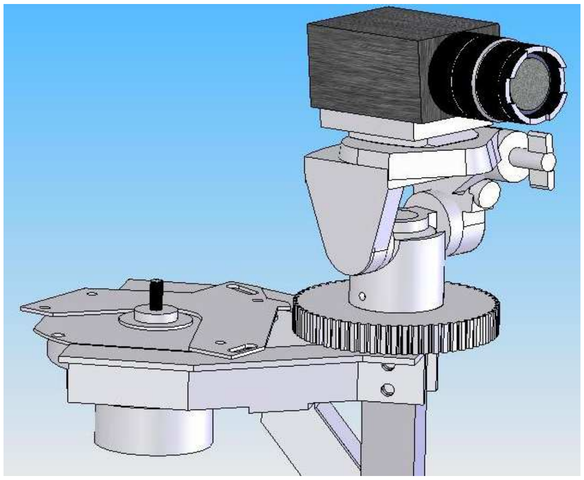

Figure 17: "Path Tracking System"

proper transform of the boundary and trajectory lines from the camera frame into the robot global frame. Figure 17 shows the mechanical system for the PTS where a 24V servomotor made by Japan Servo is used to pan the camera.

5.3 OBSTACLE AVOIDANCE AND PATH FINDING

MI-1 uses the laser range finder to build a Cartesian style occupancy grid map around itself. The laser rangefinder, which outputs angle and distance points, is used for obstacle avoidance. The raw data is converted by the software to x,y coordinates on the local reference frame. The path-planning program requires an x,y array of obstacle points. Eight points are created around each obstacle point offset by the radius of the robot. This is done because the robot sees itself as a dimensionless point on the occupancy grid. This new array is then fed back to the path-planning program. Filled cells are obstacles and unfilled cells are clear. This map is then used to determine incremental steps towards the desired occupancy grid goals. Every time MI-1 completes a full sensor update cycle the map is rebuilt without the use of pervious obstacle position data. The process for finding a path on the occupancy grid is a grass fire algorithm. Occupancy grid goal cells are usually located on the edge of the map, pointing to the next waypoint relative to MI-1 or the goal point found by the vision system during the autonomous challenge, with MI-1 being at the center. The grass fire algorithm fills in empty cells with numbers representing the distance to the goal until all of the cells around MI-1 are filled. Then a path finding algorithm outputs a cell to cell path based on the information provided in the grass fire algorithm, see Figure 18 below. The output cell array is then converted to discrete x and y coordinates. These discrete coordinates represent the incremental steps towards the desired occupancy grid goals.

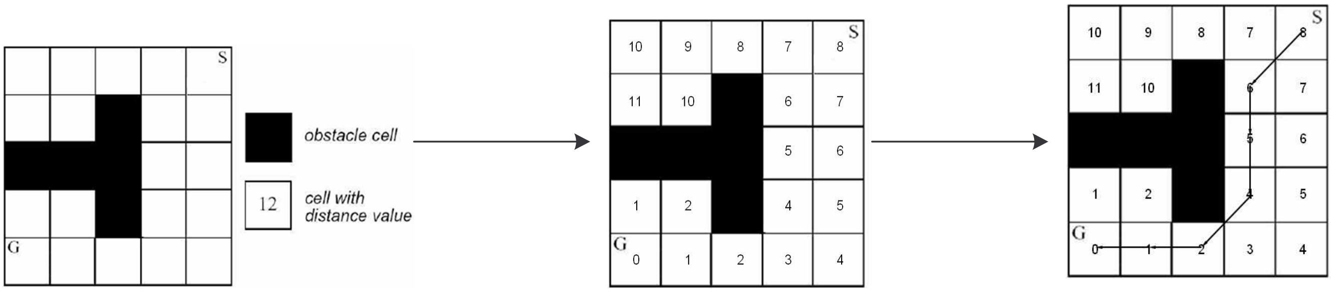

Figure 18: Grass Fire Path Planning Example

5.4 AUTONOMOUS CHALLENGE

MI-1 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 and finding the position of an occupancy grid goal. The main sensors used in the autonomous challenge are the laser ranger finder and the digital camera. MI-1 uses its vision software to track the course boundary lines to create a virtual carrot on a stick to guide the robot in correct direction. When obstacles are detected within the occupancy grid, MI-1 will find the path to the desired goal point each time it builds a map. All of the motion control is controlled using a closed loop trajectory generation program.

5.5 NAVIGATION CHALLENGE

In order to complete the navigation challenge, MI-1 uses an algorithm very similar to the one used in the autonomous challenge. The main difference is that the vision system is completely removed form the program. First, we use our own custom algorithm for finding the shortest path between all the waypoints. This information is then input into MI-1 to define the path it will take during the competition. Then using the DGPS, digital compass, and motor encoder feedback, MI-1 localizes and finds the direction to the first waypoint. While moving, MI-1 uses the encoder feedback to localize under short distances while waiting for DGPS and digital compass updates. Once the DGPS and compass have given their respective position and heading estimates, this information is then passed into a Kalman filter which provides a localization estimate with a smaller standard deviation than any one sensor by itself. This process helps MI-1 to localize with very high accuracy. Aside from the localization process, MI-1 uses the laser range finder to build a local occupancy grid map around itself. Just as in the autonomous challenge, when obstacles are detected within the occupancy grid, MI-1 will find the path to the desired goal point each time it builds a map. All of the motion control is controlled using a closed loop trajectory generation program.

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 CLIMBING

MI-1 has the ability to climb an incline of up to 30 degrees by the motion of the front and rear castor arms. The motors are capable of driving the vehicle up a 30 degree incline at 1.3 mph.

6.3 REACTION TIME

MI-1 is limited by the slowest sensor update and processing time for the path planning algorithm. This amount of time has been estimated to be approximately 1 second. At 5 mph the robot will move slightly over 7 feet before reacting.

6.4 BATTERY LIFE

The robot requires an average of 26 continuous amps to operate and the two Optima D34 batteries have a reserve capacity of 55 amp-hours each. Since the batteries are connected in series, the robot has a theoretical run time 55/26 hours or 126 minutes. In order to create as little stress on the batteries as possible, each set of batteries will only be used for a maximum of 60 minutes before being recharged.

6.5 OBSTACLE AVOIDANCE

The laser rangefinder, which outputs angle and distance points, is used for obstacle avoidance. The points are observed by the software in x,y coordinates on the local reference frame. The path-planning program requires an x,y array of obstacle points, offset away from the actual location of the obstacle the radius of the vehicle. This is done by turning each obstacle point into eight points circling the original point. This new array is then fed back to the path-planning program.

6.6 WAYPOINT ACCURACY

MI-1 uses differential GPS during the navigation challenge to achieve an accuracy of at least .1 meters while localizing. In combination with the encoder feed back from both servo drive motors and the digital compass, the waypoint accuracy will be less than .1 meters through the use of a Kalman filter.

7 SAFETY CONSIDERATIONS

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 MI-1.

MI-1 includes two forms of emergency stopping, wireless and manual. For the wireless e-stop, a Radio Shack 61-2667A, which is connected to one of the outputs of the power inverter, was used to wirelessly provide or interrupt AC power to the relays that are connected to the motors. Whenever the “OFF” button is pressed on the remote control of the Radio Shack unit, AC power to these relays is interrupted, which in turn open the relays’ internal switch, thus cutting the DC power to the motors. The mechanical switch, Mouser 653-A22E-MP-01, is connected to the AC line that provides power to the relays; hence, when the mechanical switch is pressed, AC power is cut to the relays, thus, opening the internal switches and cutting DC power to the motors.

Another consideration of safety for MI-1 was that no one would be injured while working on the vehicle. All connections that pose an electrical shock hazard have been covered and the frame has been painted in a non-conductive paint to prevent electrical shortage. In addition to this all sharp edges were de-burred during assembly.

8 COST

Throughout the design and development of MI-1 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 19:

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-7358 Motion Controller	1	3,624.50	3,262.05
NI CVS 1456 Compact Vision System	1	7,596.11	6,836.50
NI PXI-8252 IEEE1394 Interface Board	1	544.50	490.05
NI PXI-8430/4 RS232 Serial Interface	1	709.50	638.55
NI PXI-8430/4 RS485 Serial Interface	1	764.50	688.05
SCB-68 I/O Connector Block and Cable	1	385.00	346.50
Quicksilver Motors and Controllers	2	4,040.00	1,743.94
Gear Boxes	2	509.00	509.00
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
ISG Digital CMOS Camera	1	1,234.45	1,234.45
Mechanical Drivewheels and Chassis	N/A	983.24	983.24
Optima 12V Gel Cell Batteries	4	680.00	320.00
Electrical Components	N/A	600.00	600.00
Donated Maching Time	N/A	1,000.00	0.00
Aluminum Heat Treatment	N/A	400.00	0.00
Donated IGUS Linear Slides	4	350.00	0.00
LMS Driver	1	720.00	0.00
Total			**33,938.15**

Figure 19: Budget

9 CONCLUSION

MI-1 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 that MI-1 will be very successful in this year's Intelligent Ground Vehicle Competition. We also believe that our design innovations, especially the "Path Tracking System", will set MI-1 apart and establish new standards in the field of autonomous robotics. Above all we are proud to be a part of the first IGV team from CSUN and we hope that we have laid the groundwork so that our school will be successful at IGVC for many years to come.