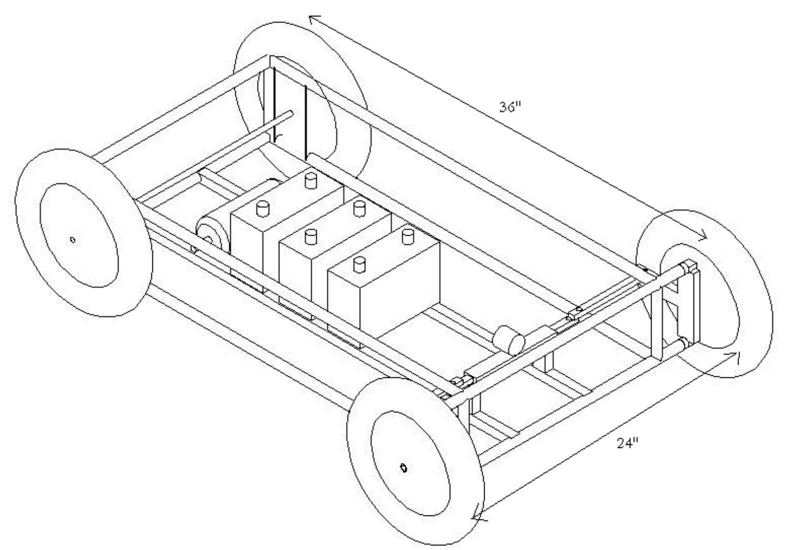
The College of New Jersey

The Autonomous Vehicle Team from TCNJ Presents:

NJAV
New Jersey Autonomous Vehicle



Team Members

Mark Adkins, Cynthia De Rama, Jodie Hicks, Kristen Izganics, Christopher Macock, Stephen Saudargas, Brett Ziller

Required Faculty Advisor Statement:
I hereby certify that NJAV is a new vehicle designed and built completely from scratch by the first team from The College of New Jersey. The team consists of seven undergraduate students with mechanical, electrical, and computer engineering backgrounds. Each member received four credit hours in senior project credit for their work on this project.

Dr. Orlando Hernandez, Department of Engineering, The College of New Jersey
Faculty Advisor

Introduction

The team members of the New Jersey Autonomous Vehicle Team are excited to present the product of their year's worth of hard work. This vehicle, designed and built entirely from scratch, was constructed and tested for the sole purpose of competing in the 13th annual Intelligent Ground Vehicle Competition. The team spent several hours researching options for their completely innovative design of the vehicle, while also keeping in mind their financial limitations since they are the first team from The College of New Jersey to enter the IGVC.

Design Process

The team members of NJAV formed our project team in May of 2004. At this meeting, team jobs were assigned, summer tasks were agreed upon, and we discussed the progress and work of previous teams that had competed in the IGVC. The team jobs were assigned as follows:

Mark Adkins	Senior Electrical Engineering	Systems Integration / Navigation
Cynthia De Rama	Alumni (Dec. 2004) Electrical Engineering	Electromechanical Controls
Jodie Hicks	Senior Electrical Engineering	Team Manager / Obstacle Detection
Kristen Izganics	Senior Electrical Engineering	Obstacle Detection System
Christopher Macock	Senior Mechanical Engineering	Mechanical System
Stephen Saudargas	Senior Computer Engineering	Line Detection System
Brett Ziller	Senior Electrical Engineering	Power System

It was at this time that our team decided upon its goals and what exactly we wanted to accomplish as a novice team entering into the IGVC. Our team wanted to complete our vehicle from scratch and also be competitive at the competition. Over the summer, each member researched their individual parts and work on the project began. Ideas for fundraising were put into action and preliminary designs were considered. Our main focus was placed on the obstacle detection system and the line detection system, since our team members had never encountered topics like these before.

Results of Research

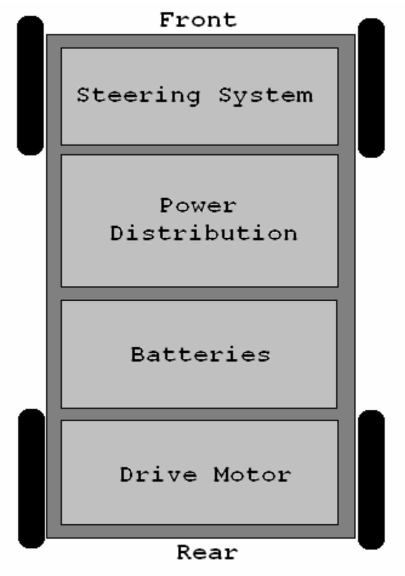
Since our team was new to the autonomous vehicle concept, we read the reports of some of the previously successful teams to get a better understanding of some of their designs. Initially, we debated how many wheels would give our vehicle the best maneuverability. After reading the reports, our team decided that the teams with four wheels had the best results. When it came to deciding the size of our vehicle, we used the constraints given to us by the IGVC. Since the minimum length was 36", our team used this as a guide since a shorter wheelbase results in a tighter turning radius. We believed this would be advantageous for quickly avoiding obstacles and reacting to commands from the computer. We used these results of our research as the guidelines for the rest of our vehicle design.

Mechanical System

Frame and Chassis

Steel square tubing with an outer dimension of 1" per side and a wall thickness of 1/16" was used in the construction of NJAV's frame. Figure 1 displays a picture of the early stages during the construction of NJAV's chassis.

Figure 1: A Picture of NJAV's frame.



The material selected for the frame had to be strong enough to support the weight of the vehicle, all of the electronic components and the payload, yet lightweight as to minimize drive power requirements. The figure to the left shows the component layout, which is how all of the electronic components fit into the chassis of NJAV. This design made the electronic components easily accessible, while also concealing them from the weather in a neat and organized manner.

Drive Train

Through the generous donation from Mr. Alex Michalchuk, technician at TCNJ, the team acquired a motor suitable for NJAV. This motor features a built-in gear reduction unit that provides a final shaft speed of 175 RPM, a true differential between the left and right axles, and a housing that is nearly the same width as our desired vehicle frame. A picture of NJAV's drive train can be seen in Figure 2.

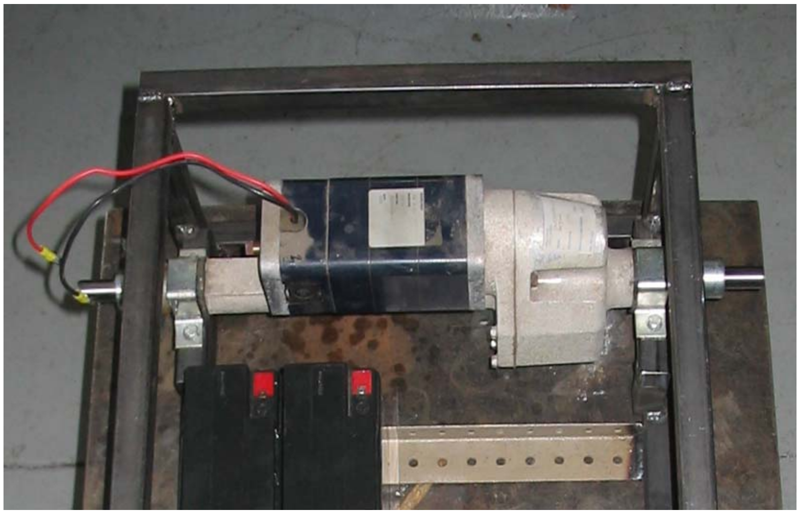


Figure 2: The drive train used in NJAV.

Using this motor, NJAV is able to traverse the ramp inclines it will encounter during the competition by using its maximum power output. Through several calculations, using our estimated weight of approximately 100 pounds, we discovered our motor needed to have .2 horsepower or 150 watts at 2000 RPM (or greater power output) in order to power NJAV. This drive train successfully accomplishes this task.

Steering

Our team decided that in order for our vehicle to be successful, the steering must have a fast response time and accurate feedback. NJAV's steering works off of a pitman arm steering configuration. This configuration can be seen in the picture at the right and below. In the picture at right, the steering configuration can be seen on the vehicle itself, and in the bottom picture is a figure displaying how this configuration works.

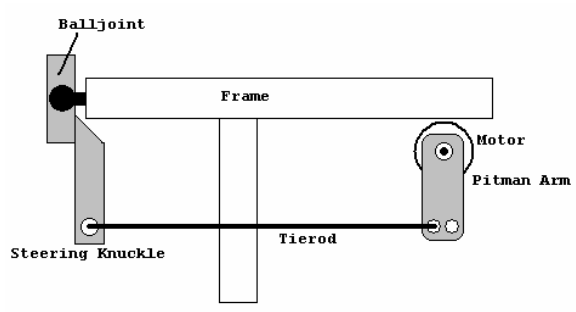


Figure 3: Steering system of NJAV.

Figure 3 shows the placement of the steering knuckles, steering arms, tie rods, pitman arm, and actuating motor on NJAV. Due to its small size, low power consumption, free cost, and immediate availability, an automobile windshield wiper motor was selected to actuate the steering system. Through testing, this motor has proven to be powerful enough to quickly move from one extreme to the other, while maintaining minimal power consumption.

NJAV's steering is connected to the laptop of the vehicle through a digital I/O. A steering system with discrete positioning was chosen due to the elimination of A/D converters. A small finite number of steering positions was determined to be more than sufficient. Thus, a feedback array containing seven discrete steering positions was created. This feedback array can be seen in Figure 4.

Figure 4: Steering position array: isolated (L) and installed on vehicle (R).

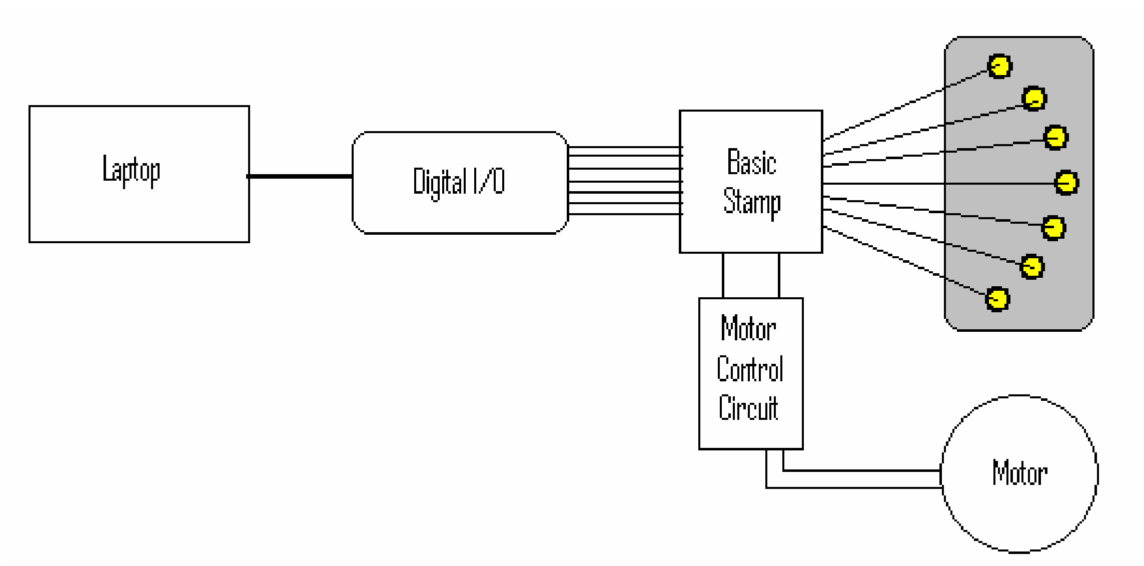


Figure 5: Device interaction for steering controller.

Figure 5 shows the connections from the laptop to the steering array on the vehicle. With the constraints of non-volatile memory, self-contained I/O, and serial PC communication, the Basic Stamp II microprocessor was chosen as the microcontroller to interface with the Digital I/O.

This microprocessor has 16 individual lines of I/O, which allows each steering position to have its own line matched to a dedicated line from the central computer, as well as a left and right output line to the motor controller. This is how NJAV will be directed along the path during the competition.

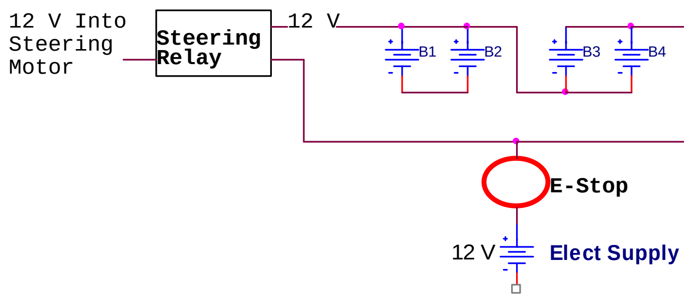
Electrical System

The electrical system of NJAV consists of the power system, sensors for obstacle detection, and a digital potentiometer. Also, the vehicle contains a digital compass and a GPS unit, which are discussed in the navigation section. All of the electrical components are placed on the vehicle in different places which were chosen based on easy access for the team members. The power system and the digital potentiometer are placed within the chassis of the vehicle, and the sensors are placed on the front, top edge of the chassis. The digital compass and GPS unit are placed on a tower at the top of the vehicle in order to receive accurate data without any electrical interference.

Power System

NJAV is powered by four Helios Sealed Lead Acid 12 Volt/17 Ah batteries: two batteries in parallel, series connected with the other two batteries in parallel. Each battery weighs 13 pounds for a total weight of 52 pounds. The output from the battery supplies are connected to a 3 Amp fuse and then branch into an ideal terminal strip rated at 250 Volts and 20 Amps. A switch was then added between the battery and the fuse to easily cut power to the electronic components. Due to the varied voltage needs of each component, varied voltage regulators (LM317T chips) are used to control the voltage to each component.

The motor battery supply was tapped into at 12 Volts and 24 Volts. These outputs were connected to 12 V relays. These relays are controlled by two switches powered by the batteries. The 24 Volts are connected to a 30 Amp fuse box, and then connected to the drive motor controller. This prevents any components from accidentally being blown by an excess amount of current. 12-gauge wires, along with 12-gauge connectors, are used for the connections supplying power to the components needing larger draws.



The figure above shows the circuit configuration for all of these connections. A governor potentiometer limits the maximum velocity and another potentiometer is used for throttle control. The Curtis motor controller allows for both forward and reverse capabilities.

Sensors – Obstacle Detection System

NJAV's obstacle detection system consists of four ultrasonic sensors. Our team chose to use ultrasonic sensors as opposed to laser range finders because they are resistant to vibrations, electromagnetic interference, and ambient noise, as well as inexpensive. These factors were important, because, otherwise, any disturbance from the other systems of the vehicle could affect the accuracy of the distance detection.

The four ultrasonic sensors chosen for NJAV were the Devantech SRF04 Range Finders. They have low power consumption, a compact size, and a range of detection. The sensors are driven by a 5 V source, 30 mA minimum to 50 mA maximum, and can detect objects up to three meters. The BASIC Stamp II microprocessor was chosen to interface between the team laptop and the four sensors. Once the sensors are detected in the microcontroller, the distances they configure are then sent through a driver into MATLAB, which is the main software in our vehicle. The sensors are used to detect any obstacles during the autonomous competition as well as the navigation competition. Figure 6 shows the four sensors onboard NJAV.

Figure 6: The sensors mounted on the front of the vehicle chassis.

Software

All control algorithms implemented on NJAV were developed and written within MATLAB. The MATLAB environment provides easy control of digital I/O lines for interfacing with the drive and steering motors. With MATLAB's additional toolboxes, many built-in functions for mapping and image processing were utilized to simplify the control algorithms.

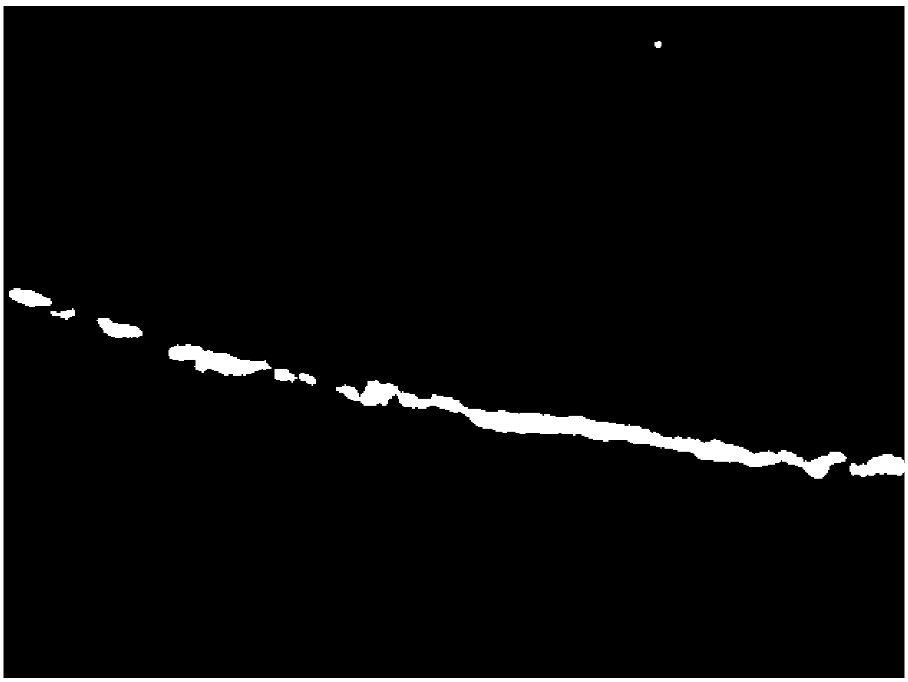
Control Hardware

A Dell Inspiron 5160 laptop computer collects all information from the sensors and cameras and determines the vehicles best heading. The laptop uses a 3.2 GHz Pentium 4 Processor with Hyperthreading and 512 Megabytes of 400 MHz memory. All software is written in the MATLAB development environment on the laptop.

Camera – Line Detection System

NJAV uses a Logitech QuickCam Pro 4000 web cam to detect the lines on the obstacle course path, as well as any potholes the vehicle might encounter. Our team chose to use MATLAB instead of LabVIEW because of its faster run time. Through the use of MATLAB, it takes this system five steps to filter out and detect a white line. Below is an example picture taken during the testing of NJAV:

This is a 480 x 640 RGB image from the camera. The next step would be for the MATLAB code to increase the contrast between green and any other colors. Then the code would analyze the grey scale image created by taking only the blue plane of the picture by running it through Otsu's algorithm to find a threshold value. This yields our desired product of a clear definition between green and white. MATLAB then creates a binary image using the calculated threshold. This is useful because a value of "1" corresponds to white and a value of "0" points to not white. Following all of these steps, MATLAB uses a median filter to filter out any small unwanted artifacts to yield the final image seen below:



The white line in this image is very clear and can easily be avoided by NJAV. After this filtered image is created, an algorithm goes through each cell in Figure 7 and decides if there are enough white pixels to flag that cell as being dangerous to the vehicle. If a cell is deemed dangerous, that cell is added to an array of flagged cells. Then the algorithm checks each column starting at the bottom of the image (closest to the vehicle) and moves upwards to find the first cell that is flagged. Calibration is then used to determine approximately how many inches it is to the cell and returns this value. This number is then sent to the system integration system, which tells the steering components which way they need to turn to avoid this line.

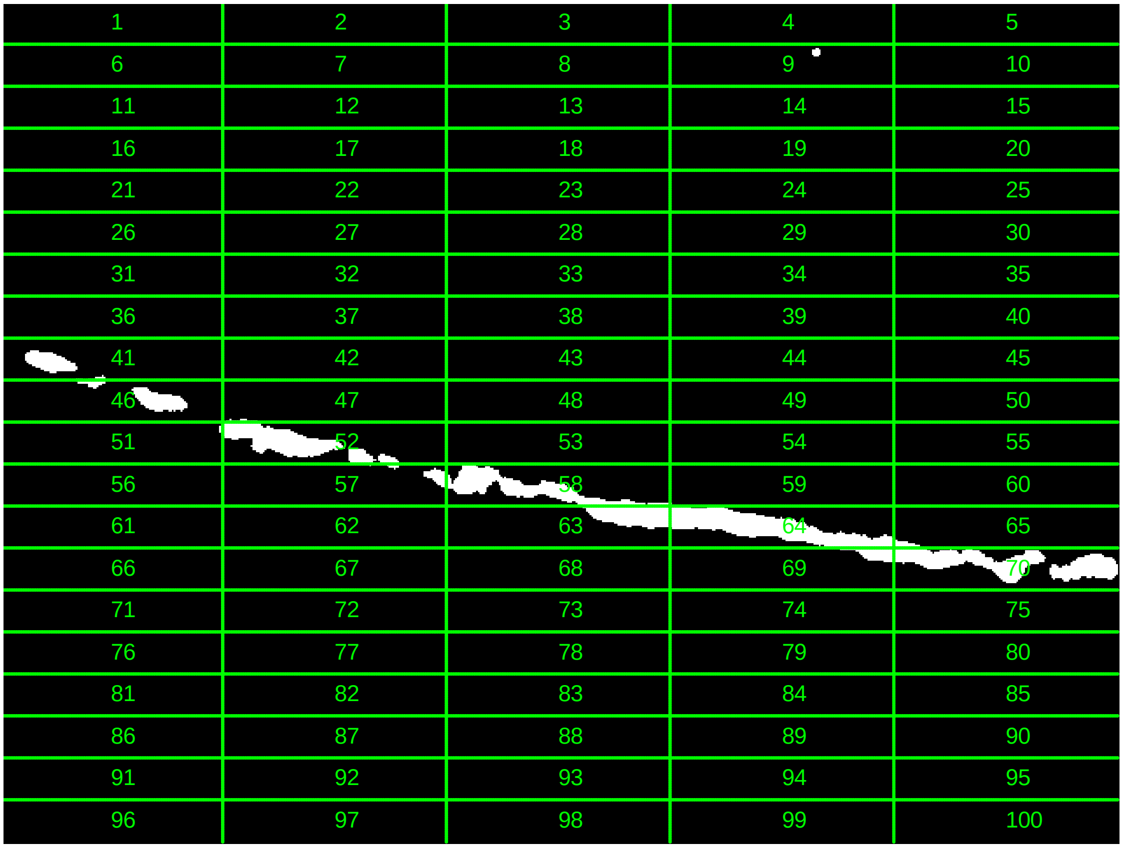
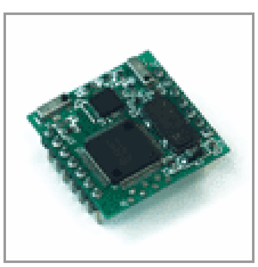


Figure 7: This is a divided image ready to be checked by the algorithm.

GPS Receiver

The GPS receiver used for the navigation competition is the WAAS enabled USB enable GPS receiver made by Deluo. It takes advantage of the WAAS correction algorithm to increase the resolution of the GPS signal.

Deluo Digital Compass



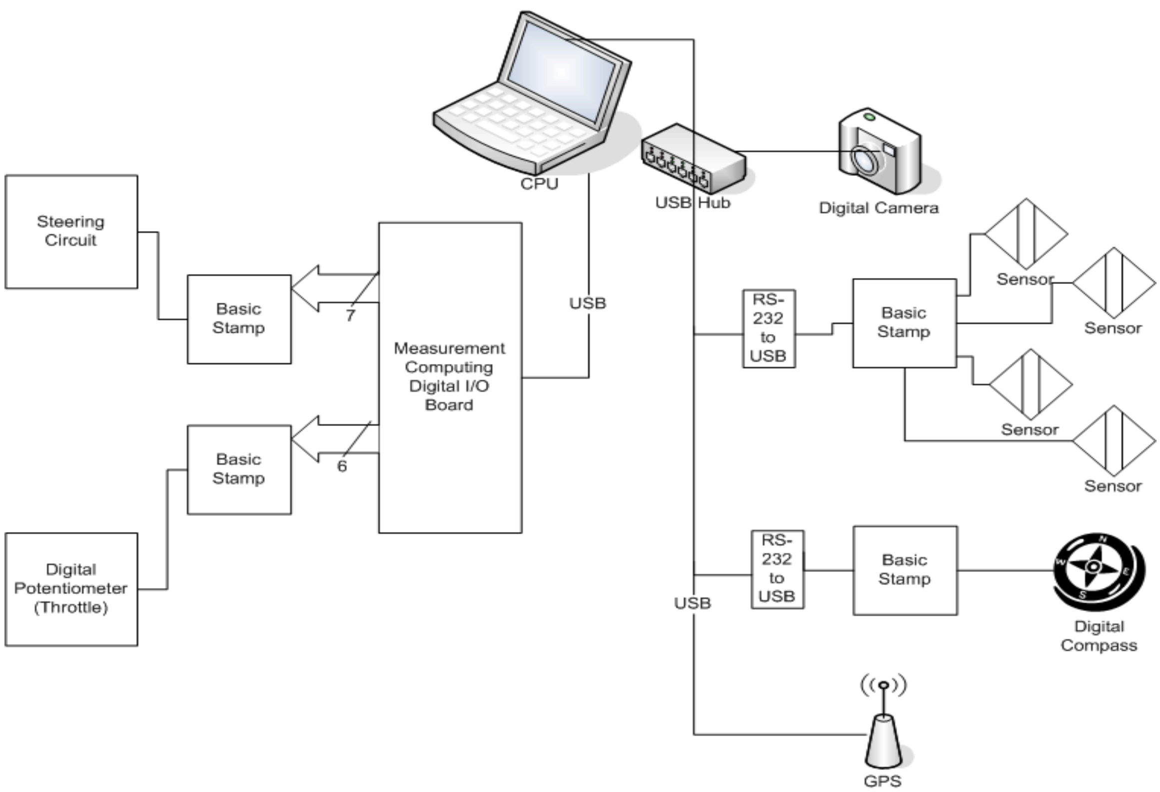
The digital compass used to determine the vehicles heading is the PNI Corporation V2xe. This compass is an integrated 2-axis compass and magnetic field sensing module. The module is not tilt compensated so it must be maintained at the most level plain to ensure accurate readings.

Digital I/O Board

In order to interface with both drive and steering circuits a Measurement Computing PMD-1024LS I/O board was used. The board has 24 digital I/O lines and communicates with the computer through a USB interface. This board is high current and can easily trigger both relays and transistors.

System Architecture

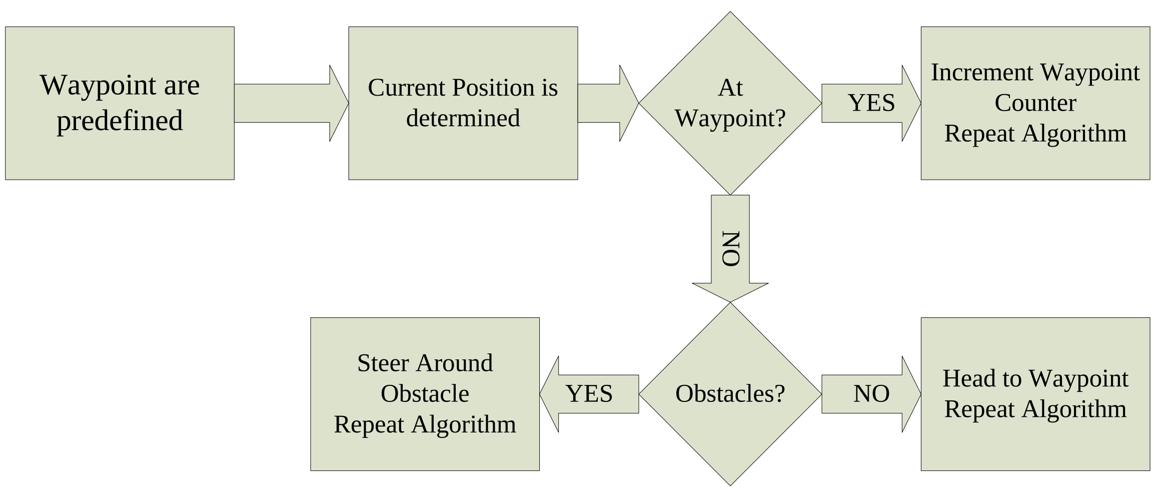
An overall system hierarchy of NJAV was developed to clarify all communication between the individual devices and the laptop. The block diagram shown on the next page represents all of the system components and how they are set to communicate with the laptop. The left side of the block diagram shows all of the control lines. The right of the block diagram describes the four input systems. All systems that require a serial interface must first be converted to a USB signal which is accomplished using an IO Gear RS232 converter.



Navigation Algorithm

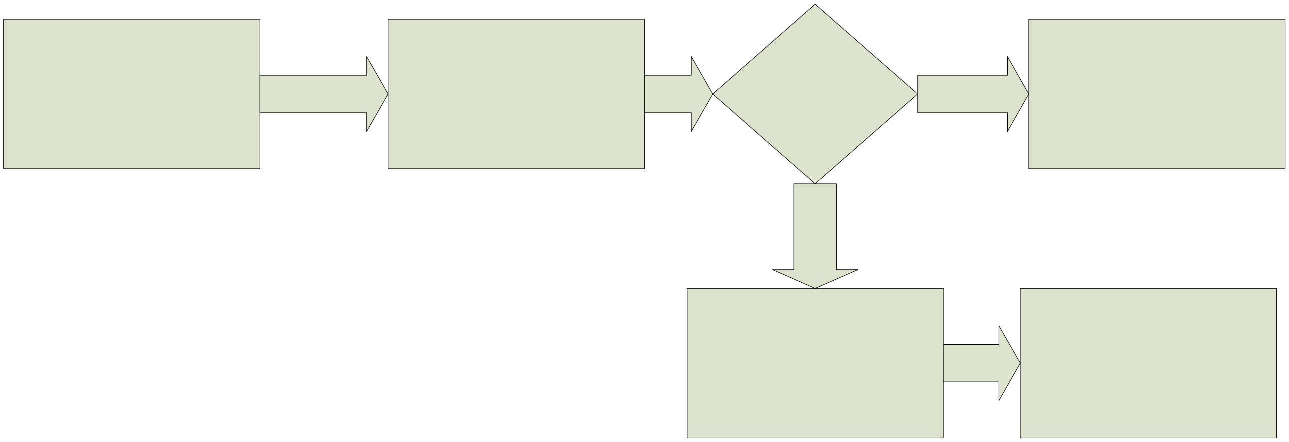
The main concept behind the navigation algorithm is to have the vehicle travel from one waypoint to another and continue to do so until all desired waypoints have been reached while avoiding any obstacles the vehicle may encounter. The waypoints are defined by GPS waypoints and thus knowing the vehicles current location and heading the computer can tell the vehicle where it should go and how fast it should travel.

The system first stores all desired waypoints in memory. The car then determines its current position and then calculates its distance from the waypoint. If the vehicle is within two meters of the waypoint the waypoint counter is incremented and the algorithm restarts. If the vehicle is not within two meters of the waypoint the actual heading of the vehicle is collected from the digital compass. Then the desired heading of the vehicle is calculated based on the GPS points. A correction is determined from these two headings. Before the vehicle makes a correction first the sensors are checked to verify that the desired path is clear. If the path is clear the car will then travel that path and the algorithm repeats. If the vehicle's path is not clear a correction around the obstacle is then determine and the algorithm will repeat. The obstacle avoidance correction is an ever changing function where the vehicles optimal path is determined in accordance to obstacles locations. The vehicle's desired direction has been determined through repeated testing of the vehicle.



Obstacle Course Algorithm

In this navigation course two environmental sensing systems are used. The sensor and camera systems which were described earlier provide information to the controller and will be used for the vehicle to travel forward along the set path. The obstacle course uses a state flow style of navigation. Certain states are predefined and depending on the current state of the vehicle only certain states can be attained. This will provide an easy method to handle special cases and test the vehicle accordingly.



Vehicle Safety

Our vehicle is equipped with an emergency push down kill switch, which can be seen at right. A single pole, single throw emergency push-down stop switch was selected. It is connected to the power that controls both the drive motor and steering motor. Pushing down the button and stopping this connection will ensure the termination of the vehicle’s motion. The remote emergency stop uses a relay supplied by a remote control car. This emergency switch is a precaution to ensure the safety of the course, the vehicle and any persons in the vicinity.

Budget

Initialize Systems

The total cost of our vehicle is broken down in the table below:

Obstacle Detection System (Sensors)	$183.95
Mechanical System	$526.53
Power System	$290.00
Line Detection System (Camera)	$50.00
System Integration / Navigation System	$1, 090.00
TOTAL	$2, 140.48

Our team was very fortunate to receive our laptop from our engineering department, as well as other donations from several companies, friends, and family. We had several fundraisers to help raise the remaining funds needed to build NJAV, as well as travel expenses.

Conclusion

NJAV is the vehicle designed and constructed by the first team from The College of New Jersey. NJAV is fully autonomous and will maneuver easily throughout the autonomous and navigation competitions. A digital compass and GPS unit, along with other components, have accomplished the task set forth to our team for preparing for the navigation competition. Four ultrasonic sensors and a web cam are the main components our vehicle will use for detecting obstacles and lines during the autonomous competition. Our team is very excited and fully prepared to compete in our first Intelligent Ground Vehicle Competition.