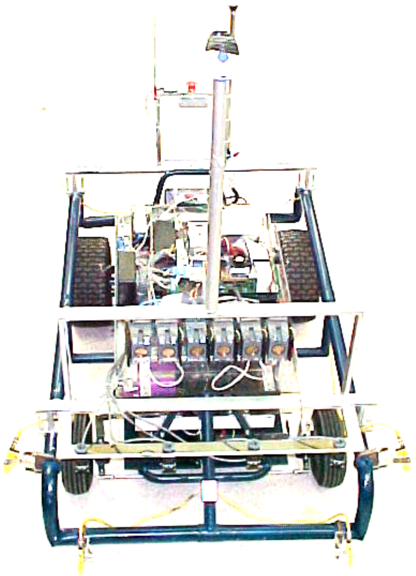
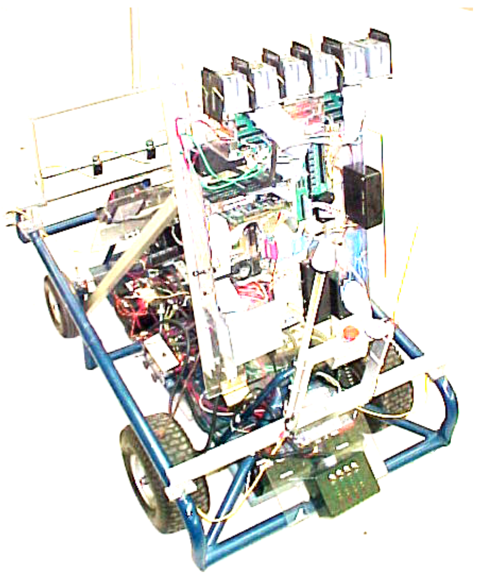
Centurion II

Vehicle Design Report

Bluefield State College

Ground Robotic Vehicle Team, May 2003





I, Dr. Robert Riggins ,Professor of the Electrical Engineering Technology Department at Bluefield State College do hereby certify that the engineering design of the vehicle, Centurion II, has been significant in the change and each team member has earned two semester hour credits for their work on this project.

Signed, Date

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1. Introduction

The Centurion II team of the Autonomous Ground Robotic (GRV) team of Bluefield State College (BSC) presents Centurion II for the Intelligent Ground Vehicle Competition (IGVC). The first Centurion robot competed in the 10th Annual IGVC. Centurion II differs from Centurion in several vital areas as described in this report. In August, the GRV team decided to split into two teams, in which the Centurion II team would concentrate on redesign and improvement of our existing platform, while a new team, the Vasilius team, would concentrate on a new platform. We made the decision to split into two teams because some of the lessons learned from the 10th Annual IGVC involved improvements on Centurion and some of the lessons learned could only be accomplished by starting over. The Centurion II team consists of six undergraduates; some overlap exists with the Vasilius team members. We estimate 900 man-hours were spent on Centurion II for the 2002-2003 academic year. Although we had a small multi-departmental team, we know Centurion II will do well in all four competitions.

2. Design Process

The first task the Centurion II team had on returning from the 10th Annual IGVC was to decide on our design process for the upcoming year. Our approach was to review the methods used by the previous first and second place design contest winners for the last three competitions, compare these to other known methods, and choose one for us. We chose the five-stage design process used by the United States Military Academy for MAGIC in 2001. This process is simple yet powerful and adapts well to redesigning existing platforms such as ours. Figure 1 illustrates the five stages of this process.

2.1 Identify the Need

To identify the need all team members first reviewed the competition rules from the previous competition. All team members then studied our list of notes and ideas generated from Centurion's competition experiences. Based on these studies we then listed concepts used in the design of Centurion that needed changing. These changes include:

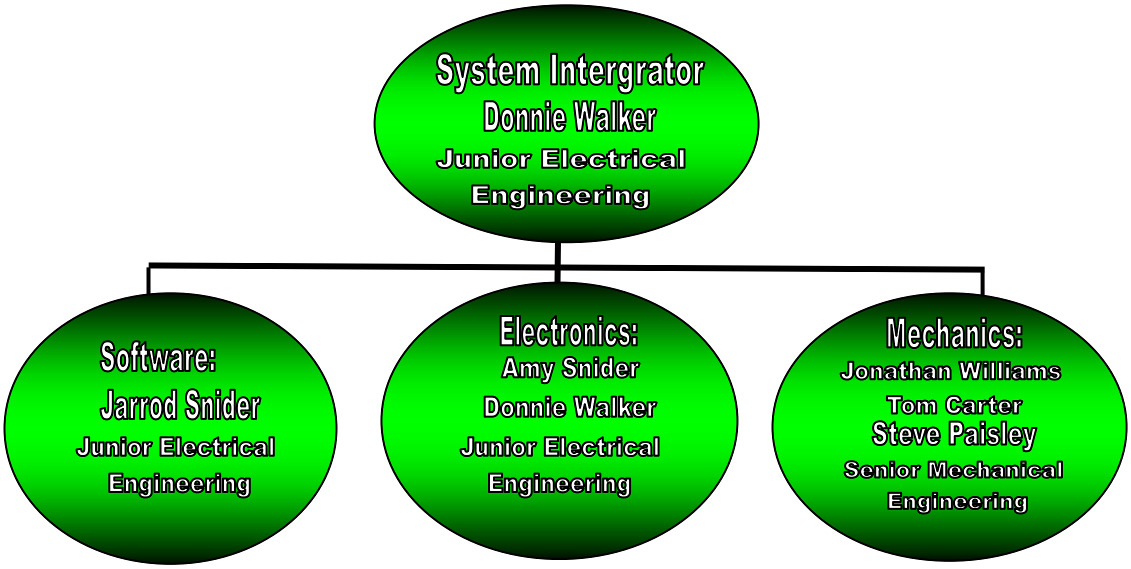
- Using an encoder for feedback control
- Moving the center of gravity back to improve traction and turning torque

- Totally rewriting the software for better reliability and completeness
- Changing the technique of object avoidance for improved reliability
- Making the vision less sensitive to light and dark transitions
- Designing and constructing a more suitable cover and camera mount
- Decreasing the width so navigation between obstacles would be easier

Our goal for the next 9 months was to "**Develop a new Centurion capable of winning all four competitions in the 11th Annual IGVC**." Our customer is the 11th Annual IGVC group of judges and administrators.

2.2 Plan the Process

In this stage of the design process we established the structure of the team and the types of checks and balances to be employed to meet the needs identified. We divided the six-person team into three sub-teams: the mechanical sub-team, the electrical sub-team, and the software sub-team. An overall systems integrator served as the team's leader.



In August, the team wrote a detailed schedule listing all the steps required to meet each of the identified needs. Every team member then wrote a proposal due to the advisor on how he or she would do the steps outlined by the whole team. Each week, every member had to write a summary of the previous week's accomplishments and what was planned for the following week. Once a week the team met and discussed these summaries, updating when necessary. At the end of each semester we presented our progress to the school and to sponsors.

2.3 Develop Specifications

We developed our specifications for each of the needs identified in Stage 1 using the rules and regulations as our guideline. We decided on the following specifications:

- Build an encoder with at least +/- 45 degree-range and 0.5 degree-resolution
- Move the center of gravity back at least five inches
- Rewrite the navigation code so pictures can be processed at least one per second
- Add proximity sensors that can sense up to two feet for reactionary mode
- Fix the vision to work in shade and sunlight
- Build a cover that would protect the electronics from rain and weigh < 10 pounds
- Decrease the width of the robot by at least 10 inches

The whole team developed each of these specifications, corresponding directly to the needs identified in Stage 1.

2.4 Generate the Centurion II Concept

To meet each of the specifications listed above each sub-team, identified in Stage two, researched conceptual design options and chose a concept. For example, to move the center of gravity back we could have chosen any one of many concepts such as rebuilding the structure, moving components around, or changing the wheel base. We chose to build a frame extension and moved two batteries to the rear. In this stage we developed detailed plans using CAD for each of these concepts. Details for this stage are available on request but are lengthy.

2.5 Generate the Centurion II Product

Each sub-team fabricated and tested all components based on the decisions from the Concept stage. During the product generation stage, we also assessed safety, reliability, and durability of each component. For example, we tested the remote E-Stop repeatedly on high and low batteries and through obstacles both outside and in the building.

This final stage gave us a measure of how well we met the needs identified in the first stage. All needs identified in Stage 1 were met according to the specifications given in Stage 3 except for one. Although we gave it a good effort, we could not get our rewritten software to process pictures at one frame per second or faster. The reason for this is the limitation of the single on-board computer and the amount of filtering and other processing we want to do on each image. The result of this failure is that we have a slower robot. Next year we may install a framegrabber, camera, and computer that are superior to the ones we now have.

3. Centurion II Mechanical Design

3.1 Frame Design

One of our design process specifications from 2002 was to build a strong structure capable of supporting all components over rough ground while keeping the total weight under

250 pounds. To meet this specification, we designed and built Centurion II using Lexan sheets for support plates and shelving, and 0.125-inch square aluminum tubing for frames. Three separate decks on Centurion II allowed us to place heavier components lower and lighter components higher so that the center of gravity is low. We encircled the entire body with a bumper for ease of lifting and to provide a mount for sensors.

The lower deck is a steel plate serving as a strong base to the rest of the robot. This layer is strong enough to hold all four 20-pound batteries, the main propulsion motor, the drive train and gearing, two motor controllers and the steering motor. The middle deck contains the GPS receiver, the encoder for steering, and two inverters. The top deck holds the computer components, sensor interface electronics, the sonars, and E-Stop electronics.

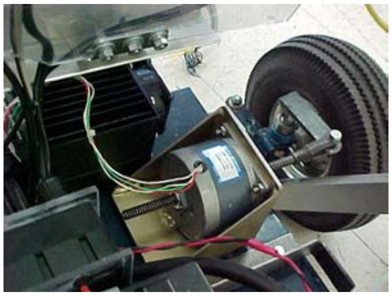
3.2 Cover Design

One of the needs identified in our design process was to develop a new cover capable of protecting Centurion II's electronics from rain while keeping the cover weight less than 10 pounds. The mechanical engineering team members accomplished this by designing a Lexan-based curved top that directs the rain away from the center of the robot. The Lexan top is strong enough to support the 20 pound payload/video camera.

3.3 Drive Motor

Centurion is a one-wheel drive robot with a one-horsepower 24-volt DC motor. Our gear analysis led us to use two sprockets in order to reduce the 3000-rpm motor to a 5 mph maximum robot ground speed. We have shown during analysis and testing that Centurion II has more than enough torque to start from a stall on a dry firm 15-degree positive slope. A problem arises when the robot runs through mud or wet thick grass as the Centurion team experienced in Orlando 2002. For these conditions, we use a chain placed around the drive wheel.

3.4 Steering Motor



The steering motor is a linear stepper motor with 300-lbs of force designed to rotate a rod in or out a specified number of revolutions. A worm gear translates this linear motion to steering. A motor controller interfaces the computer to the steering motor. Steering commands from the navigation software specify turn angles, giving Centurion II the ability to steer to a specified angle.

3.5 Sensor Placement

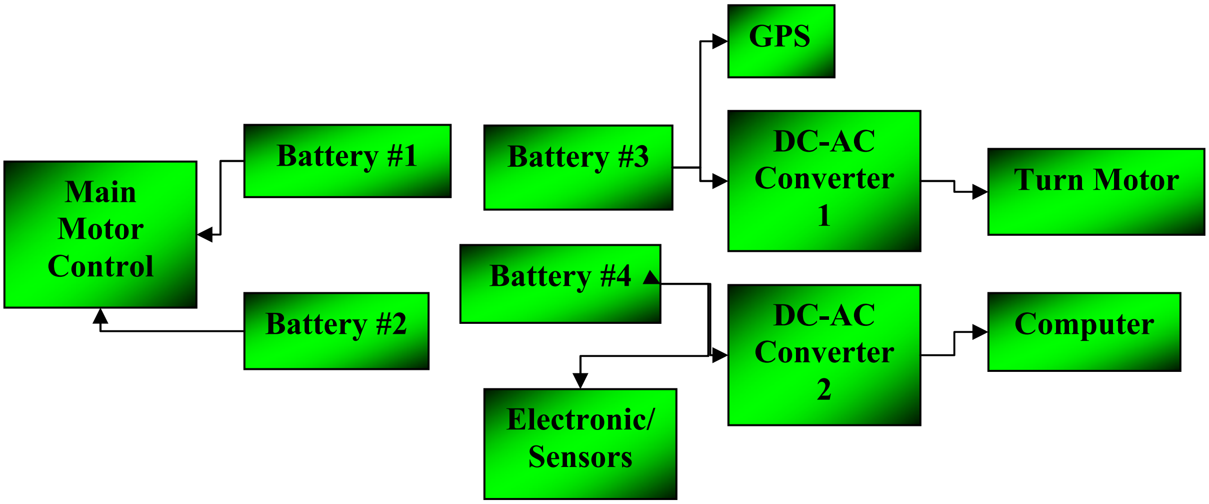
Centurion II has five sets of sensor concepts: vision, diffused visible, proximity, sonars, and GPS. Vision consists of a camera mounted on a telescoping steel pole set in front of the cover. We placed our four diffused visible sensors on the right and left front sides and on the front, all connected to the bumper. The four proximity sensors are also fastened to the front bumper. We mounted the sonars on the top layer of Lexan. The GPS antenna is located on the E-Stop post on the rear of the robot.

4. Electronic Design

In this section we describe the electronic design of the power system, control system, sensor system, emergency stop system, and computer system.

4.1 Power System

We designed the power system configuration for Centurion II so the robot would operate on its own power for a minimum of 3 hours. Four Genesis Hawker Energy batteries powering everything except sonars was the configuration we chose.

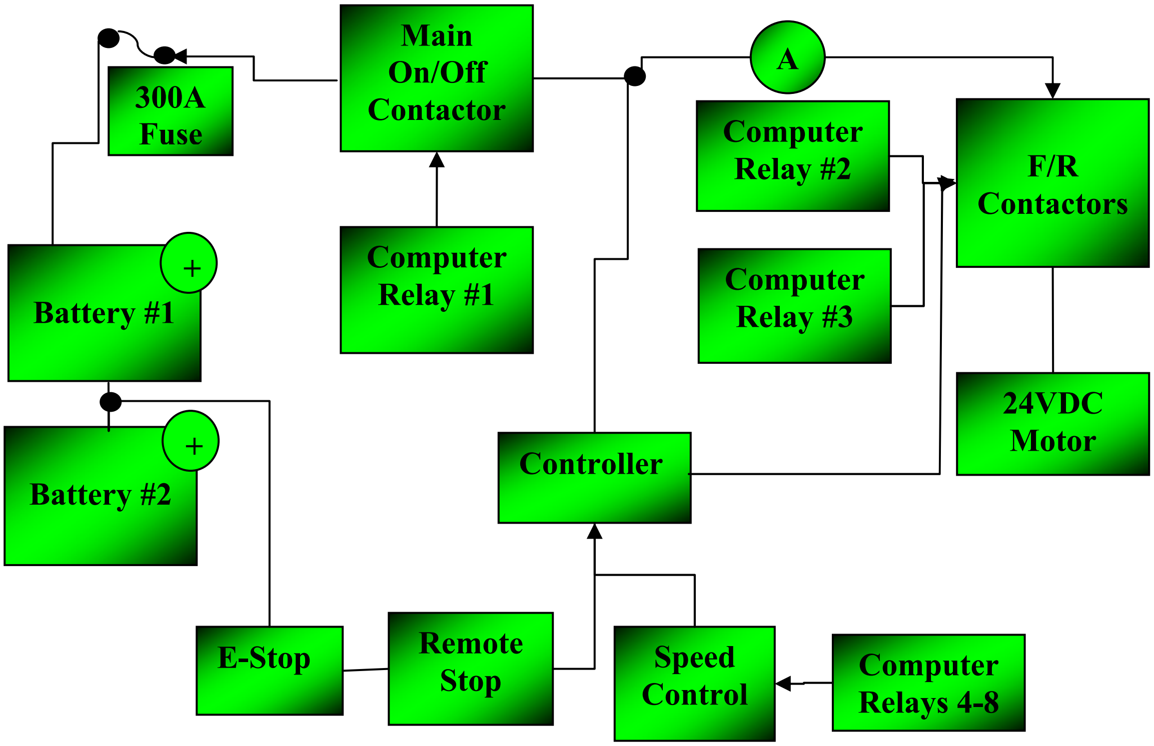


With this power system configuration we found the weakest link to be the computer battery, lasting on the average about 3 hours without charging in the field. On-board circuitry charges the batteries without the need for opening the robot. A 300-watt inverter connected to battery #3 supplies power to the turn motor and another 350-watt inverter connected to battery #4 powers the computer. A battery monitoring circuit placed in full view at the rear enables us to know how much battery charge remains on each battery. The sonars have their own 6-volt batteries. These batteries are a little larger than credit cards and are designed to handle a large pulsating current.

4.2 Control System

The control system consists of the main propulsion control and steering control. The main propulsion control system uses a Curtis pulse-width-modulation MOSFET controller connected to 100-amp contactors to control speed of the main propulsion motor. We connected a main contactor between the 24 volts on the series-connected motor batteries and a 300-amp fuse. A forward/reverse contactor pair allows us to switch polarity to the motor, thereby changing directions between forward and reverse. Relays connected directly to the computer I/O board interface the computer to the contactors. We use eight relays: one for main power, one for forward motion, one for reverse motion, and five for speed control. One task for the main propulsion control system design was to constrain the maximum speed to five miles per hour while making sixteen speeds available to the programmer.

The steering control system controls and monitors the turn angle of the front wheels. One of the needs we identified was an encoder, so we now have an encoder mounted directly on the front axle. A vital task in steering control system design for the electrical team was to provide just the right damping for maximally flat and stable control response.



4.3 Sensor System

Centurion II has five sensor systems: vision, diffused visible, proximity, sonars, and GPS. In this section we describe individually the electronic design of each of these systems. Later in Section 5 we will describe the integration of all these sensors.

4.3.1 Electronic Design of Vision

Centurion II's vision system consists of a web-cam and a software capture control for visual basic that serves as a soft framegrabber. Other than the camera and the USB connection, no electronic design was needed.

4.3.2 Electronic Design of Diffused Visible Sensors

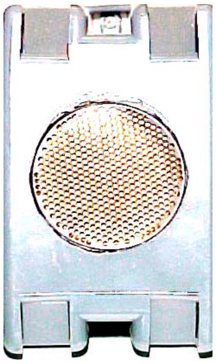
Four diffused visible sensors mounted on the front of Centurion II detect the presence of pre-programmed colors such as white and yellow against the background of green and brown. The purpose of the sensors is to detect road edges and potholes. Another function of these sensors is to detect sand. Each diffused visible sensor outputs zero volts for the "off" condition and 12 volts for the "on" condition. The electronic design needed for these sensors included developing an interface circuit and cables. The sensor interface circuit connects the diffused visible sensors to the computer input terminals. The circuit supplies 12 volts to the sensor and reconditions the 12-volt sensor output to five volts for the computer input.

4.3.3 Electronic Design of Proximity Sensors

Four proximity sensors on the front detect the presence of objects from zero to two feet away. These sensors detect any type of object regardless of size, shape, or color.

Each proximity sensor has a relay that trips when the presence of an object is detected. Electronic design for these sensors consisted of designing a simple junction box connecting ground or five volts to the computer input terminal. The junction box also supplies 12 volts to the sensors for power.

4.3.4 Electronic Design of Sonar Sensors



We have six sonar sensors mounted on the front of Centurion. The purpose of the sonars is to detect and locate objects from two to 30 feet in front of the robot.

Each sonar transmits a 40 KHz acoustic pulse and receives an echo if the pulse strikes an object. For each sonar we had to design an electrical circuit to convert the time difference between transmission and echo to an eight-bit input to the computer input terminals. The decimal equivalent of this eight-bit binary number is proportional to object distance. Our sonar circuit requires 5 volts for power while each sonar requires a special six-volt polapulse battery.

4.3.5 Electronic Design of GPS

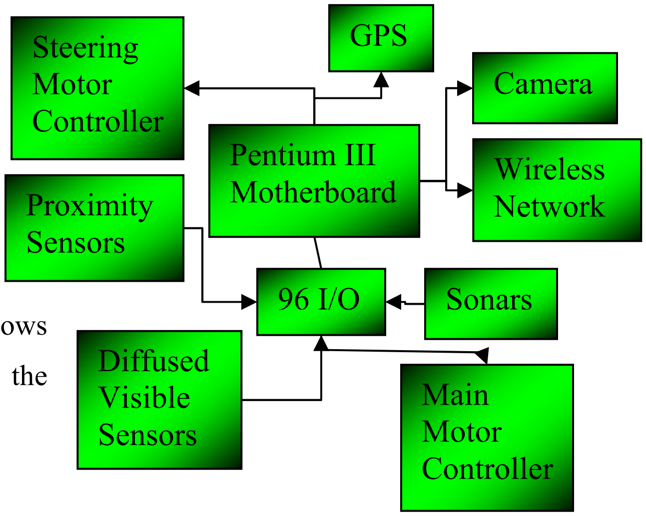
Centurion II uses the Canadian Marconi Company GPS receiver that connects directly to the computer serial port. No electronic design was required for this sensor.

4.4 E-Stop

As required by competition rules, Centurion II has both a manual E-Stop on the robot and a remote E-Stop. These E-Stops connect in series to the propulsion motor controller as shown in the diagram on the control system. In developing the remote E-Stop we used code modulation so as not to have interference from other robots or interfering emanations from other sources such as computers and motors. Centurion II also has a completely independent "kill" switch for safety.

4.5 Computer system

A 733 MHz Pentium III motherboard supplies the computational power for Centurion II. Four 8255 peripheral interface integrated circuit chips allow the robot to control and monitor up to 96 inputs and outputs. Power for the motherboard comes from a standard computer power supply attached to one of the two inverters. The diagram shows how the sensors and control devices attach to the motherboard.



An off board laptop connects to Centurion II through a wireless network. In this way, we can operate and

test without having to physically touch the robot.

5. Software Design/Autonomous Algorithm

5.1 Design Objectives

As stated in the design process and in the competition requirements, design objectives for our software design are:

- To develop an autonomous algorithm that processes images and does all long-range planning computations at least once per second and does all short-range reaction computations at least once per 10 milliseconds. We arrived at the "one second" and "10 millisecond" specifications based on robot speed and size.
- To develop a software structure that can be easily maintained and accessed by many different programmers.
- To write the most efficient program possible for performing all four major autonomous functions and testing.
- To keep safety, reliability, and durability top priorities in software design

In order to meet these software design objectives we had to choose and optimally integrate the sensor suite of Centurion II. First, we will describe this sensor integration.

5.2 Sensor Integration

The five sensors on Centurion II synergically integrate together to provide a broad range of sensory input in order for the GRV to perform four major functions: lane following, object detection, leader following, and waypoint navigation. We developed sensor integration on Centurion using two complimentary ideas: long-range trajectory planning and short-range reaction.

Camera	Long-range trajectory planning
Sonars	Long-range trajectory planning
GPS	Long-range trajectory planning
Diffused Visibles	Short-range reaction
Proximity Sensors	Short-range reaction

Sensor Type	Priority
Diffused Visibles	Highest
Proximity	High
Sonars	Medium
Camera	Low
GPS	Low

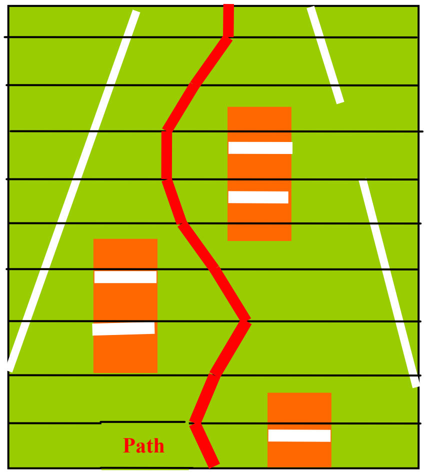
Centurion II plans its trajectory every one second using any combination of the three planning sensors. If no errors occur in trajectory planning and execution, then the robot will not need to use the reaction sensors. In the event a reaction sensor detects a road edge or obstacle close to the robot, then the robot responds to the reaction sensor. Once the reaction sensors are all clear then the robot will go back to trajectory planning. Our testing has shown this concept works well. Many times during testing we had to force errors in the planning process in order just to test the reaction process. This philosophy is similar to how computers operate in both normal mode and interrupt mode. Just as computers use priority levels in their interrupts, Centurion II uses a priority system for the five sensors as illustrated in the table. Although Camera and GPS priorities are low, these sensors are used all the time except during "interrupts" from the reaction sensors.

Centurion's algorithm combines the information gathered from sonars and the camera to produce a 3-D map of the course in front of the robot. This map shows lanes and obstacles from six inches away to 30 feet away. The program transfers object distances as measured by the sonars to the map produced from the camera information. In the next sections, we describe how Centurion employs these concepts in sensor integration to perform the four major functions.

5.3 Lane Following and Obstacle Avoidance

Centurion II uses a trajectory planning process to plot the optimal path between lanes and obstacles using the 3-D map produced from the fusion of camera and sonar information. We use several methods of image processing: Sobel Amplitude and Canny edge detection, as well as Binary Thresholding. Processing speed on Centurion is of utmost importance, therefore, instead of analyzing each pixel of the map, we developed two other time-saving approaches we call the "nine-line algorithm" and the "push algorithm".

The "nine-line algorithm" determines the path that has the widest room between lanes and obstacles on each of the nine equally-spaced horizontal lines (this divides the map into 10 equally-sized horizontal slices.) We found, given camera angle and field of view, the distance between two consecutive lines was slightly smaller than the white pail, the smallest obstacle on the course. The algorithm then establishes candidate paths with the most "elbow" room between each horizontal line. Both maximum and minimum distances from obstacles and lanes are allowed since one lane may be absent or dashed. The robot turn angle and time of turn are a combination of past and present paths creating a recursive-type algorithm.



The "push algorithm" divides the map into ten regions on the left and ten regions on the right. The sum of all pixel gray-scaled values in each region create an obstacle/line "force" that pushes the robot away from the region. Regions at the bottom of the map have more weight than regions at the top. All these “forces” are summed and the robot takes the least resistant path between them with a turn angle proportional to the resultant force.

5.4 Leader Following

The leader following algorithm operates in almost an inverted method as compared to lane following/obstacle avoidance. Instead of avoiding lanes and obstacles, this algorithm tracks an object. Using Binary Thresholding and a variant of the nine-line approach outlined above, we turn the robot left and right so as to keep the object in the center of the image. The robot maintains distance using a combination of camera and sonars. If the image moves toward the top of the image, the robot increases speed, and vice versa. Sonar measurements taken in the center front also give distance. At this time, the fusion of distance information is an average of sonar and camera, but in the future we plan to develop a Kalman filter that optimally combines measurements based on the dynamic model of the robot.

5.5 Waypoint Navigation

Centurion II’s waypoint navigation algorithm uses GPS and proximity sensors to navigate to target points. This algorithm has the structure as shown in the insert. The GPS receiver Centurion uses is neither WAAS-enabled nor differential. However, we can achieve five-foot accuracy by subtracting initial errors between given and measured positions at the Start. As long as the robot can finish the course in less than five minutes, GPS errors should not change much (see our analysis in Section 6.)

1. **Input coordinates of Start and all Targets**
2. **Find initial error between given and measured Start position**
3. **Start Centurion II in forward motion**
4. **Move to next target by comparing robot position to next target position**
5. **Monitor proximity sensors for obstacles**
6. **If obstacle, stop, turn, go to Step 3**
7. **Increase target number if target is found**
8. **If target number is ten, then stop robot**
9. **If target number < ten, go to Step 4**

6. Analysis of Predicted Performance and Results

Our research indicates Centurion should perform as indicated in the following table. The table also indicates our results so far. A "*" symbol means we have not yet measured that performance item. Each prediction listed in the table comes from analyses of components as well as overall performance. For example, to analyze object detection we compared the theoretical detection distance, pattern width, and pattern shape of the sonars to measurements. We did the same for the proximity sensors. Both sonars and proximity sensors used together give us a full detection range of two inches to 30 feet.

Performance Measure	Performance Prediction	Performance Results
Speed	5 mph	4.9 mph
Ramp Climbing	25-degree incline	*
Turn Reaction Time	45 degrees/2 seconds	45 degrees/2 seconds
Battery Life	3 hours weakest link	3 hours weakest link
Stop Reaction Time	Immediate	Almost Immediate
Object Detection	0 inches to 32 feet	2 inches to 30 feet
Dead-Ends and Traps	Chosen paths are clear	*
Potholes	Chosen paths are clear	*
Waypoint Accuracy	5 feet one sigma	5-10 feet one sigma

7. Other Design Considerations

7.1 Safety, Reliability, and Durability

We kept safety top priority throughout this project. Some of our safety features include the following:

- We use non-conductive Lexan with aluminum supports
- Besides both required E-Stops we have an independent "kill" switch
- On-board charger circuitry is separated from batteries
- Contactors and batteries are on opposite ends of the robot
- All components are mounted away from drive chain
- Plastic housings are used for all electrical circuits
- We never test Centurion II without at least 2 team members present

We have noticed the lack of reliability of many of the robots during past competitions. Therefore, we have stressed the reliability of Centurion II. Redundancy is the tool we used to achieve a higher level of reliability. As described in Software Design, different sensor groups have redundant functions. Both the camera and the diffused visible sensors detect the presence of lanes. The camera algorithm also doubles with the sonars and proximity sensors in detecting objects.

Switching from metal supports to all Lexan and Aluminum enhanced Centurion II's durability. Lexan is flexible enough to act to some degree as a shock absorber. As a result, component vibration and bouncing are kept to a minimum.

7.2 Cost

The following table shows the cost of Centurion II's component's.

Item	Actual Worth	Our Cost
Stepper Controller	$800	$800
Diffused Visibles	$400	$400
Proximity Sensors	$600	$100
Sonars	$150	$150
GPS Receiver	$600	$600
Propulsion Motor	$250	$250
Main Motor Controller	$250	$250
Steering Motor	$200	$200
Steering Motor controller	$750	$750
Motherboard	$400	$400
Digital I/O	$500	$500
Miscellaneous	$600	$300

Not counting student and sponsor labor, Centurion II would cost a total of $5500 to replace. We have spent approximately $4800 in parts and have received about $700 in donations.