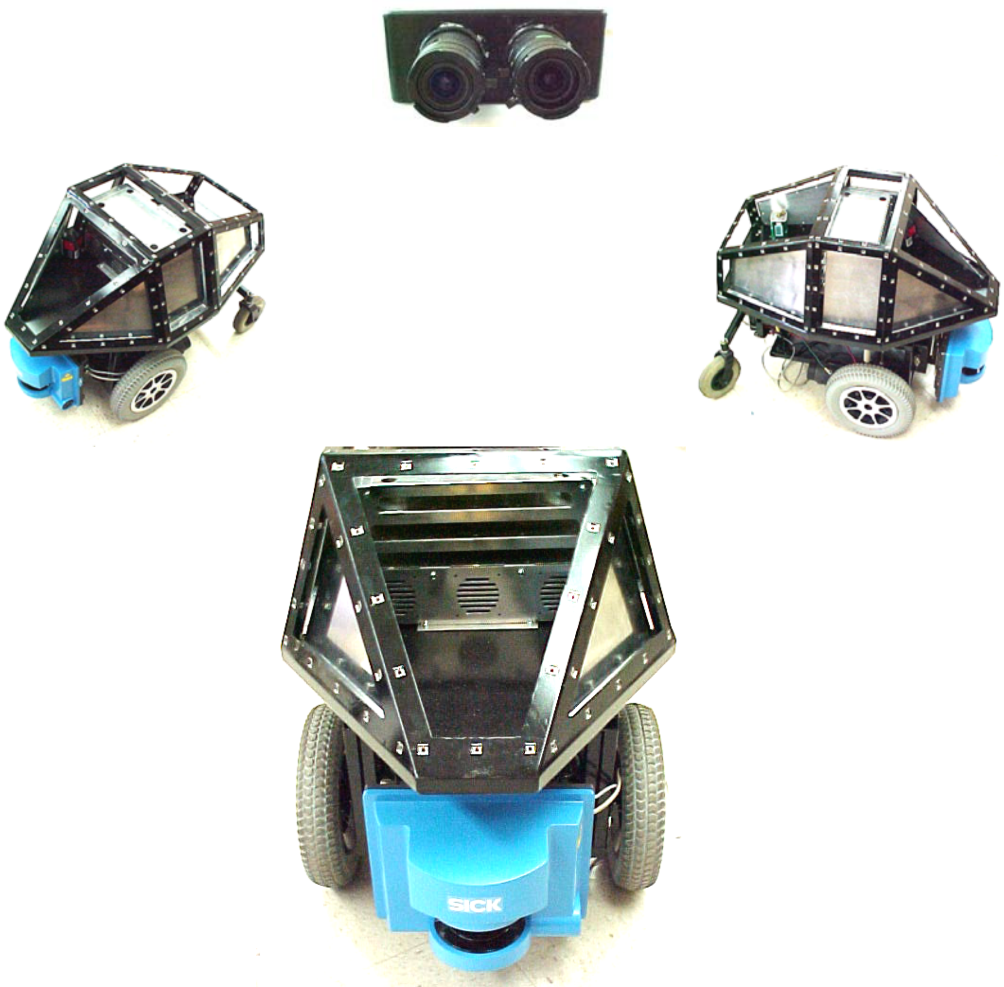
Bluefield State College

Vehicle Design Report
2003

Vasilius



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

Signed, Date

______________________________ ____________

Bluefield State College
Phone: (304) 327-4134
E-mail:_briggins@bluefieldstate.edu

1. Introduction

The 2002-2003 Vasilius Team of Bluefield State College is honored to bring new and innovative ideas to the 11th Annual Intelligent Ground Vehicle Competition (IGVC). Our vehicle draws upon many features of past GRV designs. For example, Vasilius uses a camera vision system and a laser measurement system like most GRVs. However, in addition to these standard systems, we decided to explore a new idea of modeling an autonomous vehicle after human senses and the human decision making process. First, Vasilius' vision system has stereoscopic vision capability, mimicking a human's eyes. Stereoscopic vision allows Vasilius to create a 3-D map from cameras alone. Second, we prioritized various sensor inputs used by the autonomous algorithm. This simulates a human making a decision and slightly later in time changing that decision because of an unforeseen problem. The Vasilius Team has developed a winning vehicle that will compete in all four challenges of the 2003 competition: Autonomous Challenge, Vehicle Design, Navigation Challenge, and the Follow-The-Leader Challenge. In this report, we describe the development of Vasilius and how we incorporated the "human" theme throughout the design. This report is divided into sections of focus. The sections of focus are: Design Process, Mechanical System, Electrical System, Software Design, Analysis/Predicted Performance, and Other Design Considerations.

2. Design Process

To achieve creative and innovative solutions in any engineering project requires both a systematic and organized design process. In our initial meeting in the fall of 2002, our GRV team sought to produce a vehicle which would satisfactorily perform its required functions while staying within our budget. As stated by *Design Ideas* (Miller, 1998), "an optimal solution has a balance of ideal aims and practical limitations." We decided that our design process for Vasilius, as shown in Figure 2.1, would have the following six phases: identification of the customer, problem recognition, preliminary ideas, problem solution, construction, and testing.

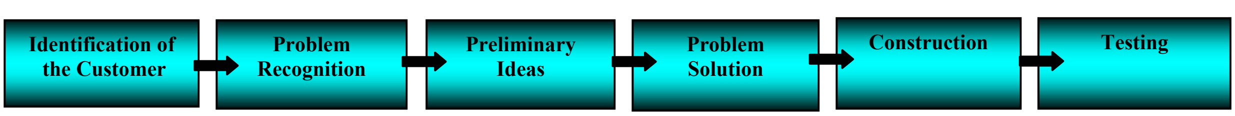


Figure 2.1: Design Process

2.1 Identification of the Customer

Our mission of designing Vasilius began with identifying our customers. We decided our customers are ourselves, BSC, our community and sponsors, and the IGVC judges. We felt our team was talented in a wide array of disciplines and that we would undoubtedly produce a vehicle that was pleasing to our college and community. Local companies donated many of the parts used on Vasilius. It is important for us to show sponsors that our finished product is a success. Therefore, we document progress on a weekly basis and give presentations to the school and sponsors once a semester.

2.2 Problem Recognition

Recognizing the problem and setting our overall goal for the project constituted our next phase of the design process. Our goal is straightforward; we want to win all four competitions in the summer of 2003. Our team studied the requirements from the 2002 competition and met to discuss ideas. Few engineering problems have clear-cut methods from start to finish but rather evolve over the duration of the design process. In recognizing this inevitability, our GRV team initially made a list of the requirements, limitations, and general factors affecting our ultimate goal.

2.3 Preliminary Ideas

The next phase in the design process was to brainstorm preliminary ideas so as to profit from a collective interchange of ideas rather than just one single idea. It is in this stage of the design process that rough sketches were drawn and preliminary notes attached. For instance, our team desired to avoid the bulkiness exhibited by Centurion, our GRV entry from last year, with the hope that a more compact robot would enable us to maneuver in and around obstacles more effectively. We realized that it was advantageous to determine as many design solutions as possible. The team then selected the best ideas and made detailed drawings using Computer Aided Drafting techniques. This enabled us to determine sizes, angles, clearances, and other information necessary for further analysis. After deciding on a plan for our new vehicle, construction began with extensive testing throughout the process so as to produce the best vehicle at this year's competition.

2.3.1 Team Organization

During the preliminary ideas phase of the design process we organized the team. The Vasilius team consists of nine engineering students. All of the Vasilius team members are undergraduates from various disciplines, including electrical, mechanical, computer, civil and architectural engineering. All team members participated in the initial design process. We assigned each member tasks that matched their abilities. Our team has devoted approximately 1600 person hours in the development, design, fabrication and testing of this project. The team members for Vasilius are listed in Table 2.1.

Team Members	Responsibilities	Class Level- Engineering Major
Jarrod Snider	Project Leader, Programmer, Structure, Testing, Electronics, GPS, LMS, Vision, Networking	Junior -Electrical
Amy Snider	Electronics, Testing, Vision, Structure, Fabrication	Junior-Electrical
Jeremy Woody	Electronics	Senior-Electrical
Ravi Srivastava	LMS, Programmer	Senior-Electrical
Donnie Walker	Structure, Electronics	Junior-Electrical
Steve Paisley	Structure, Power Systems	Junior-Electrical
Jack Lamm	Structure, Fabrication	Senior-Electrical /Sophomore-Mechanical
Kenny Dunford	Computer-Aided Design	Senior- Architectural /Senior-Civil
Marc Shapiro	Programmer	Senior- Computer Science

Table 2.1: 2002-2003 Team Members

2.3.2 Design Tools

To achieve the mechanical design of Vasilius we used various software packages including AutoCAD and Inventor. For the electrical system design we used Electronic Workbench and PSpice. After identifying our target specifications from our initial meetings concerning how the vehicle should look and perform, several students outside the team produced initial conceptual drawings in their respective software packages.

2.4 Problem Solution

Once the lists of drawings were developed, the team chose the one we felt adequately met the demands imposed by the competition. By taking a systematic approach throughout the vehicle development, the team was able to create a product that was accessible, well-organized, and compact. We felt that our preliminary designs, using the computer aided design packages, minimized costly fabrication errors. We knew from the beginning that one of the most important topics in any robotic design is to plan exactly how all the parts will integrate with each other.

2.4.1 System Integration

In developing Vasilius, our team placed great emphasis on system integration because of the necessity of coordination between many distinct units onboard the vehicle. As stated in the *Journal of Robotic Systems* (Adams, 2003), “The study of robotic systems is the theory and methodology common to all collections of interacting, functional units that together achieve a definite purpose”. We instituted two concepts for system integration for Vasilius. One is a decentralized control concept and the other is a planning/reactive concept. Both concepts mimic human behavior.

2.4.1.1 Decentralized Control Concept

Vasilius is controlled by two computer systems. One computer is dedicated to vision and planning functions. The other computer concerns itself with reaction sensors and sudden changes in the long-range plan. In this way, control is divided between these two computers. Figure 2.2 shows a block diagram of this concept.

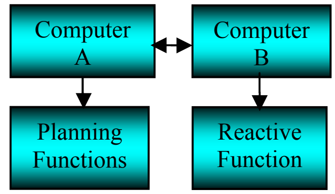


Figure 2.2: Decentralized Control

2.4.1.2 Planning/Reactive Concept

The Vasilius software integrates the inputs from all the sensors to perform the major functions of the vehicle; lane following, obstacle avoidance, leader following, and waypoint navigation. As described in the Software Design these sensors are divided into planning sensors and reactive sensors. Reactive sensors have a higher priority so they can override planning sensors.

2.5 Construction

Construction of Vasilius required manufacturing and engineering skills to work hand-in-hand. An initial design was given to the manufacturing team. The design had to be modified to accommodate the manufacturing process as well as the team's abilities. A final compromise was reached such that the overall design would only slightly deviate from the initial design. These slight deviations included component placement, amount of steel used, and weight.

2.6 Testing

Testing the vehicle was the final stage in the design process. During the initial testing of the vehicle, small problems were discovered and eventually solved. Once basic operation was reliable and consistent, the team focused on safety and redundancy. A series of tests were performed on the vehicle. These rigorous tests consisted of "tricking" the vehicle as well as setting up a variety of dangerous situations for the vehicle to react to. Some minor changes were made to the E-Stop system, software, and reactive sensor placement. Testing still continues on Vasilius; however the team is very confident in all aspects of the design.

3. Mechanical System

The overall mechanical design of Vasilius focused on simplicity, durability, compactness, maintainability and most importantly, safety. The Vasilius team was able to meet every aspect of design. With the optimal mechanical design of Vasilius, the team produced an excellent platform for the vehicle. The mechanical design can be divided into three separate categories; vehicle frame, drive system, and vehicle body.

3.1 Vehicle Frame

The vehicle frame is constructed of steel tubing. Steel tubing was chosen due to its light weight, durability, and its ability to house wiring. The tubing acts as conduit to conceal and organize connections as well as shielding vulnerable lines from RF noise. Two types of 1/8 inch thick tubing were used. One-inch square tubing was used for the parts of the frame that did not require significant holes to be drilled. This allowed the design team to keep the weight to a minimum. The second type of tubing (1.5″ x 1″) was used for the remainder of the vehicle's frame. The tubing was welded together in a simple rectangular arrangement. The rectangular design allowed the frame to be very strong while creating a protective carriage that houses the batteries, chargers, and other various components. A 1/16 inch thick steel plate was used on the bottom of the frame to enclose the bottom portion of the frame. The plate provides a surface to place the batteries as well as component protection from debris and water.

3.2 Drive System

Vasilius uses two 24-volt DC motors to power the two drive wheels independently. The motors are attached to the drive wheels at 90 degree angles and pivot vertically through a bracket welded to the frame. The brackets prevent any horizontal movement reducing stress on the motors. The motors are attached to the suspension system and travel with the wheels independently. The angles that the motors are mounted also vary as the vehicle travels across uneven ground. This ensures that a motor will not hit the ground when its respective wheel goes into a hole. The two rear wheels are free to rotate and change direction as the vehicle changes direction. The rear wheels are mounted on a pivoting arm that allows the wheels to travel vertically, independent of the main drive wheels. The pivoting arm allows 30 degrees of rear wheel travel in both directions. This differential drive system design provides the vehicle with a minimum width, short wheel base, low center of gravity, and significant ground clearance.

3.3 Vehicle Body

The vehicle's body frame work is constructed from 1 inch square aluminum tubing. The exterior of the body consists of formed aluminum with Lexan panels around the entire surface. The entire body is very light-weight, waterproof, and capable of protecting the components inside. The Lexan panels are held in place with quarter-turn fasteners that can be removed, by hand, very quickly. Due to the number of panels and their positions, components can be added or removed easily without removing the entire enclosure. The body of Vasilius protects components from water and from heat. The outer shell is equipped with fans that cool and circulate the air inside the vehicle. Shelving inside the vehicle body allows for component positioning and spacing, assisting in cooling the interior of the structure. The vehicle body design achieved protection, maximum space utilization, ease of maintenance, as well as a pleasant appearance.

4. Electrical System

The goal of the Vasilius team was to model an electrical system after the human decision making process. This idea was new to the team and more complex than any of the previous BSC vehicles. However, the team achieved their goals and objectives in the design, producing a new and improved electrical system capable of winning the IGVC. The electrical system consists of four parts; the power system, sensors, computers, and vehicle control.

4.1 Power System

Two 12-volt deep cycle marine batteries connected in series provide the power to the controller, motors, main computer, and LMS. Two smaller 12-volt batteries power the sensors, emergency stop contactor, and a DC-DC converter. The on-board laptop is equipped with two batteries for its own power. The DC-DC converter provides +12V, -12V, and 5V for the various requirements of the electronics. After performing a power consumption analysis, the team was able to balance the power consumption across all of the batteries. This balance provides maximum run time and prevents “weak links” in the power system. In normal operation, the vehicle operates for six hours on a fully charged set of batteries. All of the batteries are mounted and connected with quick replacement in mind. A complete replacement of batteries can easily be completed in just a few minutes.

Vasilius is equipped with its own on-board charging system. The charging system consists of one 24-volt charger and two 12-volt chargers. The on-board laptop also has its own charger. Once switched to a charging mode, all batteries and electronics are isolated. The electronics are then available to be powered from an AC outlet. Therefore, all the batteries are charged simultaneously, and the vehicle can be tested via an extension cord while the batteries are charging.

Vasilius has battery monitors on-board as well. The LED displays allow the user to easily see the voltage level of every battery. Therefore, actions can be taken before the voltage levels become dangerously low.

4.2 Sensors

Vasilius is equipped with a multitude of sensing devices. This variety of sensors was chosen in the electrical system design to provide various levels of data and redundancy similar to human senses. The following are the sensors on-board Vasilius, a brief summary, and their respective data:

- **Stereoscopic Camera** – The team designed and built a stereoscopic camera using two grayscale board-level CCD cameras with 6mm lenses. The two cameras had to be synchronized, integrated, and packaged. The stereo camera mimics human eyes. Like the human brain, Vasilius can take two slightly different images and create one image with depth information. The ability to associate distance with objects using only cameras is extremely valuable in the sensor fusion process. Camera data contains the entire environment; lines, potholes, obstacles, etc.

- **LMS** – The LMS uses a laser to scan 180 degrees of the environment the vehicle is traveling towards. The LMS data contains the precise distance and angle of all obstructions in its field of view.

- **DGPS** – The DGPS uses the global positioning satellites to obtain a position fix. It then uses a reference station and/or WAAS satellites to obtain corrections that improve position accuracy. The DGPS data contains position (latitude, longitude), heading, and velocity.

- **Digital Compass** – The digital compass detects the earth's magnetic fields. The digital compass data contains accurate heading when moving slow or stationary.

- **Encoders** – The encoders detect movement of the motor shaft with great precision. They also are capable of measuring ambient temperature. The data from the encoders contain position, velocity, azimuth, and motor temperature.

- **Diffuse Sensors** – Diffuse sensors detect a user defined color. By emitting light that reflects form a surface back to the sensor, the frequency can be analyzed and compared to a programmed frequency. The sensors can be programmed to detect a particular frequency (color) on the ground.

- **Proximity Sensors** – Proximity sensors detect obstructions. By emitting light that reflects from a surface back to the sensor, an obstruction can be found.

After selecting the sensors, the team categorized, prioritized, and integrated them. As shown in Table 4.1, the sensors were categorized as planning, reactive, or feedback devices. Next, the sensors were prioritized to achieve multiple levels of redundancy. After participating in previous competitions the team saw a clear lack of redundancy in most of the vehicles, causing low reliability. The Vasilius sensor design focused on providing the vehicle with human-like redundancy having sensors that "back-up" other sensors. In basic human navigation a plan is devised and then executed. However, if some unforeseen situation occurs, a reaction must occur in real-time and a new plan implemented. Vasilius mimics this method by using planning sensors to constantly devise a planned path of navigation. Isolated from the planning process, reactive sensors constantly check for mistakes and dangerous situations. The two processes are done in parallel interacting and trading control when necessary. Feedback is always provided for both processes and constantly updated. This approach provides more opportunities to correct mistakes and identify traps and dead-ends. Most importantly, Vasilius is very safe. By design, Vasilius should never run off the course or crash into an obstacle.

Device	Category
Stereoscopic Camera	Planning
LMS	Planning
DGPS	Planning/Feedback
Encoders	Feedback
Digital Compass	Reactive/Feedback
Diffused Sensors	Reactive
Photo Sensors	Reactive

4.1: Sensor Categorization

4.3 Computers

Designing an electrical system modeled after human decision making required a great deal of processing power. The human brain is divided into many sections that are responsible for different thinking processes. These processes occur simultaneously, yet separate from one another. However, the processes communicate and update each other constantly. The Vasilius team was interested in two of the processes; planning and reaction. The computing system was divided into two parallel systems to achieve this idea. A central computer is responsible for planning and vehicle control, while a second computer constantly checks for unforeseen situations and correct execution of the desired plan. Working together, the computers can provide a redundant, effective, and self monitoring means of navigation. A third, off-board, computer was also implemented to provide remote control, monitoring, and convenience. The three computers are listed below.

1). Onboard Central Computer (primary)

- Specifications:
    - 533 MHz processor
    - 128 MB RAM
    - Windows 2000
    - 4 Input framegrabber with two 2 input synchronization capability
- Responsibilities (Planning)
    - Controls motors and brakes for vehicle control.
    - Responsible for camera inputs, image processing and image analysis.
    - Receives peripheral updates from secondary computer.
    - Makes navigational decisions based on the vision algorithm and secondary computer updates.
- Feedback
    - Positioning - Encoders.
    - Speed – Encoders.
    - Azimuth - Encoders.

2). Onboard laptop (secondary)

- Specifications:
    - 1.8 GHz processor
    - 256 MB RAM
    - Windows XP
- Responsibilities (Reactive)
    - To obtain and interpret/analyze all non-vision peripheral data.
    - Make decisions based on data.
    - Relay information to the central computer.
- Feedback
    - Positioning - GPS.
    - Heading - Digital Compass.

3.) Off-board laptop (Monitoring and Remote)

- Specifications:
    - 1.8 GHz processor
    - 256 MB RAM
    - Windows XP
- Responsibilities

- To provide a convenient method of remote control.
- Perform system monitoring during testing.
- Allows user to see the following data:
  - Acquired images.
  - Sensor status.
  - Algorithmic computations.
- System monitoring without interrupting vehicle operation.
- Gives user a valuable tool for testing and debugging
- Allows user to do the following:
  - Write new algorithms remotely.
  - Remotely modify existing algorithms.
  - Execute software on the vehicle's main computer remotely.

Figure 4.1 shows the two onboard computers as well as the off-board computer. The two onboard computers make up two parallel subsystems that create the entire electrical system.

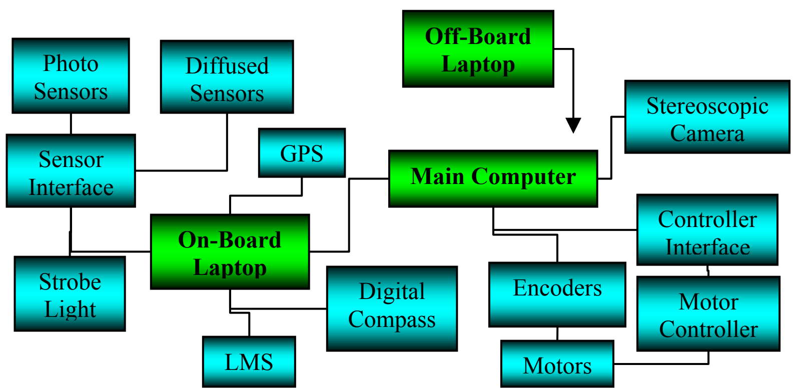


Figure 4.1: Computer Integration

4.4 Vehicle Control

Vasilius uses a closed loop proportional integrated derivative control system consisting of a central computer, controller interface, motor controller, motors, and encoders. The motor controller originated from an electric wheelchair. Therefore, it required an analog signal from a joystick. The team designed and built an interface that would provide the controller analog signals from the computer's digital signal. Two analog signals are generated, one for forward/reverse and one for left/right. The multi-axis controller then sends the correct signals to the motors. Encoders monitor the motors and provide feedback to the central computer. The electric wheelchair motor controller

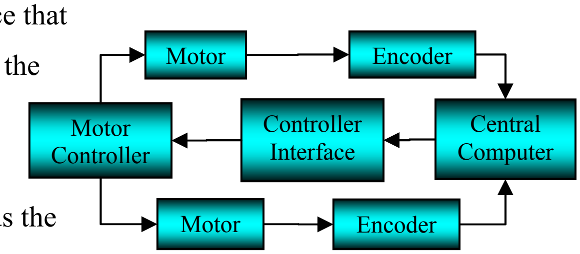


Figure 4.2: Control System

was chosen because it was designed for a single human input that controls vehicle direction, speed, and azimuth. This method of control enhances our overall human-like design. Figure 4.2 shows a block diagram of Vasilius' control system.

5. Software Design

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 twice 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 the vehicle size and speed.
- 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.
- To keep safety, reliability, and durability top priorities in software design.

To meet these software design objectives we had to choose and optimally integrate various sensors.

5.2 Sensor Integration

The sensors on Vasilius fuse together to provide a broad range of sensory input in order for the vehicle to perform four major functions; lane following, object detection, leader following, and waypoint navigation. We developed sensor integration on Vasilius using two complimentary ideas: long-range trajectory planning and short-range reaction. Each sensor function is shown in Table 5.1.

Sensor	Function
Stereo Camera	Long-range trajectory planning
LMS	Long-range trajectory planning
DGPS	Long-range trajectory planning
Diffused Sensors	Short-range reaction
Proximity Sensors	Short-range reaction

Table 5.1: Sensor Functions

Vasilius plans its trajectory twice per second using any combination of the three planning sensors. If no errors occur in trajectory planning and execution, the vehicle will not need to use the reaction sensors. In the event a reaction sensor detects a road edge or close obstacle, the vehicle responds to the reaction sensor. Once the reaction sensors are all clear then the vehicle

Sensor	Priority
Diffused Sensors	Highest
Proximity Sensors	High
LMS	Medium
Stereo Camera	Low
DGPS	Low

Table 5.2: Sensor Priority

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 just to test the reaction process. This philosophy is similar to how humans navigate. Just as humans use priority levels in their senses, Vasilius uses a priority system for the sensors as illustrated in Table 5.2. Although the stereo camera and DGPS priorities are low, these sensors are used all the time except during "interrupts" from the reaction sensors.

Vasilius' algorithm combines the information gathered from the LMS and the stereoscopic camera to produce a 3-D map of the course in front of the robot. This map shows lanes and obstacles up to eight meters away. The program transfers object distances as measured by the LMS to the map produced from the stereoscopic images. In the next sections, we describe how Vasilius employs these concepts and sensor integration to perform the four major functions.

5.3 Lane Following and Obstacle Avoidance

Vasilius uses a trajectory planning process to plot the optimal path between lanes and obstacles using the 3-D map produced from the fusion of stereoscopic images and LMS data. We use several methods of image processing: Sobel Amplitude and Canny edge detection, as well as Binary Thresholding. Processing speed on Vasilius 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 ten 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 Object Detection and LMS data, we turn the robot left and right so as to keep the object in the center of the vision screen and at a specified distance. The robot maintains distance using a combination of stereo vision and LMS data. If the disparity of the two detected objects from the stereo images decrease, the robot increases speed, and vice versa. LMS measurements also provide distance. The LMS is only used to ensure that the object being tracked stays within a specific distance threshold.

5.5 Waypoint Navigation

Vasilius' waypoint navigation algorithm uses DGPS, a digital compass, LMS, and proximity sensors to navigate around obstacles to target points. This algorithm has the structure as shown in Figure 5.1. The DGPS receiver has both WAAS-enabled and differential beacon modes. With a beacon, we can achieve 2-foot accuracy 67% of the time. By subtracting initial errors between given and measured positions at the start, we can subtract off this error. As long as the robot can finish the course in less than five minutes, DGPS errors should not change significantly.

1) Input coordinates of Start and all Targets
2) Find initial error between given and measured Start position
3) Start Vasilius in forward motion
4) Move to next target by comparing robot position to next target position
5) Monitor LMS and proximity sensors for obstacles
6) If obstacle, react until clear, go to Step 4
7) Increase target number once target is found
8) If target number is ten, then stop robot
9) If target number < ten, go to Step 4

Figure 5.1: Waypoint Navigation Algorithm

6. Analysis of Predicted Performance and Results

Design and testing indicates that Vasilius should perform as indicated in Table 6.1. 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.

Performance Measure	Performance Prediction	Performance Results
Speed	5 mph	4.9 mph
Ramp Climbing	20-degree incline	18-degree incline
Turn Reaction Time	360 degrees/ second	315 degrees/second
Battery Life	8 hours	6 hours
Stop Reaction Time	Immediate	Almost Immediate
Object Detection	0 to 8 meters	0 to 8 meters
Dead-Ends and Traps	Chosen paths are clear	*
Potholes	Chosen paths are clear	*
Waypoint Accuracy	2 feet one sigma	2 feet one sigma

Table 6.1: Analysis

7. Other Design Considerations

7.1 Safety

Safety was our most important concern in all aspects of the design, fabrication, and operation of Vasilius. We believe that part of its autonomous function is safety. This was accomplished through many different processes and was infiltrated throughout our design process. Especially important are the two manual pushbuttons located at the rear of the vehicle which, when pressed, disconnect power to the motors thereby effectively stopping the vehicle. In addition, we included a remote e-stop system consisting of an infrared transmitter and an onboard receiver. Fuses, circuit breakers, and disconnect switches protect all of Vasilius' components from overloads, noise spikes, and short circuits. Our overall system of interrelating sensors provides us the opportunity for safe navigation because of the inherent redundancy applied throughout our software.

7.2 Reliability

We have noticed the lack of reliability in many of the vehicles from past competitions. Therefore, we have stressed the reliability of Vasilius. 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 stereo camera and the diffused sensors detect the presence of lanes. The stereo camera algorithm also doubles with the LMS and proximity sensors in detecting objects.

7.3 Durability

Vasilius' solid mechanical design makes the vehicle very durable. Its framework houses and protects components. The exterior shell of the vehicle prevents water and debris from coming in contact with the electrical system. Components on the exterior of the vehicle are waterproofed and designed to withstand minimal damage. The vehicle can be operated under normal circumstances without fear of accidental damage to vital components or affecting the vehicle's overall performance.

7.4 Cost

Item	Actual Worth	Our Cost
Main Computer/ Framegrabbers	$4,200.00	$3,410.00
LMS 220/interface	$8,852.46	$5,707.72
Two Laptops	$4,800.00	$4,232.00
DGPS	$3,000.00	$2,100.00
Six Diffuse Sensors	$517.50	$517.50
Two Encoders	$1,322.00	$1,322.00
Digital Compass	$806.00	$806.00

Item	Actual Worth	Our Cost
Two board-level cameras Two 6mm lenses	$960.00	$960.00
Six Proximity Sensors	$600.00	$90.60
Steel for Frame	$200.00	$0.00
Aluminum/Lexan	$500	$0.00
Miscellaneous	$600.00	$600.00
Total	$25,357.96	$19,745.82