Bluefield State College

Vehicle Design Report

2005

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

Signed, Date

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Introduction

The Bluefield State College (BSC) Independent Projects Organization (IPO) team is proud to present an innovative and exciting project that we have created over the last year. As time has progressed we have had Centurion, Vasilius, and now Anassa. Anassa is a highly integrated and control-oriented ground robotic vehicle (GRV). Anassa is the most “intelligent” GRV that BSC has ever produced. Seamless data flow between interconnected systems allows for quick responsive navigation decisions, trap recognition, and obstacle avoidance. Our vision in imitating human thought pattern processes is why our growth in this field has and will continue to be exponential. This project will increase Bluefield State College’s stature in robotics and our future as the leaders of system integration and applied technology.

Project Anassa is one of the best overall designs to come forth from Bluefield State College. Every detail from idea, to design and completion has been meticulously tested and evaluated. This report will document each area of focus and show how attention to detail will generate a leader in autonomous systems. The areas of focus are: Design Process, Mechanical System, Electrical System, Software Systems, Analysis /Predicted Performance Results, Other Design Considerations, and Future Directions for Anassa.

1. Design Process

The design process in Figure 1 came from the team’s previous experience in the Intelligent Ground Vehicle Competitions (IGVC). For time management concerns, the team’s goal was to utilize previous design information / testing and encompass new and innovative ideas to build upon past successes.

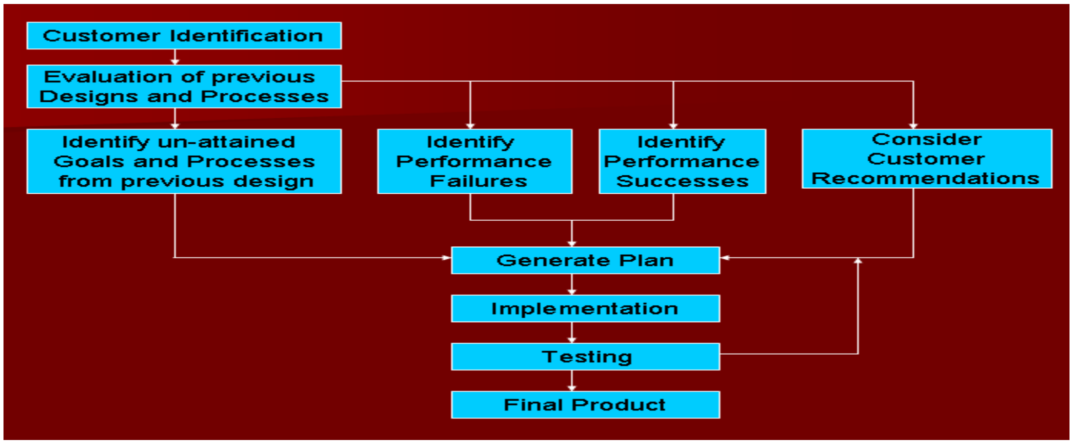


Figure 1. Design Process for Anassa

1.1. Customer Identification

For the customer identification phase of the design process, the BSC IPO team recognized the benefits of an intelligent ground robotic vehicle. The initial customer was Team CART (Center of Applied Research and Technology) which used Anassa as a test platform for the large-scale ScorpionFox vehicle that will participate in the DARPA Grand Challenge in October 2005. Not to limit the GRV's highly innovative and versatile platform, the team's additional customer base is mine search and rescue, military mobility, intelligent transportation systems, and industrial applications.

1.2. Evaluation of Previous Designs

After customer identification, a series of meetings were scheduled to evaluate previous robotic designs. From those meetings a list of un-attained goals, performance failures, and performance successes were identified and discussed. In addition new goals, design ideas and customer recommendations were listed and taken into consideration.

1.2.1. Identify Un-attained Goals

In previous designs such as Vasilius, the necessity of a stable platform with the proper weight distribution was identified as an area needing improvement. This instability in Vasilius limited speed and maneuverability of the exceptional GRV. Another un-attained goal was reliability. The probabilities of hardware failures overshadowed the team because of the complexity and sensitivity of the JAM controller (JAM is the name of a controller created by BSC students) and lack of replacement parts to facilitate quick repair. Although these goals were not attained in previous designs, Anassa will achieve these goals.

1.2.2. Identify Performance Failures

The LMS mount design height limitation was a critical flaw which was identified in the Vasilius GRV. In the 2004 competition, tall grass reduced the effectiveness of the unit and reduced the team's chances for success. Another flaw identified with Vasilius was that the glare on the competition course bridge reduced the effectiveness of the navigation algorithm. Also, non-rigid camera masts in previous designs created some vision stability problems. Anassa will overcome these performance failures.

1.2.3. Identify Performance Successes

Design concepts that proved successful in previous GRV designs were dual processing power of multiple computers, compactness of the GRV, internal real estate assignment, body design, and the sensor integration algorithm. Anassa capitalizes on all these past successes.

1.2.4. Consider Customer/Team Recommendations

The team's main recommendation was a control system that was universal in nature, well-documented, and easy to troubleshoot / repair. This system would be designed so that it could be integrated into any 24-volt control system for use with multiple projects, could be easily bypassed for manual control, and would be designed for system growth. Projects include the DARPA Grand Challenge as well as the IGVC.

1.3. Generating a Plan

1.3.1. Team Organization

During the first stages of the design process a team of engineers was assembled. Team Anassa consists of students in many different disciplines including electrical, mechanical, and computer science fields. Each team member was assigned specific responsibilities according to his/her strengths. A unique concept utilized this year was the position of a system administrator. The system administrator coordinated various design and testing schedules and provided information for each member as to the status of various processes. This concept kept the team on schedule and brought team productivity to the maximum potential. For each team member, the following table shows responsibilities, class information, and estimated hours worked in fabrication, design, and testing of Anassa.

Team Member

Team Member	Responsibilities	Class Level-Major	Hours worked (est.)
Mark Myers (Team Leader)	Navigation Software Design, Electrical design	Senior – EET	900
Lenny Lewis	Hardware	Junior – EET	750
Joy Huntley	Software Design	Junior – CS	600
Joshua Mullins	Electrical Design	Junior – EET	300
Heather Williams	System Administrator	Junior – EET	600
Jesse Farmer	Mechanical Design	Junior – MET	300
Tabitha Pack	Graphics	Sophomore – CS	100
		Total Man Hours:	2650

Table 1

1.3.2. Design Tools

Multiple software packages were used in designing Anassa. Software such as PSPICE, Solid Edge, Matlab, Visual Studio, and Multisim played a critical role in the development of an intelligent and streamlined GRV. The platform was designed in Solid Edge allowing 3D visualization before the final product was ever reached. All wiring diagrams and designs were done in PSPICE and Multisim which allowed for testing and layout before these circuits were made. Matlab was used to model lens distortion and to calculate various other parameters of GRV functions. Visual Studio provided user-friendly interfaces for testing and executing programs.

1.4. Implementation of Plan

1.4.1. System Integration

For system integration on Anassa, the main concern was effective communication between all systems. For that purpose, the BSC IPO team developed the Majohele control system as seen in Figure 2 (Majohele is the name given to a control system created by BSC students.) This system provides data pathways for communication of all system components and adds additional safety feedback loops in software and hardware. The system is similar to a human nervous system. One computer mimics the upper level brain function such as decision making and the second computer acts as the cerebellum and communicates with the nervous system and handles feedback.

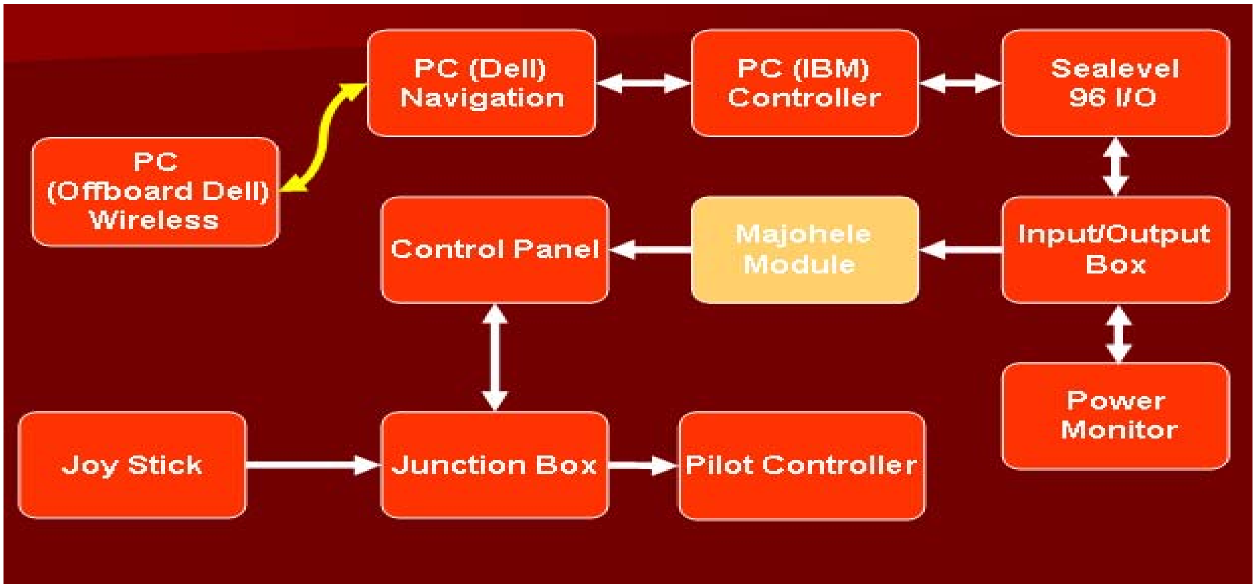


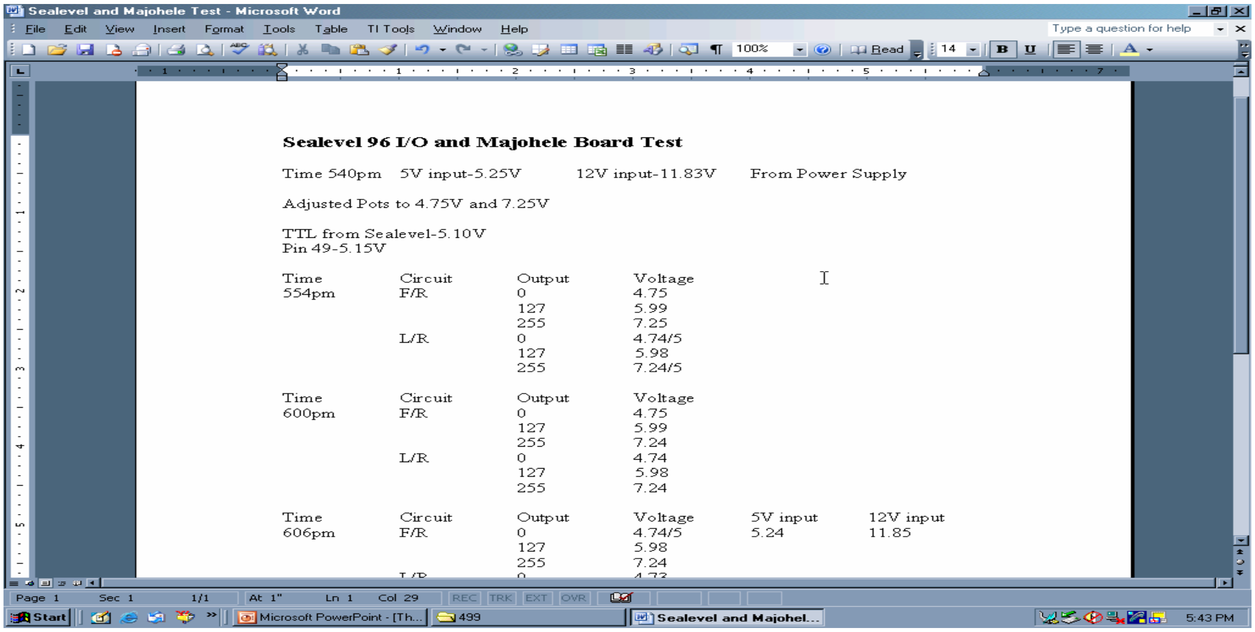
Figure 2. Anassa's Control System

1.4.2. Construction

Initial construction began with the Majohele Control System. The system components were acquired along with documentation. Additional documentation of circuit board construction, pin configurations, wire colors and routing was done for troubleshooting and for future design additions. Construction of the temporary platform similar to the final design was completed next, to allow for testing of interconnected systems and to allow time for the final platform fabrication to be contracted and completed.

1.5. Testing

An extensive and rigorous testing schedule of each component was completed as set forth in the design process. All modules constructed had to pass predetermined guidelines for stability and reliability. As a part of documentation, performance results were tabulated and filed for future reference. For example, the figure below illustrates a test procedure for the I/O and control board.



Sealevel 96 I/O and Majohele Board Test

Time 540pm 5V input-5.25V 12V input-11.83V From Power Supply

Adjusted Pots to 4.75V and 7.25V

TTL from Sealevel-5.10V
Pin 49-5.15V

Time	Circuit	Output	Voltage
554pm	F/R	0	4.75
		127	5.99
		255	7.25
	L/R	0	4.74/5
		127	5.98
		255	7.24/5

Time	Circuit	Output	Voltage
600pm	F/R	0	4.75
		127	5.99
		255	7.24
	L/R	0	4.74
		127	5.98
		255	7.24

Time	Circuit	Output	Voltage	5V input	12V input
606pm	F/R	0	4.74/5	5.24	11.85
		127	5.98		
		255	7.24		
	L/R	0	4.73		

The testing component of the design process is a continuous loop. After off-board testing, multiple systems were interconnected and evaluated for performance and to make sure that design requirements were met. For example, in the later stages of testing, a module designed for battery monitoring proved to be flawed. Preliminary testing proved successful; however, once the system was integrated the error surfaced. This critical fault allowed voltage to surge through Anassa's ground network and damage systems.

This mistake proved to be a valuable learning tool for the team. The extensive documentation allowed the team to find the miscalculation, track down all potential damage, redesign, and recover from the significant event within days. The replacement components had been built or acquired in the early stages, so repair was quick and efficient.

2. Mechanical Design

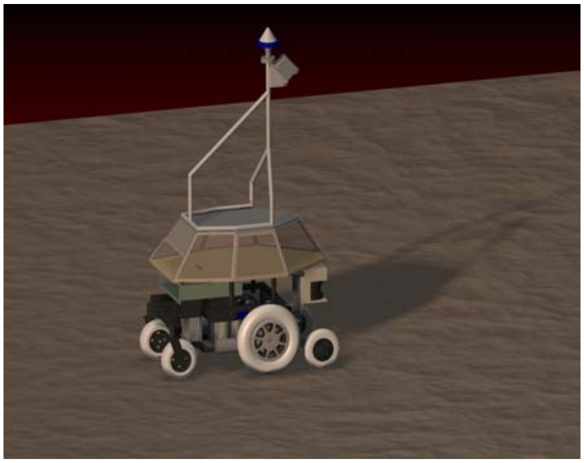
2.1. Vehicle Frame, Drive System, Chassis

Rather than reinvent the wheel, our team concluded that due to the already established outstanding dynamics and stability of certain outdoor electric wheelchairs in the medical community, we would convert the Jazzy1170 XL Electric Wheelchair chassis and frame. The Jazzy 1170 XL is a rugged outdoor chair with a frame constructed from 2.5"x3/4" and 1" square milled steel that will carry a weight-bearing load of up to 400 lbs. It has been modified to accommodate the Anassa control platform making Anassa's overall dimensions 26"x 45". The compact width of the frame along with the outstanding solidity allows for a tight turning radius of 22.5 inches. The chassis includes an active-trac suspension, 16" pneumatic wheels, adjustable 9" solid rear casters, and adjustable 8" anti-tip wheels for stability. Both chassis and frame are designed with a low center of gravity allowing a ground clearance of 4.25 inches with a curb climbing height of 6 inches. A two motor mid-wheel drive design powered by two 12 volt deep cycle batteries provides excellent maneuverability while also allowing for a range of speeds up to a maximum speed of 6 mph (Anassa limits the chair's top speed to 4.9 mph for IGVC.)

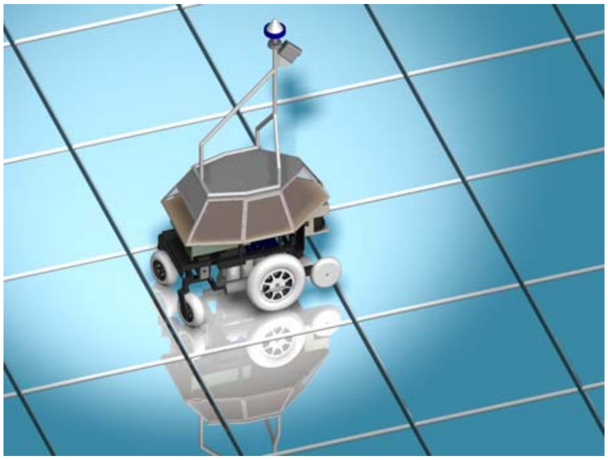
2.2. Vehicle Platform

The vehicle platform design of Anassa incorporated key concepts such as low cost, ease of manufacturing, and quick production while at the same time making many improvements over Bluefield State College's previous IGVC robots. The new design was first conceptualized by using Solid Edge v16, a 3-D modeling software package. Utilizing Solid Edge, we were able to arrange and place components in a way that provided more space and avoided clutter.

With the design of Anassa, improvements were made to the rigidity of the body and mast assemblies. This was accomplished by welding these components into two separate, solid structures. In addition, these and other components were designed to fasten to the chassis to allow easy access to the internal parts and also to allow easy disassembly and transportation. All sheet metal parts were cut out with a CNC laser torch, which gave clean and accurate cuts on all parts. The body panels and mast were made out of polished aluminum, which not only reduced the amount of internal heating, but was also aesthetically pleasing.



Another key objective in this design was making the body watertight to allow the robot to operate in light rain. This was accomplished by using weather stripping around all removable panels and enclosing the battery and other under-body components with sheet metal skirts. We chose to use skirts around the robot's lower half to protect all under body components from dirt and water. Furthermore, a hood was designed for the camera to protect it from rain and shade it from the sunlight. Every one of these issues was resolved while at the same time improving the robot's aesthetics.



3. Electrical Design

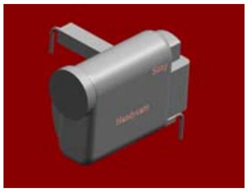
3.1. Power System

The power system requires 24 volts. Two 12V deep-cycle marine batteries are placed in series to provide power to the Laser Measurement System (LMS), controller, motors, and manual joystick. Two smaller 12V batteries are used to power the DC-DC converter, emergency stop button, and Differential Global Positioning System (DGPS). A power analysis has shown that Anassa can operate on internal power for up to four hours. Battery and power monitor modules are designed to allow the system to self monitor. These components add to the safety of the overall system by allowing the computer to make the decision about low voltage levels and the possible resultant errors.

3.2. Sensors

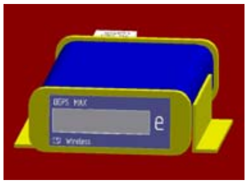
Anassa takes advantage of cutting edge technology, and the suite of sensors that were integrated into Anassa came from previous successful designs. Each sensor has special characteristics that the overall system requires to achieve success. Some sensors provide redundant information to allow for increased accuracy. Others provide unique qualities that enhance the human aspects of Anassa. The following is a list of sensors and a description of each:

- **Digital Camcorder**- This sensor acts similar to human eyes, giving vision data allowing detection of potholes, line boundaries, and obstacles obstructing the path. The ability to handle various lighting conditions plus the availibility of abundant accessories make this the sensor of choice.



- **LMS**- The LMS uses a laser to measure in an 180-degree field in which the vehicle is traveling. It allows for precise measurement of angle and distance to an object in the LMS plane of view.

- **DGPS-** The DGPS uses satellites to acquire a fixed position and then utilizes a reference station and/or WAAS satellites to improve position accuracy. The DGPS data contains position (latitude and longitude), heading, and velocity. Anassa will also use the Omnistar correction service, achieving sub-meter accuracy.



- **Encoders-** Encoders detect movement of a motor shaft with great precision. The precise feedback ensures proper movement. The encoders are also capable of measuring

ambient temperature. The data from the encoders contain position, velocity, azimuth, and motor temperature.

3.3. Computers

Three computers are utilized in project Anassa. The primary computer's main objective is to correlate sensor data into a virtual map for the navigation algorithm to make decisions based on real-time data. The secondary computer is strictly for control and feedback. The control (secondary) computer interprets data sent from the navigation (primary) computer and translates it into mechanical action corresponding to the GRV vector (intended direction and speed of the GRV.) The third computer is utilized off-board. While its primary function is to provide remote system diagnostics and data recovery, its secondary functions are internet control and peer to peer wireless control.

3.4. Vehicle Control Modes and Functions

For vehicle control, two modes were integrated into the Majohele system to provide complete and total control of Anassa: a manual control mode for movement in non-autonomous situations and a computer control mode (or autonomous mode) for autonomous navigation.   A single toggle switch is used to choose between modes. Autonomous mode utilizes the Majohele module as a virtual joystick to mimic the original joystick that came with the electric wheel chair.

4. Software Design

4.1. Design Objectives

The major design objectives in software construction were to utilize a module type approach and to encompass safety in each software module. Various modules could be implemented to provide various scenarios of software interaction. For example, simulations were built to mimic data from sensors and to help create the decision making or "intelligence" of the navigation algorithm all the while keeping safety, reliability, and durability in the forefront of the venture. An algorithmic cost structure was built to make quick and efficient real-time decisions based on learning from test results. Therefore, Anassa can learn from her mistakes.

4.2. Sensor Integration

The eyes and ears of Anassa are the Sony Digital Camcorder and the Sick LMS. Anassa's unique vision is created through a vision module that removes lens distortion, recognizes colors in multiple light environments, and provides accurate distance measurements comparable to stereoscopic vision systems. Next, the highly accurate LMS data and the color vector vision data are integrated into a virtual real-time map. The integration of these sensors create redundancy, error reduction, and the ability to utilize data beyond the scope of the LMS plane alone.

The DGPS brings Anassa's virtual map into real geodetic space. This incorporation allows Anassa to find any target in or out of the sensors' range. In addition, the DGPS allows Anassa to maneuver out of seemingly impossible trap situations and expand her artificial intelligence capability.

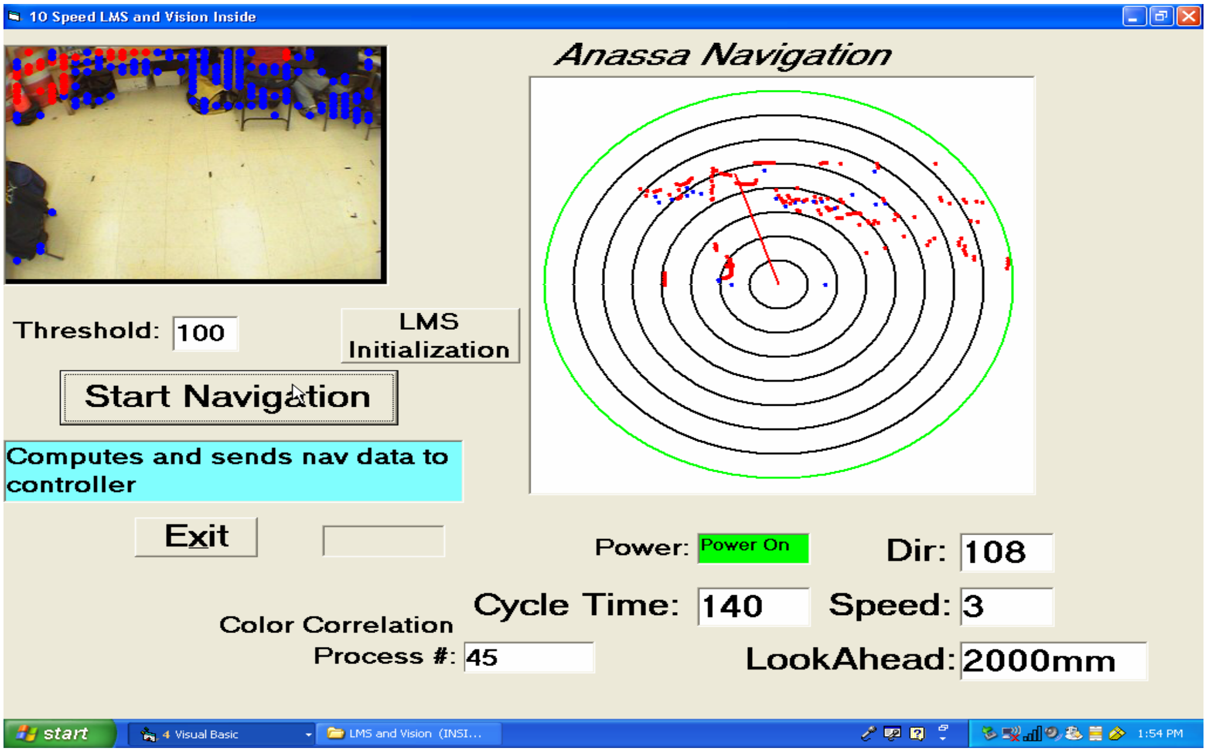
An important point of the total software system is that the navigation module can function with all or just one sensor input. The additional sensor systems make for a more precise and informed decision; however, with sensor failures the system could still interact with its environment and complete the mission.

4.3. Navigation, Lane Following and Obstacle Avoidance

Humans weigh the cost of decisions in their everyday life. Over time they learn which decisions provide the best outcome and utilize this knowledge to create a path through life. Anassa employs the same technique. Lane following and obstacle avoidance is achieved through the navigation algorithm's unique cost module.

This cost structure is a learning tool for Anassa and allows for ever increasing intelligence and learning. Anassa learns through modification of her cost module. Various parameters are evaluated and have a cost applied to each one. Parameters of cost evaluated are path width, angle of approach, number of obstacles in path, the amount of planned path deviation to reach target, trap probability, and bearing to target in GPS applications. With that information in memory the navigation algorithm examines the multiple paths and simply chooses the most favorable approach much as a human being would.

Next, speed needs to be determined. This is done through zones on the robot's mapped space. Data points in each zone determine speed of the GRV. For example, as an object becomes closer, Anassa reduces speed. Also, after obstacles are cleared, speed increases to minimize travel time. In addition to zones, a ramping function is built in to allow for smooth transitions of speed. The figure below illustrates Anassa's reaction to clutter displayed by a graphical user interface. Speed is represented by the length of the vector.



Threshold: 100

Computes and sends nav data to controller

Power: Power On

Dir: 108

Cycle Time: 140

Speed: 3

Color Correlation Process #: 45

LookAhead: 2000mm

Anassa also has a unique system named the Lookahead module. This module was created to enhance the rate that Anassa could handle data. For example, a human driving in a car looks ahead to see possible obstacles. As obstacles approach the focus is on the closest obstacle, however the path ahead is still in memory but is not as relevant as the current view. Then once the path clears, planning returns to the distant view. This logic allows for decreased processing time by optimally trading focus between the closer, more critical obstacles and obstacles in the distance. However, Anassa takes all the data into account for trap recognition and then, in obstacle avoidance situations, utilizes the cost set to possible trap angles in computation of its vector. This approach takes significantly less time to compute the vector.

In the rare event a trap is not avoided, a module was designed to aid Anassa in the art of escape. This is done with probabilities of angles that would allow Anassa to back out of a trap in the initial trap footprint and recognize which direction of travel will relieve the trap situation. In previous GRV vehicles, an oscillation or a simple backup routine was utilized. Anassa has the ability to realize a trap situation and calculate the most probable angle that will release her from the situation. Later designs of this application will encompass a GRV-placed GPS point in the direction of travel to allow for complex trap solutions that allow the vehicle to travel in the wrong direction to relieve the trap situation.

Another possible situation is the "no path found" scenario. In this event, Anassa has a HighPoint module which will actively search for an unseen path. Anassa calculates the best or most cost effective path toward the destination and examines new data as she progresses. Therefore with the combination of trap recognition and the HighPoint module, Anassa can actively search seemingly dead end routes to find hidden paths.

Anassa solves the dashed line problem by always requiring at least one line in view. If a line and obstacles on one side disappear, Anassa turns and searches for the missing line on the opposite side. By always maintaining obstacle/line points on the map, Anassa will not "escape" the path by darting out between dashes.

5. Analysis of Predicted Performance

Design and testing indicate that Anassa should perform as noted in Table 2. The table also indicates our results so far. A "*" symbol means that measured performance could not be evaluated without further research. Each prediction listed in the table comes from analysis of components as well as overall performance.

Performance Measure	Performance Prediction	Performance Results
Speed	6 mph	4.9 mph (software restricted)
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 2

6. Other Design Considerations

6.1. Safety

Anassa was integrated with multiple safety features. In software, each computer contains an active loop that examines system power, battery condition, and control and communication status. In the event of errors the system has the ability to stop the vehicle until problems are identified and corrected. In hardware, independent multiple E-Stops were designed to provide various levels of control. A hard E-Stop shuts all systems down completely. A soft E-Stop allows for controlled shut down without the harsh effects of the hard E-Stop. A remote E-Stop provides for wireless soft stops up to a distance of 100 feet.

6.2. Reliability

Redundancy is the tool we used to achieve a higher level of reliability. Back up components were acquired or built to facilitate quick repair. Software was written to handle sensor failures and data loss. Consequently, Anassa’s reliability is by design.

To ensure reliability, rigorous simulations and testing with multiple scenarios to cover every conceivable error condition were done. As with any testing and quality assurance process, this will be continuous. Therefore, the team will adhere to the highest standards of reliability.

6.3. Durability

Anassa's mechanical and electrical 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 impact. The vehicle can be operated under normal circumstances without fear of accidental damage to vital components or affecting the vehicle’s overall performance.

Electrical durability comes from the team’s design process. Every advantage was utilized from previous design concepts, previous failures, and experience of a top quality team and GRV.

6.4. Cost

Cost was evaluated to facilitate documentation and budgets for future replication of the Anassa concept vehicle. Table 3 has a brief listing of various components included in the construction of Anassa.

QUANTITY	DESCRIPTION	OUR COST	ACTUAL COST
1	1170 Wheelchair frame(Used)	$ 1,037.00	$ 5,977.00
1	Dell computer	$ 1,600.00	$ 2,400.00
1	IBM computer	$ 0.00	$ 1,600.00
1	Sony camera	$ 700.00	$ 700.00
1	180 degree LMS(SICK)	$ 3,000.00	$ 5,000.00
1	DGPS-w/antenna/cables	$ 1,800.00	$ 2,700.00
1	Sea Level w/input/output boards.	$ 400.00	$ 400.00
1	Aluminum platform	$ 0.00	$ 200.00
1	Remote receiver kit	$ 39.95	$ 39.95
1	LED Battery monitor kits	$ 30.00	$ 30.00
1	Computer sense battery monitor	$ 24.00	$ 24.00
1	Computer sense power monitor	$ 12.00	$ 12.00
1	Heavy duty 70 amp contact relay	$ 0.00	$ 80.00
1	Hard E-Stop	$ 0.00	$ 30.00
1	Soft E-Stop	$ 30.00	$ 30.00
2	12 volt chargers	$ 120.00	$ 120.00
2	Control 12 volt batteries	$ 150.00	$ 150.00
1	Majohele controller	$ 25.00	$ 25.00
1	Cable connection box	$ 15.00	$ 15.00
5	Toggle switches	$ 16.00	$ 16.00
1	Misc. wire, cables & connectors	$ 50.00	$ 80.00
1	Misc. mount screws & hardware	$ 20.00	$ 20.00
1	Temporary platform	$ 0.00	$ 15.00
Total		$ 9,068.95	$ 19,663.95

Table 3

7. Future Directions for Anassa

The Anassa project has opened many doors of opportunity. Future directions for Anassa include:

- An adaptive cost structure. Such a cost structure would allow Anassa to learn in real-time.
- The assignment of uncertainties to sensor information and the modeling of the dynamics of Anassa. This information would feed an estimator such as an extended Kalman filter.
- The ability to autonomously search closed coal mines for high levels of gas such as methane. This application is very pertinent to the coal mines in the BSC area.