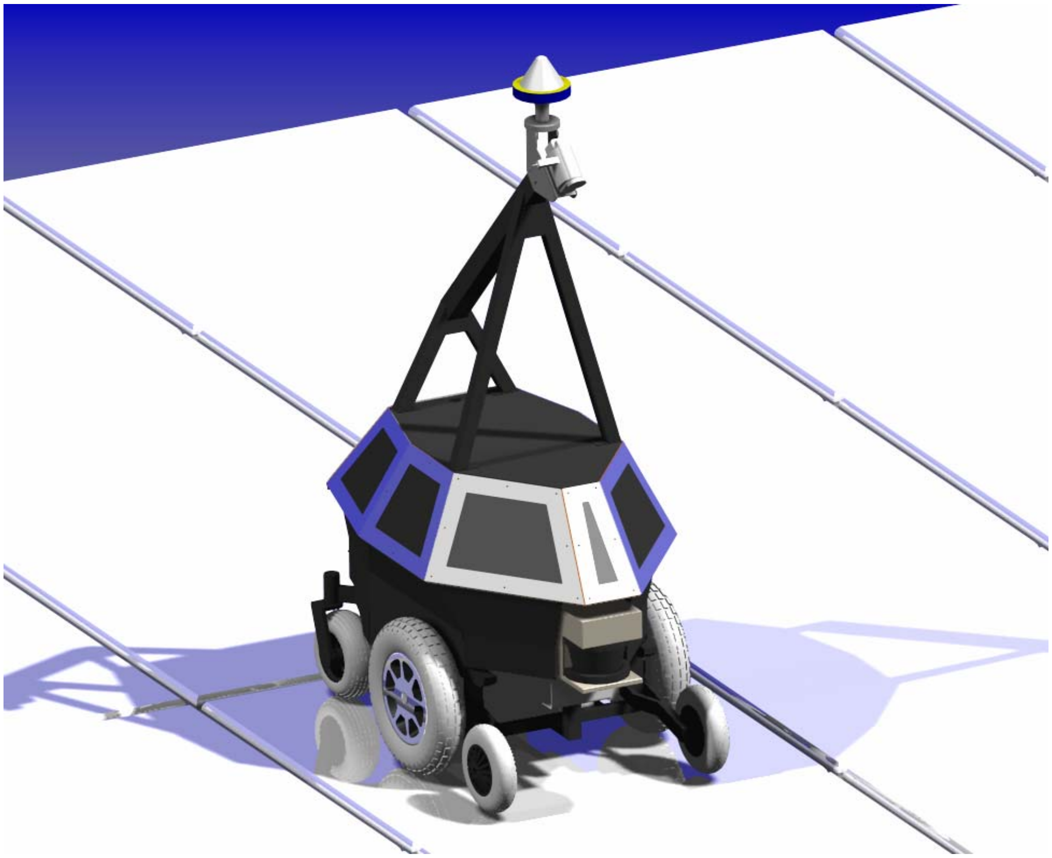
Bluefield State College
Vehicle Design Report
2007



Justin Stiltner, James Cardwell, Dwight Backus, John Browning, Justin Milam, Joshua Johnson, Cailan Blankenship, David Davis, Weston Monk, Justin Nichols, Mark Hankins, Jonathan Bonhomme, Brett Butler, Jason Duncan, Jordan Gibson

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 vehicle, Anassa III, has been significant and each team member has earned at least two semester hours credit for their work on this project.

Signed, Date

____________________________ ________

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l.0 Introduction

Bluefield State College, the Center for Applied Research and Technology, Inc. (CART), and the student robotics team are pleased to announce that the Anassa III robot is operational and ready for entry into the 15th annual Intelligent Ground Vehicle Competition. The current robot dubbed Anassa III is the evolutionary product of our original Anassa platform and the new student talent that the program has been able to attract during the previous year.

Anassa III has three major design innovations that we would like to give special attention:

1. The implementation of an adaptive vision algorithm for learning.
2. The installation of new hardware to facilitate object avoidance when doing reverse locomotion.
3. The inclusion of serviceability in Anassa III's design.

These innovations are detailed in Section 9 (Design Innovations). Our design team has an ongoing goal to increase the intelligence of Anassa to approach the characteristics of human thought processes which we believe are necessary to sustain autonomy for an extended period of time and when confronted with complex terrain.

Anassa III's team consists of a diverse field of students from four engineering technology disciplines: electrical, computer science, mechanical, and civil. Team members, responsibilities, class level and major, and hours expended on this project are shown in Appendix A.

The following report will describe both the design process and the product of the process in detail; however, we will first make some acknowledgements.

2.0 Audience

Although the judges of the Intelligent Ground Vehicle Competition (IGVC) event remain our primary focus, there are several secondary programs that benefit directly from the Anassa program. The Anassa program continues to serve us as our testing platform for developing and proving technology on a small scale before transferring it to our larger scale robotic projects. Currently we are developing two full-scale passenger vehicles; both are robotic, one is an electric race vehicle developed for the 2007 DARPA Urban

Challenge, and the other is a test vehicle for DARPA Urban Challenge algorithms. The Center for Applied Research and Technology, Inc. is our technology transfer affiliate and it is currently involved with autonomous vehicle research, mining safety, power utility maintenance, and other projects. The IGVC program at BSC is supported and managed by CART.

3.0 Contributors and Sponsors

Several local industries have made donations of parts, discounted our purchases, or provided assistance in some way that has greatly benefited our projects. These industries are Pemco, Inc., ConnWeld Industries, WalMart (Bluefield, Va.), DBT, and Charlatte America.

3.1 Funding and Budgetary Considerations

Funding for the project was limited and we must operate within tight budgetary constraints. Expense was many times the determining factor in our equipment selections. To reduce the expense of the project, we used inventoried components when available and solicited donation of parts as much as possible. Components used in the project are itemized in Appendix B along with their actual and replacement costs.

4.0 Design Planning Process

4.1 Evaluation

Design planning began with an evaluation of Anassa II and its performance in the 2006 IGVC event. We separated the Anassa II problems into two categories. Problems were either performance-related or non-performance-related.

4.2 Problem Definition

We will itemize the performance-related problems first. The results of this evaluation exposed the following:

1. Several problems related either directly or indirectly to the power supply.
2. The response from the wireless Emergency Stop (E-Stop) was unreliable.
3. Heading updates were too slow.
4. Reverse locomotion often resulted in rear collisions with objects.

5. The laptop computer was overwhelmed with reading and evaluation of vision, LMS signals, GPS signals, navigation, control and issuing commands.

The non-performance related problems were primarily difficulties we experienced in servicing Anassa II. We discovered that the wiring and component housings were simply not rugged enough. Anassa II was not physically constructed in a modular way that allowed rapid disassembly for servicing under competitive conditions. Monitoring of various functions to determine critical values relating to the operation of the robot required that personnel hover in too close proximity to Anassa II, thus physically blocking the navigational movements of the robot and possibly causing unnecessary course corrections or risking total confusion of the program logic due to our close presence.

We will describe our solutions to these problems throughout this paper.

5.0 Development of Design

5.1 Safety

Safety considerations in the design, building and testing of Anassa III were given top priority. All laboratory and workshop labor was performed in groups of at least two members, and in most instances three members of the team. No member worked alone in potentially hazardous activity.

Anassa III's hardware and software incorporate several safety features. The hardware utilizes multiple E-Stops to provide several levels of control. A battery monitoring system enables continuous monitoring of battery status.

Software programs continually monitor the system for errors in control, communications, and battery charge levels. "Heartbeat" (fault monitoring) signals are measured at critical points in the system. The software has the inherent "Failsafe" ability to abort the current mission and shutdown the vehicle in the event an error is detected.

5.2 Computer-Aided Design

Autocad and Solid Edge were used in the mechanical design of the vehicle. A sample of Solid Edge modeling of Anassa III's body is shown in Appendix D. Pemco, a local industrial sponsor, used our designs to fabricate most of Anassa's body parts.

5.3 Computer Simulation

Computer simulation of sensor data was utilized to provide a controlled environment for testing and debugging algorithms associated with autonomous navigation. Sensor simulation greatly accelerated the programming process. Our simulator software was written by previous IGVC teams. Appendix C shows the main screen used by the simulator. It is clear from Appendix C the simulator emulates an actual IGVC course from the past.

6.0 Mechanical Design

6.1 Vehicle Frame and Chassis

Anassa III retains the sturdy frame and chassis from Anassa II. For purposes of identification we will describe the frame and chassis in detail as follows.

The vehicle uses a modified frame and chassis of a Jazzy 1170XL electric wheelchair. The frame is constructed of fourteen-gauge milled square steel tubing that is built to sustain a payload of four hundred pounds. Both the frame and chassis components are weatherized with a primer coating and multiple layers of enamel paint.

The chassis components include an active-track suspension system that allows all wheels of the drive system to travel independently as the vehicle moves across uneven terrain. The vehicle is elevated by sixteen-inch pneumatic tires (the drive axle), adjustable nine-inch rear articulating caster wheels, and adjustable eight-inch anti-tip wheels for stability. The arrangement of the wheels provides a four and one quarter-inch ground clearance which generates a low center of gravity. This, coupled with the active-track suspension system, gives the robot a curb-climbing height of six inches. The overall robot base of twenty-two and one-half inches wide by forty-five inches long provides a tight turning radius of twenty-three inches.

6.2 Drive System

Anassa III retains the successful drive train of Anassa II. For purposes of identification we will describe the drive train in detail as follows.

The drive train consists of two twenty-four volt DC motors that provide vehicle locomotion. The motors are connected through a speed reducer to the drive axle. The speed reducer converts the high speed, low torque output of the motors to a low speed, high torque required to move a four hundred pound payload.

The robot is equipped with two braking systems. The regenerative braking system slows the vehicle down and a mechanical disk parking brake prevents the vehicle from moving. The disk parking brake was redesigned for the purpose of incorporating encoders onto the drive motors. To increase the safety of the braking function, the single core mechanical spring of the parking brake was replaced with three smaller, stronger springs on the outer surface of the brake pad. This increased the surface area of the brake by 3.8 sq. in. while increasing total braking force by 138%.

6.3 Body

Anassa III incorporates structural modifications to allow rapid separation of the body from the chassis (see Design Innovations, Section 9). The other basic body design elements remain the same as Anassa II. The body provides easy access and protection of the instrument compartment from the weather. The overall design of the body contributes to the aesthetics of the robot, with the clear, tinted lexan plastic panels revealing the interior components of the instrument compartment while sealing out dust and moisture.

All the frame components of the body are made of aluminum to provide strength with minimum weight. To maintain rigidity, the aluminum elements are TIG-welded together to form a single unit construction. The body seals the instrument compartment with weather stripping, rubber grommets, and sheet metal skirts.

The mast and body are removable from the chassis to facilitate the loading and transportation of the robot. Appendix D shows the Anassa III body.

7.0 Electrical Design

7.1 Power System

A complete redesign of the power system reduced the number of batteries from four to two. The two remaining batteries were then replaced with two heavy duty deep-cycle batteries.

Previously we relied on two separate battery systems, one twenty-four-volt system and one twelve-volt system. Two twelve-volt batteries were connected in series to supply the twenty-four-volt circuits and two twelve-volt batteries were connected in parallel to supply the heavy current required by the twelve-volt circuits. The twenty-four-volt system supplied power to the drive motors, motor controller, manual joy stick, and the SICK LMS (laser measurement system). The twelve-volt system supplied power to the Differential Global Positioning System (DGPS) receiver, the wheel encoders, compass, controller and the power converter that supplied five and twelve volts to the electronics.

The difficulties in monitoring and managing two separate power systems proved to be unnecessary. A new system with only two twelve-volt batteries are connected in series to supply the twenty-four-volt circuits and a new twenty-four-volt to twelve-volt converter supplies power to the twelve-volt circuit.

We were able to reduce Anassa III's *power consumption* by eliminating a contactor in the Hard E-Stop circuit. Although the contactor allowed us to use a light duty switch in the Hard E-Stop circuit the contactor was a continuous drain on the batteries. The light duty switch required the use of the contactor so we replaced the light duty switch and contactor with a single heavy duty switch, thus eliminating the need for the current draining contactor.

7.2 E-Stops

Anassa III has both a Soft E-Stop and also a Hard E-Stop located on the rear instrument panel. The on-board Hard E-Stop switches all power on/off. The on-board Soft E-Stop and the wireless E-Stop both switch the controller on/off, but they do not switch the main power. These two systems are independent of each other for additional safety.

We replaced the push button Hard E-Stop with a twist-push switch that has a higher current rating. The twist-push feature eliminates the possibility of accidental operation of the switch.

A new wireless radio controlled (RC) E-Stop has been installed that extends our control range to fifteen hundred meters. This new wireless E-Stop replaces the old unit that was becoming increasingly unreliable in tests.

7.3 Wiring

All control and power circuits were rewired and rerouted to better organize the electrical system for increased serviceability. A color coding scheme was employed with the new wiring to identify the type of circuit the wiring is connecting. New quick-disconnect connectors were attached to the new wiring to facilitate servicing.

The rewiring was routed through a fuse panel that ensured all circuits were fused. Previously, few circuits were fused; now Anassa III is essentially protected from electrical “self-destruction.”. With the new wiring, we centralized the distribution of all twelve-volt power and grounding.

7.4 Instrument Panel for Monitoring and Control

In an effort to centralize monitoring, we relocated the ammeter from the robot base to the control panel. Various indicator lamps were also added to the panel to indicate power delivered to the different functions of Anassa III.

A special “super bright” LED lamp and circuit was installed to indicate the on/off condition of the controller. Previously the condition of the controller was indicated with a standard LED which was originally installed in the interior of the instrument compartment. This arrangement required personnel to be in the immediate vicinity of the vehicle to determine the condition of the lamp. With the “super bright” LED located on the exterior control panel we can now determine the condition of the controller in full sun and at a greater distance.

7.5 Special Indicators

Another new feature of Anassa III is its strobe lamp. The strobe lamp is basically an attention grabber and it is attached to the mast for maximum visibility. Visibility is also enhanced because the strobe is very bright and can easily be viewed in full sun. This strobe is programmable and can indicate any condition we desire and can also alternate between multiple parameters. Currently the strobe is activated when Anassa III detects an object in its path, and it also flashes to confirm when the vehicle has passed a waypoint location. This alerts the team as to whether Anassa III is motionless due to detecting an object and is currently calculating its navigation around the object, or is “stalled-out” due to a malfunction. When the strobe is activated, it is evident that Anassa III recognizes an object in its path.

7.5 Sensors

The following is an itemized list of Anassa III's sensors and a brief description of their function.

CSI Wireless DGPS receiver and antenna: Retrieves the latitude and longitude and determines velocity and heading..

Forward SICK Laser Measurement System (LMS): Sweeps 180 degrees for object avoidance. Although the LMS range is 80 meters, Anassa III requires only 8 meters of this range. Front-mounted for forward object avoidance.

Digital Camcorder: Provides the vision of Anassa III and is used to detect markings on the ground as well as objects in the path.

Digital Compass: Determines Anassa III's heading in addition to the DGPS heading. The digital compass is important when the vehicle is stationary. The digital compass is redundant to the DGPS.

Encoders: Supplies distance traveled and the direction traveled. They are attached to the drive motor shafts.

Gyro: Determines heading and is redundant to the DGPS.

Rear SICK Laser Measurement System (LMS): Sweeps 90-degree sweep to give the vehicle object avoidance ability when doing reverse locomotion.

8.0 Software Design

For IGVC 2007 we focused on constructing a single algorithm to be used for both the autonomous challenge and the navigation challenge. The core of this algorithm is a software map that contains positions of all perceived objects and markings, robot position and heading, and a "goal node." The goal node can be either a point down the path or a waypoint. Accounting for robot heading, the algorithm determines the goal node's position and chooses the best path between robot and goal node.

To explain the design stated above, this section focuses on two tasks: sensor integration and path planning/object avoidance. One of Anassa III's design innovations is vision-related; therefore this section also describes the vision software.

8.1 Sensor Integration

The sensor integration program places all the information available to Anassa III on a map stored in its memory. Signal processing of the sensor information has transformed the sensor data to a standard Cartesian coordinate plane surrounding the robot. Sensor information that is placed on this map is obtained from all sensors, including the camera, the LMS, the DGPS, the compass, the encoders, and the gyro.

The attributes of the map were chosen to give Anassa III an adequate field of view with a sufficiently small resolution, but not so small as to overburden the computer. The map surrounds the robot such that the map's horizontal field of view is six meters to the front, two meters to the rear, and four meters on each side. This field of view is more than adequate for the autonomous challenge. Testing has shown that Anassa's autonomous challenge program minus the vision takes only ten to twenty milliseconds per cycle, definitely fast enough for a five-mile-per-hour robot!

One advantage of using such a map to integrate all sensor information is that real-time mapping can be exploited. With heading and positional inputs available, the program can take representations of objects and markings detected in a previous cycle and rotate and or translate them to the current cycle. In this way, Anassa III can "see" outside its sensors' ranges using memory as well as instantaneous sensing.

8.2 Path Following and Obstacle Avoidance

For the autonomous challenge, Anassa III must follow a path marked mostly in field grass littered with obstacles such as construction barrels. Anassa must also navigate through a section of sand and over a bridge. The path markings maybe absent in some spots and there can be obstacle traps. Path markings could be absent on strategically bad places as at the beginning of a curve or next to a trap. Glare from the bridge and grass pose additional challenges. Shadows can appear and disappear depending on the position of the sun and presence or absence of clouds. Anassa may also have to pass close to waypoints. The Path Planner presented in this section finds a suitable path despite these challenges.

The input to the Path Planner is a matrix of nodes called the "map." The map contains all information from Anassa III's sensors, covering an eight-meter by eight-meter area. Path markings, obstacles, and the robot are represented on the map as nodes or groups of nodes. The sand, bridge, bridge glare, and bad spots in the grass can be included on the map.

The output of the Path Planner is a path from robot to a computed goal node. Two outputs sent to the controller module are the initial speed and direction that the robot needs to do to begin executing the path. The Path Planner recalculates the path on each cycle (total cycle time is kept less than 100 milliseconds) and outputs speed and direction after each program cycle.

The Path Planner uses a four-step process with each step a separate function and the steps always executed in the same sequence. The steps are as follows:

Step 1 *Calculate the "map slope" and "slope confidence"*

Step 2 *Set the goal node based on minimizing a cost equation*

Step 3 *Find the optimal path between robot and goal*

Step 4 *Execute the planned path by outputting speed and direction*

The first step determines the best direction to search for a goal node. The autonomous challenge has lanes that are roughly linear and parallel. The lanes are not perfectly linear or parallel but may have missing segments and curves, and obstacles may obscure the linearity of the lanes. Anassa III uses a concept (as Anassa II did) called "map slope" to head in the right direction despite missing segments and curves. The map slope represents a rough estimate of the quantity of linear components on the map and measures their average slope. This process involves correlating computer-generated lines with real lanes detected by the vision module. Along with the map slope, a "slope confidence" is also computed. The slope confidence is based on the total amount of measurable linearity of these components. For example, if the vision module gives two line segments representing path edges, and both segments are thin and long and relatively linear and parallel, then map slope would give the combined average slope of these segments and a high confidence level that this slope is correct. Knowing both slope and confidence helps Anassa III choose the best direction to search for a place to assign the goal node and keeps Anassa III from exiting the path through a dashed line. To do this, these two values are used in a cost equation in the next step to help set a goal node.

The second step of the path planner is an algorithm that determines the goal node by minimizing the cost function for each node. The cost function was experimentally determined, is applied to each node, and is a function of many parameters. Parameters include map slope, distance to the goal, proximity to obstacles, a Boolean variable indicating whether the node lies between obstacles or markings, the amount of turn required, and map slope confidence.

Once the algorithm chooses a goal node, a modified “wave front” routine in Step 3 calculates the shortest path between the robot’s node and the goal node. Beginning at the goal and working back towards the robot, the wave front routine assigns values to all clear nodes, starting with a zero value at the goal and increasing the value until it reaches the robot. Candidate paths flow “downhill” from the robot to goal. Another routine similar to the well-known A-star routine finds the most direct candidate path. The robot then chooses the best path to take to the goal.

Finally, in Step 4 of the Path Planner, the program outputs speed and direction commands to the controller module. These commands are consistent with the calculated path described above. However, this path is re-calculated on each controller cycle since new obstacles and markings may be detected at any time. Thus, on each cycle, these two commands are the commands needed to execute the *initial* phase of the planned path.

8.3 Vision Software Technique

Each pixel in each captured image contains information in the form of three 8-bit binary numbers for red, green, and blue $\left(R_p, G_p, B_p\right)$. One way to characterize each pixel graphically is to create a color vector in 3-dimensional space with pure red, pure green, and pure blue as orthogonal axes. Figure 8.1 illustrates such a color box where one can draw color vectors for pixels. The magnitude of this color vector represents the overall brightness of the pixel and the direction of the vector represents the relative color in the pixel.

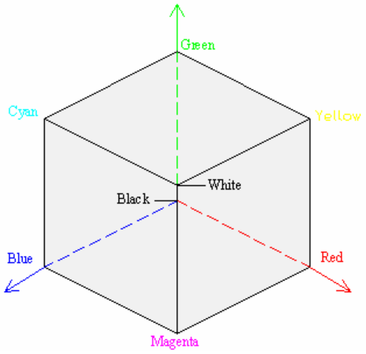


Figure 8.1 Color Cube

The algorithm filters spurious noise by using regions containing m^2 pixels in each region. Averaging the m^2 pixel color vectors in each region creates a regional color vector.

In general, Anassa III will only have to recognize and navigate through and around certain known objects and surfaces such as sand, bridges, grass, tarps, construction barrels, and path markings. Suppose there are *n* such surfaces and objects.

Each of these surfaces and objects has its own color vector as long as there is uniform distribution of color throughout the surface or object image. The algorithm assumes each region of each image must fall on or close to one of these *n* hypothesized surfaces or objects. Each hypothesized surface has a probability of being the correct surface for each measured regional vector. Any number of hypotheses is possible as long as no two vectors are collinear. The amount of separation of the hypothesized color vectors relate directly to the accuracy possible from this algorithm.

The algorithm described in this section exploits the property that the same pixel in shade or bright sun would have the same general direction in color space even if the magnitudes were very different. Therefore, the important quantities of interest are the angles between the hypothesized vectors and the actual regional color vector. The dot product between these vectors gives this angle. The algorithm chooses the hypothesis with the smallest angle for each region. Also, probabilities of occurrence can also be accounted for—for example grass could have a greater probability than sand. Since the actual angle is not important, the decision can also be made using only the cosine of the angle. For each region, the algorithm chooses the hypothesis with the cosine of the angle closest to one.

9.0 Design Innovations

9.1 Rear Laser Measurement System

As important as it is for the vehicle to avoid collisions with objects when moving in the forward direction, our testing proves that the robot must be capable of avoiding rear collisions as well. Previous generations of our Anassa vehicles have only been able to perform "blind" reverse locomotion, which allowed the robot to have rear collisions with obstacles in the immediate vicinity of the vehicle.

With the installation of the rear LMS, Anassa III now has the capability of avoiding rear collisions during reverse locomotion. The rear LMS has a 90-degree sweep; however, our tests prove that the 90-degree sweep is more than adequate to prevent any reverse locomotion collisions.

9.2 Adaptive Vision Algorithm for Learning

The color vector program described in Section 8 compares measured RGB vectors to constant pre-programmed hypothesized RGB vectors. If the RGB content of the markings and objects are time-varying, then the color vector algorithm as presented may have identification problems. For example, intervals of clouds and sunshine would cause the RGB content of white lines to change during an autonomous run. The difference between the measured RGB content and the hypothesized RGB content will vary depending on how bright the sun is or how dark the clouds are. The effects of shadows on other markings or objects are another example. A barrel shadow on the grass may make the grass RGB content very different than the grass RGB content in direct sun. In approaching the barrel, the robot may become confused between grass in shadow and sun. Glare on the bridge is yet another example of this problem. As the robot approaches the bridge, the glare may grow to the point the entire surface of the bridge has an unidentifiable RGB content.

For Anassa III, we implemented an adaptive algorithm that changes the hypotheses as the environment changes. As long as changes are continuous (not abrupt) the algorithm tracks the changes and sets up new hypotheses on each cycle. The maximum rate of change in the RGB content of measured values that the algorithm can track depends on the cycle time. Our cycle time is currently less than 100 milli-seconds. If, for example, it takes one second for a cloud to move across the face of the sun and completely block it, then this algorithm will have measured the RGB content of all regions at least ten times. The resulting changes in the measured RGB content within one second should change continuously and slowly enough for the algorithm to track.

In this sense, Anassa III *learns* by changing its hypotheses to match the environment. As long as the RGB content of each region does not change too much and too fast, Anassa III can build new tables of hypotheses each cycle. This is the first step in making our IGVC robots capable of learning.

9.3 Serviceability: Another Design Innovation

During IGVC 2006 the Anassa II team learned to appreciate the importance of quick and easy serviceability. Anassa II broke electrically and mechanically in numerous places during a very rough transport to the IGVC site. The team wasted many precious hours disassembling and assembling the robot during several days of troubleshooting that could have been used for testing. Therefore, the 2007 team designed Anassa III such that the robot could be completely disassembled and assembled in less than ten minutes. Quick disconnects and consolidated connectors allow the team to separate the robot into three major sections: the bottom frame, the middle body, and the top mast. Now, every subsystem can be easily reached and serviced as needed.

10.0 Computers

The onboard laptop computer of Anassa II proved inadequate in the 2006 competition. We have replaced the previous onboard laptop with an onboard desktop computer. The desktop unit has been designed to operate with twenty-four volts DC. Other features of the desktop unit are: dual processors, two gigabytes of ram, and a one gigahertz front side bus. We have also setup the onboard desktop computer to be wirelessly networked to an off-board laptop, thus the desktop unit does not need a monitor, keyboard, or mouse.

11.0 Reliability, Durability, and Performance

11.1 Reliability and Durability

The design team enhanced the behavioral characteristics of the Anassa III robot, and at the same time much of the work has also increased the capability of the robot to perform for extended periods of time on a complex obstacle course. Both the mechanical and the electrical systems have been extensively reworked, and we are confident that Anassa III will outperform Anassa II. Serviceability was a significant problem with previous models, and we have concentrated our efforts in this area (see Design Innovations, Section 9.).

11.2 Analysis of Performance

Design parameters and simulations indicate that Anassa III should perform as indicated in Appendix E. The table also records the results of actual testing. An analysis of components and performance is included for each prediction listed in the table.

12.0 Joint Architecture for Unmanned Systems (JAUS)

Anassa III is designed and built to implement JAUS messages in accordance with the IGVC official rules. JAUS is a relatively new initiative to develop a set of standardized command structures for controlling different types of unmanned systems, such as intelligent ground vehicles, in a cooperative environment. It will be deployed both throughout the military services and become standard in the automotive industry as well. Anassa II successfully completed Level 1 requirements for IGVC 2006. Anassa III will complete both Level 1 and Level 2 requirements during IGVC 2007.

12.1 Learning Process

Anassa III team's process for learning about JAUS was based on literature review of the current status of JAUS including a white paper entitled a *Practical View and Future Look at JAUS,* May 2006, by Jorgen Pedersen, President and CEO, re², Inc. This review helped answer such basic questions as: Why use JAUS? What is the terminology used in the messages? How are these messages routed to the vehicle? How do these messages support interoperability? What does it mean to be JAUS compliant?

12.2 Level 1 Implementation

Anassa III can read and execute JAUS message commands from an operator control unit (OCU) via an RF (802.11g) data link. Anassa III's autonomous program continuously monitors and executes the received JAUS command messages. These messages can start the vehicle moving forward in autonomous mode, stop the vehicle from moving in the autonomous mode, and activate a warning device (a strobe light.) To implement Level 1 JAUS, the autonomous program used in the autonomous challenge and the navigation challenge was slightly modified to accept JAUS.

12.3 Level 2 Implementation

Anassa III will also be able to implement Level 2 JAUS. It is very similar to Level 1 except the JAUS monitoring software will only accept messages intended for Anassa III. The monitoring software will also provide waypoint information upon request. Unlike Level 1, Anassa will have to transmit messages as well as receive messages for Level 2.

Appendix A

Team Member	Responsibilities	Class Level- Major	Est. Hours Worked
Justin Stiltner (leader)	Software Design Electrical Design	Senior – Computer Science	500
James Cardwell	Software Design Anassa Operator	Sophomore – Computer Science	800
John Browning	Image Processing Mechanical design	Sophomore – Mechanical Eng. Tech.	400
Dwight Backus	Documentation Written Report	Junior – Electrical Eng. Tech.	200
Justin Nichols	Computer Hardware Software Design	Senior – Computer Science	200
Joshua Johnson	Electrical Design	Junior – Electrical Eng. Tech.	200
Cailan Blankenship	Electrical Design	Junior – Electrical Eng. Tech.	200
David Davis	Electrical Design	Junior – Electrical Eng. Tech.	200
Weston Monk	Electrical Design	Junior – Electrical Eng. Tech.	200
Justin Milam	Electrical Design	Freshman – Electrical Eng. Tech.	100
Mark Hankins	Electrical Design	Senior – Electrical Eng. Tech.	100
Jon Bonhomme	Electrical Design	Senior – Electrical Eng. Tech.	100
Brett Butler	Mechanical Design	Freshman – Mechanical Eng. Tech.	50
Jason Duncan	GPS and Test Course	Freshman – Civil Eng. Tech.	50
Jordan Gibson	GPS and Test Course	Freshman – Civil Eng. Tech.	50
		Total Hours	**3350**

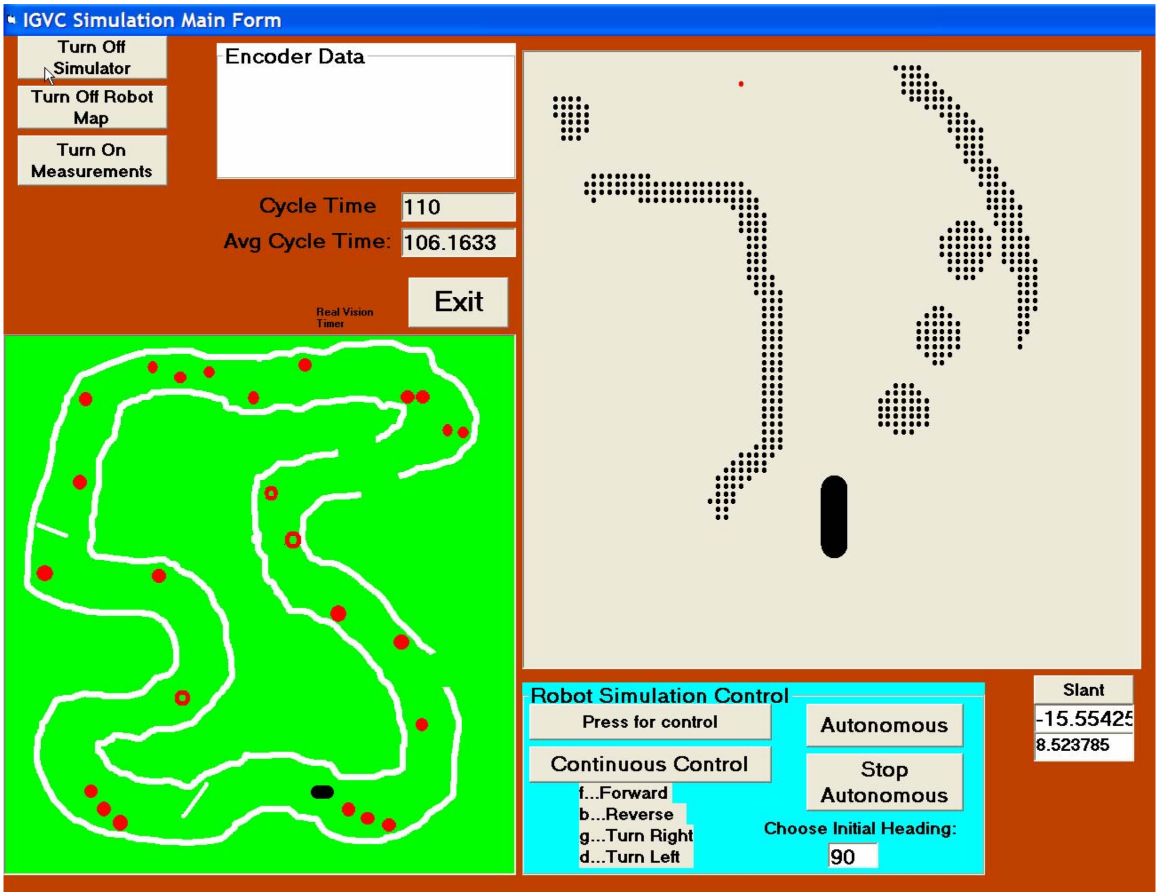
Table A Team Information

Appendix B

QUANTITY	DESCRIPTION	OUR COST	Replacement COST
1	1170 Wheelchair frame(Used)	$1,037	$5,977
1	Desktop computer	$1,300	$1,300
1	Sony camera	$700	$700
1	180 degree LMS(SICK)	$3000	$5000
1	90 degree LMS	$3000	$5000
1	DGPS-w/antenna/cables	$2100	$3000
1	Digital I/O	$350	$350
1	Aluminum Platform	$0	$500
1	Wireless E-stop	$100	$100
1	Super bright LED and parts	$20	$20
1	Compass	$700	$700
1	Computer Sense power monitor for JAUS	$12	$12
1	Heavy Duty 50-amp switch	$50	$50
1	24 to 12 volt dc to dc	$200	$200
1	Soft E-Stop	$20	$20
2	Heavy duty 24-volt charger	$300	$300
2	24-volt pc power supply	$250	$250
1	Custom Controller Parts	$25	$25
1	Cable connection box	$15	$15
5	Toggle Switches	$16	$16
1	Misc. Wire, Cables & Connectors	$50	$80
1	Misc. Mount Screws & Hardware	$20	$50
1	Gyro and controller	$300	$500
1	USB Router 2.0	$20	$20
1	Two Encoders	$0	$800
1	Fuse panel	$0	$20
1	Strobe light and electronics	$30	$30
Total		$13,595	$25,015

Table B Anassa III Parts and Costs

Appendix C



Cycle Time: 110
Avg Cycle Time: 106.1633

f...Forward
b...Reverse
g...Turn Right
d...Turn Left

Choose Initial Heading: 90

Slant: -15.55425
8.523785

Figure C Screen Capture of Simulation

Appendix D

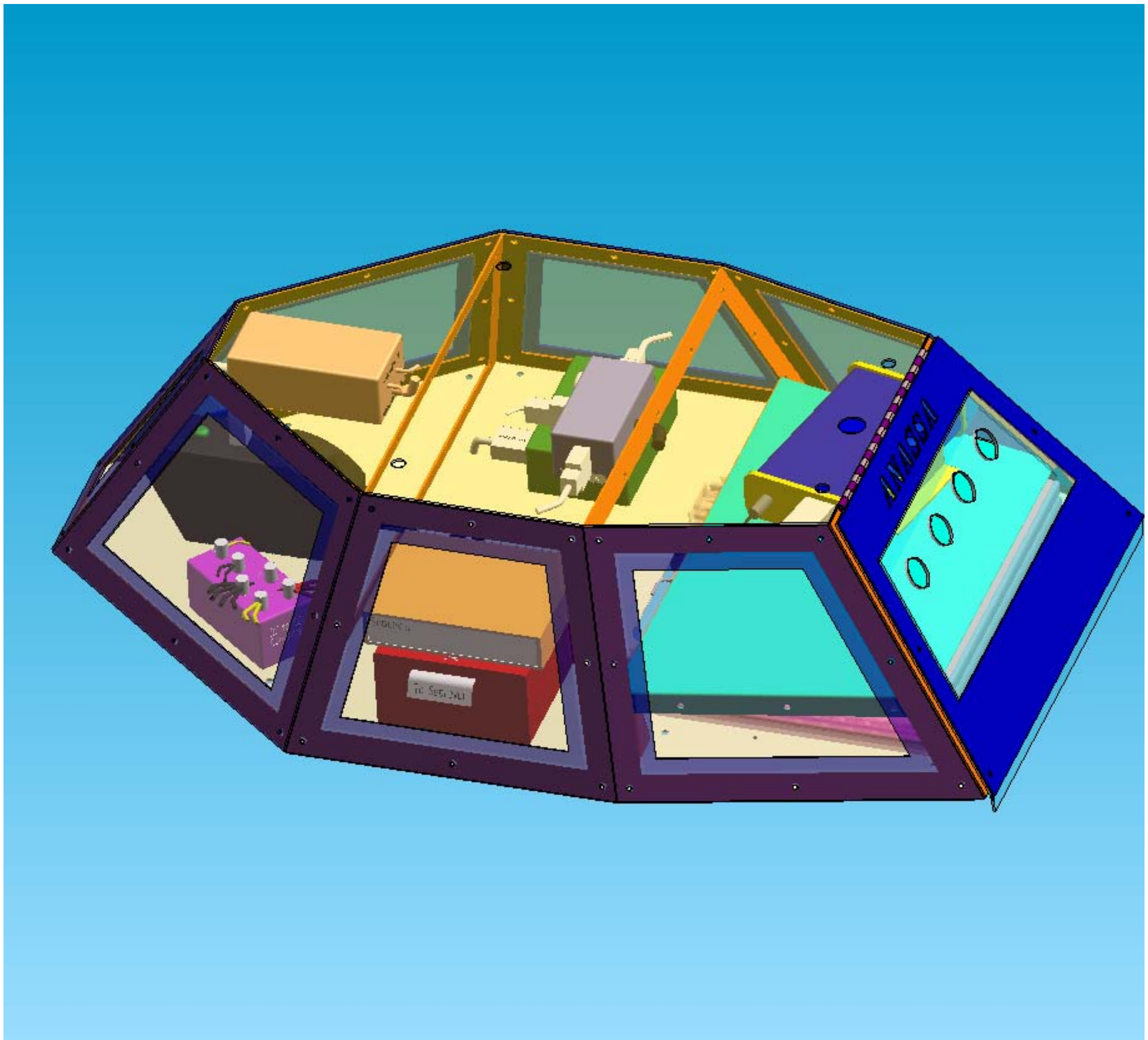


Figure D View of Anassa's Body

Appendix E

Performance Measure	Performance Prediction	Performance Results
Speed	6 mph	5.0 mph (software restricted)
Ramp Climbing	20-degree incline	20-degree incline
Turn Reaction Time	180 degrees/ second	160 degrees/second
Battery Life	5 hours	4 hours
Stop Reaction Time	Immediate	Almost Immediate
Object Detection	0 to 8 meters	0 to 8 meters
Dead-Ends and Traps	Path-planning avoids these	Works nearly 100%
Potholes	Chosen paths are clear of potholes	Works nearly 100%
Waypoint Accuracy	2 feet one sigma	2 feet one sigma

Table E Performance