



# Bluefield State

C O L L E G E

## ARCHON DESIGN REPORT 2008

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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 Archon 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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## **1.0 Introduction**

Bluefield State College, the Center for Applied Research and Technology, Inc. (CART), and the student robotics team are pleased to announce the creation of our newest robotic product, Archon. Archon is a prototype that has addressed the shortcomings of our past robot Anassa III while using what worked to its fullest potential.

The team has been designed Archon from the ground up. Unlike past iterations based on modifying preexisting devices such as electric wheelchairs, Archon has been designed completely by the BSC robotics team. This allows for features and controls not available from existing commercial vehicles as well as the ability to repair and service the new robot easily.

## **2.0 Contributors and Sponsors**

Several companies have made donations of parts, discounted products, or provided assistance in other ways that have benefited Archon. The companies include Pemco, Inc., ConnWeld Industries, Wal-Mart (Bluefield, Va.), Bucyrus, Miller's Financial, and Charlotte America.

## **2.1 Funding and Budgetary Considerations**

Funding for the project was limited and we had to operate within tight budgetary constraints. Expense was often the determining factor in equipment selections. To reduce the expense of the project, we used inventoried components when available and solicited donation of parts as much as possible. We held a bake sale and a hotdog sale in order to raise extra funds that are needed for building a new robot. Components used in the project are itemized in Appendix B along with actual and replacement costs.

## **3.0 Team**

The robotics team is diverse, containing students from every engineering and computer-based program that Bluefield State College has to offer. The students that helped in the creation of Archon are listed in Appendix A.

## **4.0 Problems with Past IGVC Robots**

As the robotic system evolves to the next level, it is crucial that we examine what issues arose from past generations. Through experience, we are able to assess what has worked and what may need reworked for the success of the current model.

## **4.1 Evaluation**

At the end of the last IGVC competition the team constructed a failure analysis of Anassa III. Appendix C contains this analysis and suggested solutions to the problems. As we studied the problems encountered, it was decided that a new robot was the best solution.

## **4.2 Problem Definition**

Although there were many issues to address when planning the new robot, some of the largest problems we wanted to address were:

1. Inability to move backwards with ease.
2. Overly complex control interface.
3. No system of internal checks to diagnose problems.
4. Limited ability to convey information from the machine back to the user.
5. Outdated control code limited performance.
6. Physical limitations of early robot designs inhibited easy movement

### **4.2.1 Reverse functionality**

The Anassa robots did possess the ability to back up; however, aided with only a back-mounted laser measurement system and no rear camera, this system was blind to white lines and any obstacles the LMS may miss behind the robot. This created a problem when Anassa found itself in a corner or other tight situation where pinpoint accuracy was needed while backing up.

### **4.2.2 Complex Operator Control Interface**

The overall operator control scheme for our former robots has been complex from a mechanical and programming point of view. Past robots required a precise sequence of switches to be pressed in order for the robot to work. Many separate computer programs were needed to initialize and run the robot in its distinct modes (autonomous, navigation, and manual). In the future, Archon will only require one button to initialize the software and mechanical components.

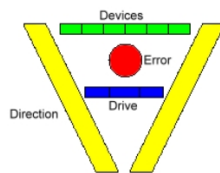
### **4.2.3 No Internal Diagnostics**

Current generations of robots do not possess the ability to diagnose a problem with their systems, and no way to check the status of sensors or other external devices. The consequence is that the team does not know that an error exists until a full test run is made. Also, there are no checks and balances concerning “pilot error” and other external forces that may influence the

robots performance. In the future, Archon will inform the controller that the sensors are working and return valid data. Further, the system will determine if pilot error is an issue.

#### 4.2.4 Limited User Communication

Currently, a few external lights coupled with the actions of the robot help to convey what operations the machine is performing or the status of the machine once it is running. The team is unaware when and why the robot does or does not do something. In the future, Archon will



display the status and diagnose errors. The green lights will show which devices are currently operating correctly, the red light will illuminate if there is an error or problem with its systems, the blue light will show speed and direction of the robot, and the yellow lights will show which way the robot is turning and how fast.

#### 4.2.5 Physical Limitations

Many of the past autonomous robots have used a modified electric wheelchair base. This design is extremely functional but has limitations, such as, an inability to turn 360 degrees with ease due to its non-symmetrical base. In the future, Archon's customized base consists of steel tubing. In the future, fiberglass will surround the steel tubing. This design is much lighter and will allow Archon to turn without restraint.

### 5.0 Development of Design

The team deliberated about numerous design ideas before deciding on Archon's schematics. The current and projected features of Archon improve upon or address issues experienced with past robots.

#### 5.1 Team Discussion

In fall 2007, the team identified possible solutions to the aforementioned problems experienced by past robot. A draft of the new design was decided upon. Archon's appearance and functionality is different from the previous robots. A new name was decided upon, Archon means "Prince" in Greek.

#### 5.2 Computer-Aided Design

The team used computer design programs, such as, AutoCAD, to make three dimensional pictures of how the robot would look. From this, the different design concepts were narrowed

down. Then the mechanical engineer students utilized the program to decide which designs could withstand the most stress and strain, while satisfying the physical design objectives.

### **5.3 Computer Simulation**

Previous IGVC teams wrote a computer simulator that represents real world sensor data. This has made the ability to test even minuet changes in the systems programming much easier.

### **6.0 Mechanical Design**

Archon's new physical design is dramatically different from our previous robots. It combines form and function to maximize the ability and versatility of Archon. Even though the design is more compact, it nonetheless has more features.

#### **6.1 Vehicle Frame and Chassis**

The most notable feature of Archon is the symmetry of the frame. This complements the new rotating vision system by allowing an identical view of the robot from both the front and rear sides. Archon is capable of making a 360-degree stationary turn with its centralized wheel system.

The body design is completely modular. This makes it easy to separate the top camera mount from the control section as well as to separate the control section from the wheel base. The new design makes it possible to change the actual wheel base. We currently have two unique wheel bases that can function differently with plans to make more to suit whatever challenge we may face. The track-based frame offers a perfect turning radius, while the wheelchair-based frame works for testing functions carried over from the Anassa robots.



#### **6.2 Drive System**

The multiple wheel bases make it is possible to use an almost unlimited variety of drive systems. The two current drive systems are based on preexisting vehicles. One has the handling and speed of a wheel chair, while the other has the power of a snowmobile. The two twin motors of both systems are controlled by a custom made control system based on a PIC microprocessor control board. This new PIC-based drive control system is easily customizable and programmable to complement the changeable base system.

## **7.0 Electrical Design**

Archon's electrical system utilizes designs from previous robots, in Archon they are used to their fullest potential. The compact size of Archon's body led to some electrical challenges. However these were overcome in order to preserve the new ergonomic and functional design.

### **7.1 Power System**

The innovative aspect of Archon's power system is the amount of control the software has over the power system. With a new PIC microcomputer-based relay system we have replaced a large amount of hardware switches with computer control allowing the software to actively control the power system of the robot.

### **7.2 E-Stops**

Safety was always a major issue with our robotic systems and with Archon this is no different, with both hardware and software methods of disabling the robot. A new key-based hard E-Stop system is the most definitive way of shutting down the system by manually cutting the batteries from the system. The key-based system also adds a level of safety to the maintenance level of the robot; this allows anyone working on the electronics to shut down the system and remove the key; this prevents someone from energizing the system. This was inspired by the "lock out, tag out" standard for working on electrical systems. There is another easily accessible manual E-Stop called the soft E-Stop which cuts communication from the control system to the drive control, effectively stopping the robot while retaining power to the system. A radio-controlled (RC) wireless E-stop allows the robot to be stopped from a long distance.

The software program has a lot more ability to detect system errors and stop the robot at appropriate times. With the new monitoring system the computer can detect if a large error occurs and immediately stop the robot. The new PIC processor-based drive control has the ability to evaluate commands coming from the computer and stop the machine if the commands are no longer recognizable due to a computer error.

### **7.3 Wiring**

The wiring in Archon uses the same quick disconnect system initiated in previous Anassa robots. This allows for the quick removal of components and systems, this makes the entire system easy to maintain and the parts easy to replace.

## **7.4 Instrument Panel for Monitoring and Control**

There has been a large shift from the switch-based control systems used in our previous robots. Through a new touch screen monitor system we are able to control the entire system from a variable system that can easily adapt to any change or when a new feature is added. In previous years to add a new apparatus holes would have to be drilled, and new wiring run to switches on the control panel, but now it is as simple as a few clicks of a mouse. The monitor control system allows information from the computer to be easily viewed through a Lexan window, which was not available on our previous robots.

## **7.5 Special Indicators**

Archon possesses an unprecedented number of indicators to correctly convey information back to the pilot. A complex light system is being implemented to convey such information as direction, mode, errors, and power state of assorted devices. With the use of a Bluetooth headset it is possible for the computer to directly speak to the operator, conveying information such as battery level and computer errors.

## **7.5 Sensors**

The following is an itemized list of Archon'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.

*Rear SICK Laser Measurement System (LMS):* Sweeps 180-degrees to give the vehicle object avoidance ability when doing reverse locomotion.

*Bumblebee Camera System:* Camera which utilizes three separate internal cameras to create a three-dimensional view of the landscape.

*Digital Compass:* Determines Archon'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 heading while in motion.

*Sony HandyCam Camcorder:* Another vision system based upon readily available camcorder systems.

*Firefly Firewire Digital camera:* Our third camera system is able to function at higher speeds than Sony while taking high resolution images.

*IMU:* Determines Archon position and attitude during high dynamic maneuvers.

## **8.0 Software Design**

Due to time constraints, the current Archon software is a modified version of the latest Anassa software. Plans for future iterations of the program include conversion to more advanced programming languages such as Visual Studio 2005 and LabView. Easy switching between multiple cameras will be included in future versions, as well as a one-click program conversion for each time a wheel base is changed. A further integration of the voice communication process will soon be implemented to allow unheard of levels of information being relayed between the operator and the machine.

### **8.1 Sensor Integration**

Archon uses the same integrated sensor and systems that Anassa has used, they have proved successful in the past; however, new functionality has been added. With identical front and rear LMS systems the program is now able to create a much more accurate map of the Archon's surroundings. With the added swivel camera system it will soon be possible for Archon to see in any direction and build a visual map for everything around the robot. In combination with the highly accurate IMU/GPS/Compass combination we now possess the ability to see an object. In addition, the robot knows and remembers its location long after the robot has passed it.

### **8.2 Path Following and Obstacle Avoidance**

The input to the Path Planner is a matrix of nodes called the "map." The map contains all information from Archon's sensors, covering an eight by eight meter area. The robot, path markings, and obstacles 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 drive controller are the initial speed and angle that the robot needs to take 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 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. Archon uses a concept (as Anassa) called “map slope” to head in the right direction despite missing segments and curves. The second step of the path planner is an algorithm that determines the goal node by minimizing a cost function for each node. The cost function was experimentally determined, is applied to each node, and is a function of many parameters such as map slope. 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. 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.

### 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 ( $R_p, G_p, B_p$ ). 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.

In general, Archon 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  $n$

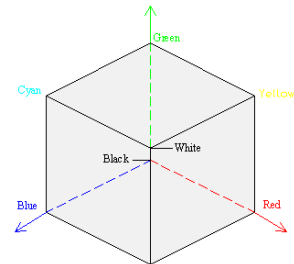


Figure 8.1 Color Cube

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.

## **9.0 Design Innovations**

Archon's design and functionality is innovative; every aspect of Archon from mechanical, electrical, and computer systems have been revolutionized. The innovations have or will be discussed throughout this report.

### **9.1 Symmetry**

The robot is externally symmetrical to allow an identical image from both the front and rear. With the combination of twin laser measurement systems and the new camera swivel system, Archon can easily travel in any direction. Archon's ascetic design is also incredibly functional.

### **9.2 Modular System**

Archon's modular system provides a near limitless number of possible combinations of parts and systems. Changing the wheel base module allows Archon to travel through nearly any terrain. The cameras are interchangeable, allowing the team to install the best possible camera for the situation at hand.

The modular system adds a level of ease to maintenance and replacement of parts. One no longer needs to solder or weld replacement parts; parts can quickly be replaced using simple connectors. This cuts down on the time and cost to maintain the robot.



### **9.3 Controls**

The control system has been the largest change from the earlier robotic models. Previously, we were largely dependent on prefabricated wheel chair controls that we could not repair ourselves. Furthermore, our control interface to the wheelchair controller was complicated and non-standard. Now the controller is entirely built and programmed by BSC students. Having an intimate knowledge of the system allows us to better troubleshoot.

Archon is the first BSC robot to use full wireless control. An RC receiver is now built straight into the control module allowing a wireless way to operate the robot without starting the computer. There is also a voice feature that allows not only a wireless, but a completely hands-free way of driving the robot. It is as simple as telling the robot where you want the robot to go and how fast you want it to get there.

Even the manual control interface has been greatly improved with the touch screen-based computer system. Now a single screen replaces a panel full of control switches while also providing meaningful output to the operator.

## **10.0 Computers**

For Archon's new computer system a tablet style laptop was implemented due to its incredibly compact size and ability to easily add touch screen systems. Despite the small size the laptop measures up to many desktop personal computers.

## **11.0 Reliability, Durability, and Performance**

Archon is in its early prototype stage; therefore, she has yet to see any real challenges to test its strength. The team is excited that the IGVC competition will provide such a proving ground for our new system.

### **11.1 Reliability and Durability**

The mechanical engineering members of the robotics team calculated many mathematical computations to find a design shape that could withstand stress while protecting its delicate electronic innards. The wheel bases were designed to cover rough terrain while providing a smooth ride for the upper portions of Archon.

## **12.0 Conclusion**

The creation of Archon has been a year-long process with countless different iteration and prototypes existing before the design concept and functionality were decided upon. Archon is a work-in-progress and will require more work to bring Archon to the level of performance that she is capable of. Of course, once the team realizes Archon's optimal performance, we will start striving to achieve the next level. As each year passes and the robots keep evolving, we will learn more and more and we will come up with more new innovative ideas.

### Appendix A: Team Members

Team Member	Responsibilities	Class Level- Major	Est. Hrs Wrk
<b>Justin Milam</b>	Team Leader	Sophomore–Electrical	600
<b>James Cardwell</b>	Software Design	Sophomore–Computer Science	200
<b>John Browning</b>	Mech. Design	Sophomore-Mechanical	300
<b>Bryan Lemon</b>	Software Design	Senior-Computer Science	200
<b>Brad Fields</b>	Software Design	Senior-Computer Science	100
<b>Dwight Backus</b>	Documentation	Senior–Electrical	100
<b>Louis McAllister</b>	Software Design	Sophomore–Computer Science	50
<b>Tony McAllister</b>	Electrical Design	Freshman–Electrical	20
<b>Cailan Blankenship</b>	Electrical Design	Junior–Electrical	20
<b>Jason Williams</b>	Electrical Design	Senior–Electrical	20
<b>Weston Monk</b>	Electrical Design	Senior–Electrical	20
<b>James Martin</b>	Mech. Design	Sophomore-Mechanical	10
		<b>Total Hours</b>	1660

### Appendix B: Parts List

QUANTITY	DESCRIPTION	OUR COST	Replacement COST
1	1100 Wheelchair frame(Used)	\$0	\$500
1	Laptop	\$1,300	\$1,300
1	Sony camera	\$150	\$150
2	180 degree LMS(SICK)	\$3000	\$5000
1	DGPS-w/antenna/cables	\$2100	\$3000

1	Wireless E-stop	\$100	\$100
1	Super bright LED and parts	\$20	\$20
1	Compass	\$700	\$700
1	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
1	Custom Controller Parts	\$25	\$25
1	Cable connection box	\$15	\$15
5	Toggle Switches	\$16	\$16
1	Misc. Cables & Connectors	\$50	\$80
1	Misc. Screws & Hardware	\$20	\$50
1	IMU	\$300	\$500
1	USB Router 2.0	\$20	\$20
1	Two Encoders	\$0	\$800
1	Fuse panel	\$0	\$20
1	Strobe light and other lights	\$30	\$30
Total		\$8,428	\$12,908

### **Appendix C: 2007 Failure Analysis and Proposed Changes**

<b>Failure</b>	<b>Fix</b>
Operator error. There were too many switches and sequences to remember to do right before each run. We only had minutes to set up sensors, choose the correct program, set color vectors, initialize the LMS, etcetera.	Replace complex switch system with computer based touch screen controls. Combine operating programs into one procedure. Store color vector data onto computer memory
No indication of sensor failure during the initial start-up time. We did not know if sensors were working or not until it became obvious in the middle of the run.	Have an on-screen checklist for diagnostic testing (including sensors) that is automatically done by the robot.
The computer was not rugged enough. We	Go to more compact and secure laptop

had many intermittent problems associated with a loose serial board, vulnerable hard drive, and the motherboard flexing and shorting out on the bottom of the case.	computer hardware. More securely mount system to resist shock.
E-Stop failure. The E-stop had great range, but would fail intermittently. This was possibly due to interference from other robots etc. The receiver required constant packets from the transmitter, so perhaps some of these packets were lost, causing the activation of the E-Stop even though the E-Stop button was not pressed.	Replace with more advanced RC pulse control transmitter. Include software-based stopping function using voice control via Bluetooth headset and wireless keyboard.
Depended on the main computer to process and integrate all sensor data while simultaneously computing the map, navigation solution, and control variables. When the main (only) computer failed, the whole robot failed.	Smart PIC-based drive control that checks the computer operation and can center and stop the machine if the computer information is faulty
Loose connections inside our controller. Possible cold solder joints. Connections were not rugged enough. At fast speeds of Anassa, the unevenness of the course caused her to bump around a lot.	Create new drive control that is more durable and that can more easily be repaired.
On the control panel, there were too many on/off switches for everything. Easy to get confused as to which switch to change, especially during the initial start time.	Run control through the computer, use touch screen to replace many switches. Have diagnostic system check operations.
GPS/Compass gives data too slow for robot's speed. Compass data lags actual heading, and GPS comes once every 7 feet at top speed. This is too long for trying to	Integrate the IMU, GPS, and compass to give position and heading data accurately at a high rate, 20 hertz or better.

navigate tight spots quickly!	
Ground clearance was too low for sharp changes in ground slope. (i.e., we would bottom out). In order to cross the bridge, we had to remove the tilt wheels. Also, we had some trouble with bottoming out when running Anassa up the ramp into the van.	Create new wheel base with higher ground clearance, as well as make it modular to easily change in different situations
The camcorder we used is damaged from past falls, and so we cannot do useful things like record a test run for analysis. Connection to the computer was via a usb port, which can be slow for video.	Have capability to use different types of cameras and easily switch between a damaged camera and a replacement
Too many different power supplies. Harder to charge when we have to charge multiple batteries.	One set of 12v batteries to power entire system with the use of a 24 v to 12v transformer.
Anassa turned completely around at least one time and started running the course backwards.	Using sensor data such as compass, GPS, and IMU, write software to enable the robot to know when it has turned 180 degrees on the course.
The Backup routine for Anassa is very different from the forward routine because of the non symmetry between front and back: the camera, the placement of the LMSs, the different types of LMSs, control is sluggish for backing up, and the swivel wheels turn in unpredictable ways when the direction is reversed.	Build as much front/back symmetry as possible. Ideally, allow the robot to choose front and back based on circumstances rather than design.