IGVC
2011

ARCHON

DESIGN REPORT

Faculty Advisor Statement:
We certify that the engineering design of *ARCHON* has been significant and each student, undergraduate only, has earned at least five semester hours credit for their work on this project.

Dr. Riggins/Dr. Ozyavas ___________________________________

1. Introduction

For the 2011 Intelligent Ground Vehicle Competition (IGVC), Bluefield State College (BSC) presents the newest version of *ARCHON*. This year's *ARCHON* is very different from any previous IGVC robot from BSC. Whereas BSC's past autonomous vehicles were mostly based on electric wheelchair frames, the new *ARCHON* was completely designed and built from the ground up by BSC students. Starting over with *ARCHON* allowed the new team to design for the more challenging requirements of IGVC 2011. This year's team, composed of a multi-disciplinary team of undergraduate students, has the goal of designing an autonomous robot that will meet *all* challenges of this year's IGVC. We believe that *ARCHON*'s innovations described in this paper will give us an edge in the 2011 competition.

Figure 2.1: Anassa (2008-2009)
ARCHON (2009-2010)

2. Design Process

2.1. Design Methodology

Designing an entry for an annual performance-based competition such as the IGVC is an exercise in continuous improvement based on the lessons learned from years past. BSC's previous robot, known as Anassa (Figure 1 top), was our most successful autonomous robot to date, placing third overall in IGVC 2009 and first in the autonomous challenge in IGVC 2008. Anassa, though very successful, had a wheelchair base and wheelchair motors and controller which limited flexibility and control of the design.

For the past two years, the previous IGVC teams have entered older versions of *ARCHON*, and each time, the entire robot including the base and controllers was completely designed and fabricated by the team. This total design concept of not using any pre-existing base (such as wheelchairs, go-carts, etc) allowed for team control and ownership of features, giving the team the ability to repair and service the new robot easily. Complete design freedom fostered interesting designs-- some very complicated. Last year's version of *ARCHON* (Figure 1 bottom) had four-wheel drive and an independent suspension system on each wheel. The wheels were mecanum, allowing the robot to move in any direction. While very impressive in looks and in theoretical function, the robot had problems in grass fields, and the team had problems with the complications of a mecanum controller. The construction and control were needlessly complicated.

Based on our experiences in past IGVCs, this year's team decided to adopt a new design process. The central theme of this process is the "Keep It Simple, Small, and Light" principle, also known as "KISSL." Our faculty advisor suggested this principle for IGVC 2011 following his "lessons learned" faculty meeting at IGVC 2010. We, the new IGVC team, decided to adopt this principle while completely redesigning the robot. Of course KISSL is valid only if all challenges for IGVC 2011 are mastered. To design the robot using this principle, the team studied the winning IGVC robot designs from other schools for past IGVCs extensively. Starting in August, design features from those robots were scrutinized in light of KISSL and performance. As an example, our team decided to make drastic changes to the drive system. Instead of an independent suspension and an individual 4-wheel drive system, we have switched to a 2-wheel drive system and a single swivel caster in the rear. This allows each wheel to be on the ground at all times. The design is simple, yet functional and effective. It has been used by many of the past IGVC winners.

2.2. Team Organization

The team is composed of undergraduate students from four engineering and non-engineering disciplines: electrical, mechanical, computer science, and marketing. Each discipline has a certain set of skills that helps bring our team together and helps provide us with a project that is complete in every aspect. Figure 2.2 shows the roles of each individual and the structure of the team. The team logged approximately 2500 hours over the past year, and each student received five credit hours of course instruction over the past year at BSC in robotics.

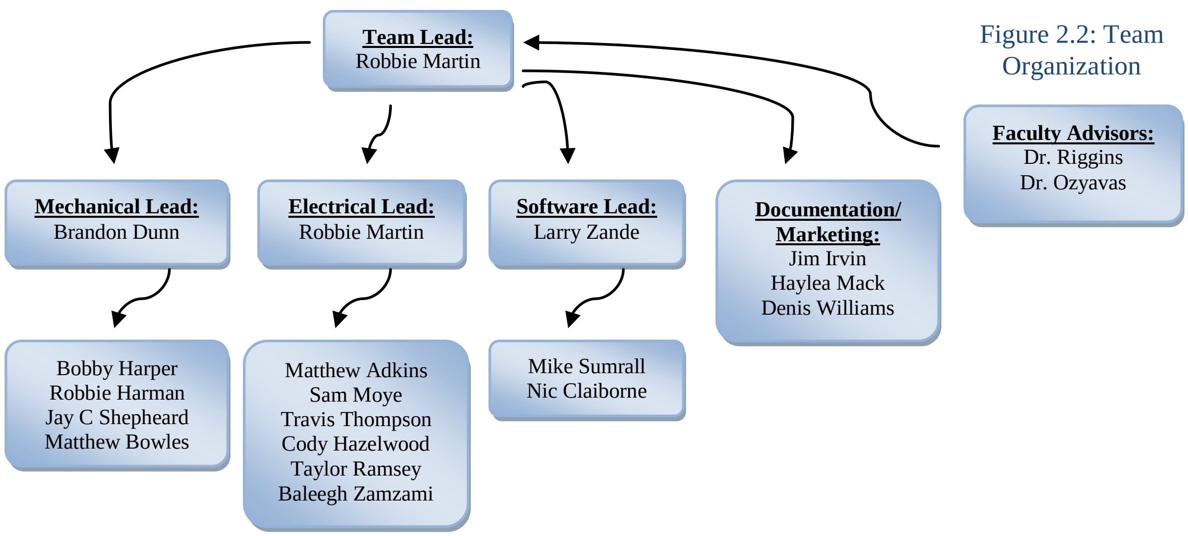

Figure 2.2: Team Organization

3. Design Innovations

ARCHON for the 2011 IGVC has a number of design innovations that are designed specifically to address the challenges of this year's IGVC. For reference, these innovations are listed here and presented in greater detail in Section 4 of the report. For ease of identification, an innovation-icon ( ) is used to indicate where innovations are being discussed in this document.

- **KISSL: Keep it Small, Simple, Light.** This principle keeps the torque-to-weight ratio up; time needed to design, fabricate, and test down; and error tolerance on the path up.

- **QuickSilver NEMA 34 I-Grade Motor/Encoders:** These motors/encoders are high torque, high quality, and high accuracy devices. Coupled with the much lighter frame of *ARCHON*, these motor/encoders will allow for precise control and high speeds (10 mph).

- **Distributed Computing Using The SilverNugget N3 I-Grade Controller:** Each motor is equipped with one of these processors that manages feedback control, E-Stops, and other control related issues.

- **Power System:** A 48-volt motor power system gives *ARCHON* smaller motors for more torque (compared to most robots that use 12-volt or 24-volt power). The 48-volt lithium battery has 1440 watt-hours of energy (much higher than all previous BSC robots ever had).

- **Modularity In Both Hardware and Software:** *ARCHON* has two basic parts: top and base. At this time there are two separate tops and two separate bases (for test and competition), and they are easily interchangeable. In software, we use an object-based approach in which the code can be re-used for many sets of sensors, controllers, tops, bases, and robots. Special connectors, such as quick disconnects, make maintenance and troubleshooting easy.

- **Path-Planning Algorithm:** More than a reaction robot that simply finds the biggest gap and charges, *ARCHON* uses a sophisticated path-planning algorithm to keep the robot away from traps, and to keep it from straying off the path through spaces and from choosing to go on the wrong side of the colored flags.

- **Goal-Setting Algorithm:** As the heart of our algorithm, this BSC-written algorithm allows the team to "tune" the goal selection process. Testing in simulation and on the test platform has yielded super results.

- **Slant Algorithm:** This sophisticated algorithm keeps the robot on the path even when faced with intermittent boundaries.

- **Ripple Algorithm:** This algorithm assigns weights to matrix nodes for use with the Waterfall algorithm. The Ripple algorithm increases the efficiency of the program by an order of magnitude.

4. Vehicle Design

4.1. Mechanical Systems

The mechanical design of an autonomous vehicle is very crucial, perhaps the most important design decision that the team has to make based upon resources. Without a great mechanical design, the robot would always be limited; therefore, much effort was devoted to *ARCHON*'s mechanical design. As shown in Figure 4.1, *ARCHON* is controlled by two independently-controlled motors with the single swivel caster wheel in the rear of the vehicle. The single caster in the rear allows *ARCHON* to move through tough spaces where other vehicles could not, and all wheels are always in contact with the ground.

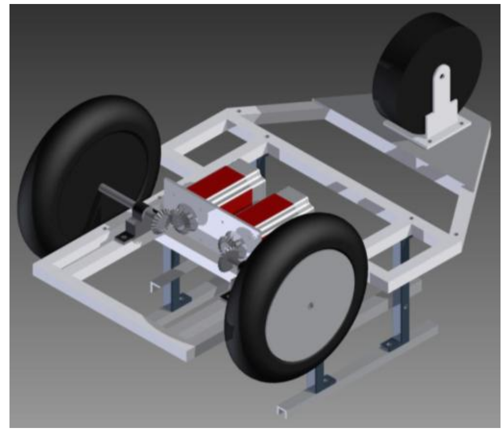

Figure 4.1: Base with motors

This base design shown in Figure 4.1follows one of our most important innovations, KISSL, the main principle guiding our design methodology. The base design is simple, small, light, robust, and has a low center-of-gravity and high torque. With all three outdoor wheelchair-type wheels on the ground, traction will never be a problem. By applying KISSL to keep the designs small, simple, and light, the team has more time to fabricate and test a great robotic vehicle in time for the IGVC competition.

4.1.1. Chassis

ARCHON is 26 inches wide, 70 inches tall (including the camera mast), and 36 inches long, and including the 20-pound payload weighs approximately 180 pounds when fully loaded. *ARCHON* meets IGVC specifications, but these dimensions are at the lower limit, keeping *ARCHON* as small as possible.

ARCHON's new base consists of 1" x 1" x 3/16" aluminum square tubing that is welded together for extra strength. 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 in a quick and timely manner. Thus *ARCHON* is adaptive to any terrain that it may encounter.

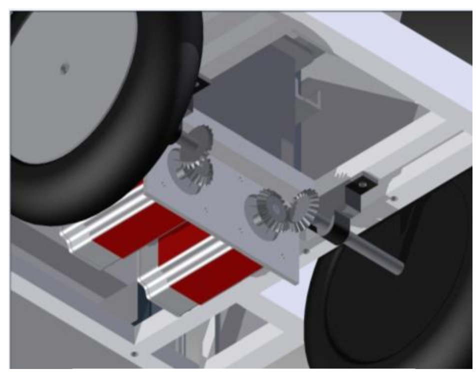

Figure 4.2: Motors with Miter gears.

Since *ARCHON* is extremely modular, it is easy for us to remove or add any new hardware. This innovation allowed us to have a separate test base constructed this year so that some team members could test while other members were working on the competition base.

This year the BSC robotics team made a lot of changes to *ARCHON*, but also to the way design, fabrication, and testing are handled in the robotics lab. Having two separate platforms for test and competition allowed parallel operations to take place, thereby speeding up the team's design and development of the robot. Both platforms have the same sensors and sensor placement and the same software. It also allows us to be able to test all software prior to going to IGVC.

4.1.2. Drive Train

The multiple wheel bases make it possible to use an almost unlimited variety of drive systems. One drive system that was used throughout the year for testing is a chain-driven setup (good for indoor testing). The diversity of the bases that are used for *ARCHON* allows the team to be ready for any type of environment (indoor versus outdoor for example). Most of the testing involves a BSC-made control system based on a parallax propeller 8-core microprocessor which is used to control two 12 VDC motors. However, in the new design for the competition base, *ARCHON* uses high quality servo motors with high quality commercial controllers (a first for BSC). These much more powerful servos on the competition base connect to the wheels with 90-degree miter gears instead of chains as on the test base (see Figure 4.2).

Another innovation for *ARCHON* is the use of a gear-driven setup on the competition base with a much higher torque to weight ratio than before. This year *ARCHON* uses QuickSilver NEMA 34 I-Grade motor/encoders with a gear ratio of 7:1. *ARCHON* controls the QuickSilver motor/encoders in two ways: direct analog input and a serial interface to the on-board laptop. The predicted cycle time for the motors is 8.33 KHz, adequate for the reaction times needed for IGVC. The voltage required for both the controllers and motors is 48 VDC. Because the motors have maximum efficiency at such high voltage, they can be smaller in size and have greater torque than motors running on lower voltage. The torque curves of Figure 4.3 show that the servos have much more torque at 48 VDC than the traditional lower voltages. Also, at 200 rpm (corresponding to 10 mph on *ARCHON*) the robot has 1650 oz-in of torque—a very high torque for that speed and a 180-pound robot.

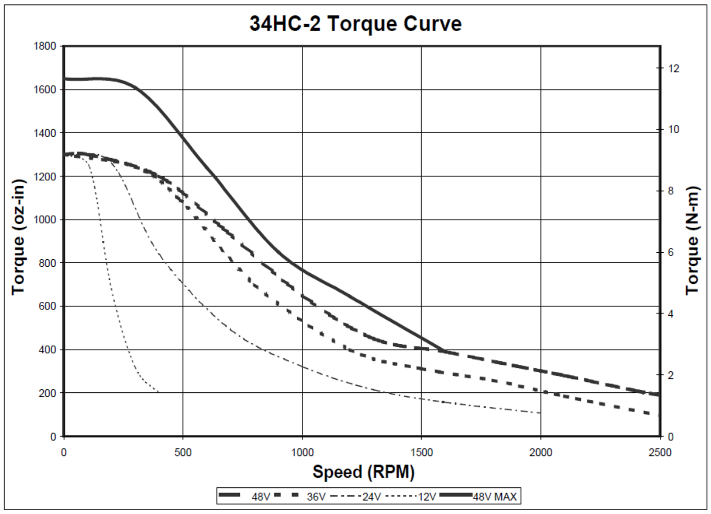

Figure 4.3: Servo Torque Curve

4.2. Electrical Systems

4.2.1. Power Distribution

ARCHON's frame is the smallest we have ever created. Consequently, we had to abandon the larger car-type batteries we had been using in favor of a smaller, upgraded battery. Now *ARCHON* uses a single 48-VDC lithium battery rated at 30 amp-hours. This lithium battery was chosen because of its size and its extended battery life expectancy (see Section 6) while powering our new servo motors.

Under normal operating conditions on smooth and flat ground, this battery will allow the vehicle to be operated for about 58 minutes at full speed. The 48 VDC supply provides power for two motors filtered by two clamping circuits, for two servo controllers, and for one 48-to-12 volt dc-to-dc converter. (A clamper circuit is connected to the motor power supply to absorb the motor's back EMF.) Therefore, all of *ARCHON*'s devices except the laptop derives their power from this single battery. Figure 4.4 shows how the power is distributed throughout the robot.

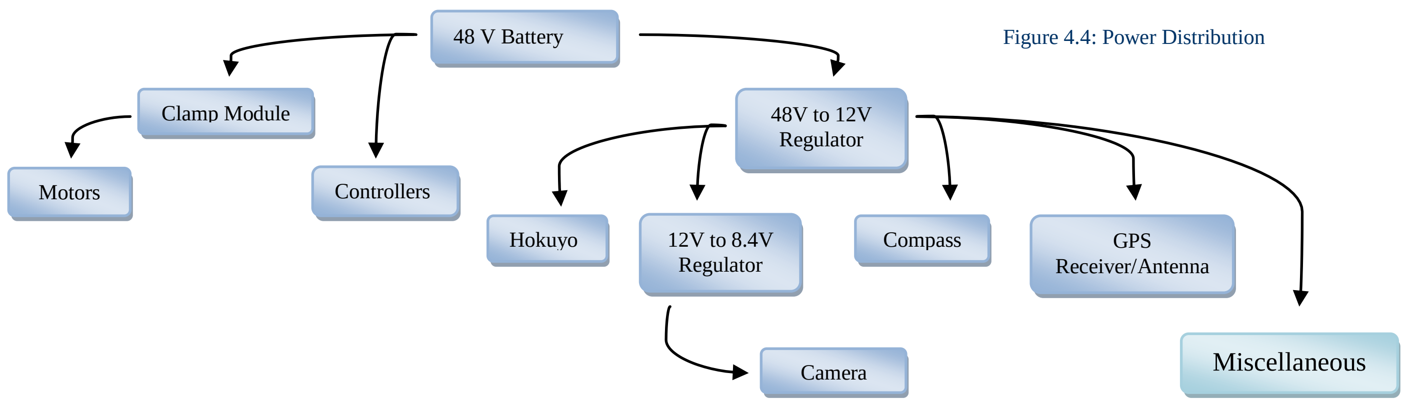

Figure 4.4: Power Distribution

To help ensure that *ARCHON* is safe, reliable, durable, and easily serviceable, several special features have been incorporated into the power distribution system. The new battery type is a definite improvement in size and energy, but we also redesigned *ARCHON*'s frame to simplify the battery replacement process. The team developed a battery rail system for easy battery access. The battery, while protected in an aluminum box, can now be removed easily from the rear of the wheel base and replaced with another in a quick and timely manner. Its location toward the bottom of the robot contributes to a safer low center of gravity.

4.2.2. Sensor System

ARCHON incorporates four sensors into its compact design: a camera, a DGPS, a Hokuyu, and a digital compass. The mounts for each sensor are designed to facilitate their easy removal for maintenance or replacement if it becomes necessary. The following is a brief description of the sensors that are used by *ARCHON* as shown in Figure 4.5.

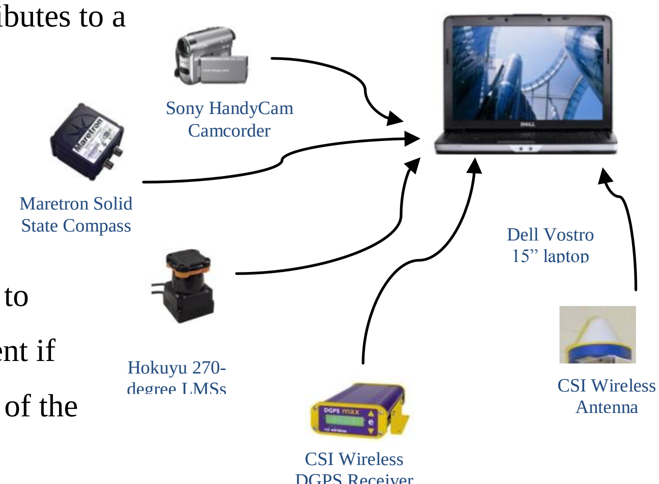

Figure 4.5: Sensor System

Camera: The team selected the Sony HandyCam Camcorder camera as the vision sensor for this vehicle. This camera is easy to use and very effective for *ARCHON* because it uses automatic lighting and focusing feedback and also has usb video streaming. The Sony HandyCam camcorder's progressive scanning and high frame rates minimize motion blurring. The camera has a 0.3x wide angle lens creating a 110° field-of-view. The wider angle field-of-view increases the effective image area and makes our navigation algorithm's mapping more complete (see Section 5).

Hokuyo: *ARCHON* uses the Hokuyo laser measurement scanner for obstacle detection. The unit is capable of collecting data in a 270° field-of-view in 0.25° increments with a range of 30m. The Hokuyo connects directly to a usb port on the on-board laptop.

DGPS & Antenna: To obtain positioning data in both the autonomous and navigation challenges, *ARCHON* uses the CSI DGPS system. The DGPS antenna is mounted to the top of the vehicle's mast while the receiver is securely positioned inside the top chassis.

Compass: A Maretron Solid State Compass helps determine vehicle heading. This compass provides a heading accuracy of 0.1° and updates at 10 Hz. This rate is sufficient for the vehicle's desired performance.

4.2.3. Wireless Remote Control and E-Stop Systems

Although *ARCHON* is fully autonomous, incorporation of a wireless remote control facilitates manual operation of the vehicle. The wireless remote control is a VEX 75 MHz transmitter and receiver. *ARCHON* can operate in one of two modes, autonomous or manual; the autonomous mode uses the on-board laptop for the command source and the manual mode uses the transmitter/receiver pair for the command source.

5. Development Environment and Software Architecture

5.1. Software Development Overview

The *ARCHON* software has been completely rewritten using the Visual C++ programming language. The change to Visual C++ has been accompanied with a reevaluation and redesign of many of *ARCHON*'s core algorithms. Archon's autonomous navigation system consists of six components: map generation, sensor fusion, map augmentation, goal selection, path-planning and control decision. Each step is repeated every 60ms.

5.2. Map Generation

ARCHON's map consists of a matrix of 6400 nodes arranged in an 80x80 grid, each node representing approximately 4 inches. The upper left node has a location designation of (0, 0) while the lower right node has a location designation of (79, 79). *ARCHON* will always consider itself to occupy node (40, 60). *ARCHON*'s map encompasses a forward-looking awareness of 20', a rearward-looking awareness of 7'8" and awareness to each side of 13'4". During the map creation stage, all nodes are assigned a nominal weight of 1000.

5.3. Sensor Fusion

ARCHON uses four primary forms of sensor data: LMS, camera, compass and GPS. Each sensor provides data in a unique format. LMS, camera, and GPS data are converted to distance and vector information prior to integration and placement of data on the map. Compass data is used solely for path-planning and is not integrated until that time.

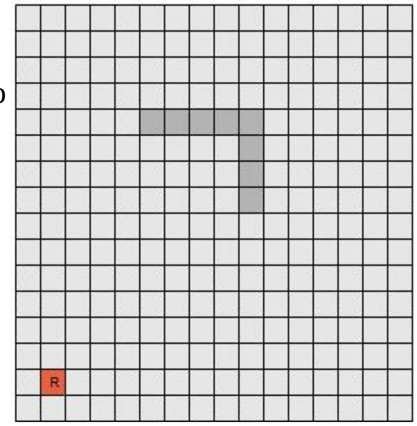

Figure 5.1: Map after LMS data added

Figure 5.1 illustrates an example of LMS data relative to the robot, represented by “R”. LMS data consists of a 1080 element array representing a 270° field of view in ¼° increments. Due to design limitations, 10° of data at each end are discarded, leaving the robot with an effective arc of 250°. Accuracy of the LMS is limited only by the resolution of the map grid. Obstacles detected by LMS are assigned a value of 3500, representing a high level of confidence due to the accuracy of hardware.

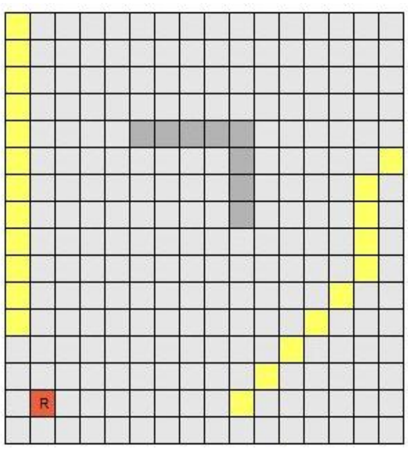

Figure 5.2: Camera data added

Figure 5.2 illustrates the addition of camera data to the example started above. Camera data is returned as a wide-angle video feed, distorted both radically and geometrically. The image is processed to generate a 181-element array. Obstacles are detected through an image analysis algorithm which detects a number of user-defined color values. Specifically, *ARCHON* will look for white boundary lines used to denote the course, for potholes, and for the flags introduced for this year’s competition. Distance measurements to obstacles are recorded in the camera array index corresponding to the vector of the detected obstacle. While accurate, camera-detected obstacles are deemed to be of lower confidence than LMS-detected obstacles and are assigned a lower weight of 3000.

5.4. Map Augmentation

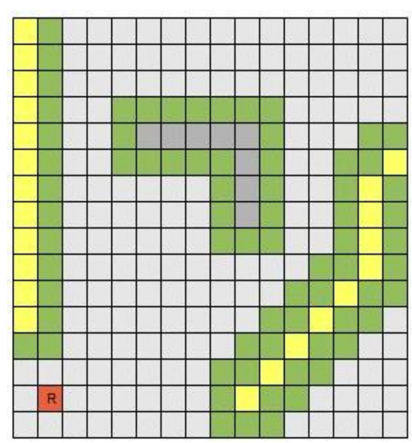

Figure 5.3: Fat layer added

As shown in Figure 5.3 the program augments extra layers around detected objects. *ARCHON* views itself as occupying a single 4”x4” node. In order to prevent collisions, *ARCHON* employs a “fat layer”, a buffer zone imposed on all detected obstacles that pushes *ARCHON* away from the detected obstacles. The fat layer is user-adjustable with a typical value of 4. A layer of 4 provides a minimum usable gap of 32” between detected obstacles. During path planning, map squares denoted as fat are treated as obstacles. *ARCHON* has a frame width of 26”, providing a minimum of 3” clearance on each side of a detected obstacle. Should additional clearance be desired, the fat layer can be adjusted in the field, pushing *ARCHON* further away from detected obstacles.

5.5. Goal Selection

Goal selection is the process by which *ARCHON* determines a destination. As *ARCHON*'s map is only an 80x80 grid, an interim goal is chosen if the desired goal is beyond the range of the current map. This interim goal is selected via a dynamic weight equation (see Equation 1below) using five parameters: straight, distance, gap, slant, and final destination (user supplied waypoints). Any of these weights, including the waypoints, can be disabled without impeding the basic functionality of *ARCHON*. All parameters are user-defined and can be adjusted in the field by a human operator. This allows for dynamic adjustment of *ARCHON*'s goal selection preferences. Parameters for setting the goal are defined in Figure 5.4

Characteristic	Definition
d	A measure in meters of the distance between the robot and the possible goal node
α	A measure in degrees of how in line a possible goal node is with the actual direction of the GPS waypoint with respect to the robot
β	A measure in degrees of how in line a possible goal node is with the straight ahead direction of the robot
S	A measure of how in line the node is with the slant of the map (slant is discussed below)
G	A measure of the gap on either side of the possible goal node if obstacles are present. (gap is discussed below)

Figure 5.4 Definition of goal node characteristics

Equation 1: Weight Equation

Slant is part of the strategy that allows the robot to stay on course despite intermittent lines. An example is a path that tends to bear to the northwest. *ARCHON* will notice this tendency and tend to favor a path following the same bearing.

Gap measures the amount of space on either side of a potential goal node. *ARCHON* will have the tendency to choose the widest gap that is less than or equal to a predefined width. Since the obstacle course at IGCV has a known maximum width, *ARCHON* can be instructed to prefer paths of less than this known width if available.

At this point the goal is selected, denoted as "G" in Figure 5.5. The goal selection process itself begins at the robot's node and iterates through all allowed nodes with a potential path. An allowed node is one which is not

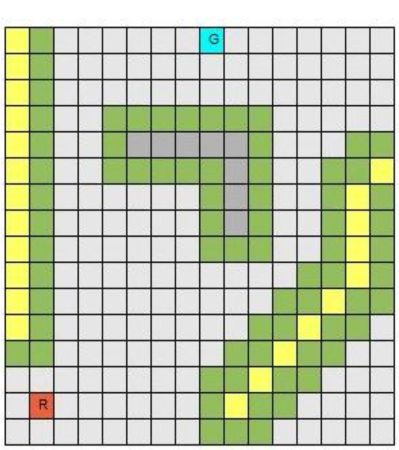

Figure 5.5: Goal Node added

occupied by an obstacle. As the algorithm searches each row for gaps, the center node of each gap is evaluated using the weight equation. If the evaluated node has a better cost than the current candidate goal node, it becomes the new candidate goal node. This process will continue until either all rows have been evaluated or there is no path to the next row. At this point, the candidate goal node is assigned a weight of zero.

5.6. Path Creation

Path selection process consists of three sub-processes: the ripple algorithm, the waterfall algorithm and the smoothing algorithm. This process creates an optimal path to the goal node. The goal selection algorithm ensures that a valid path to the goal will always be attainable.

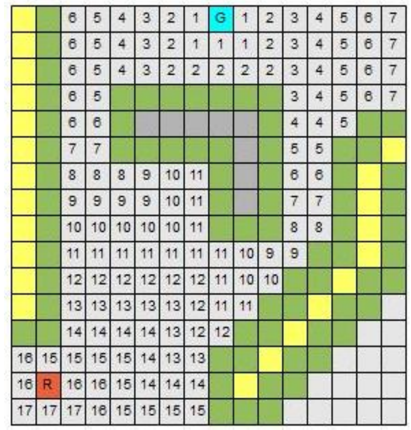

Figure 5.6: Map with ripple algorithm

The ripple algorithm assigns a weight to all map nodes not occupied by an obstacle. This process begins with the goal node and executes using a breadth first strategy. A recursive algorithm will continue checking nodes adjacent to nodes already assigned a value by the ripple algorithm until no valid adjacent nodes remain. This process is displayed in Figure 5.6.

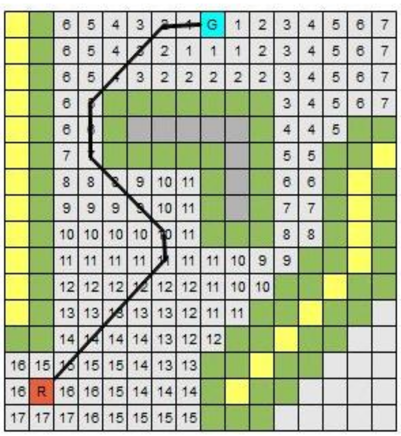

Figure 5.7: Path Selection

The waterfall algorithm is based on the well-known A* algorithm, finding an optimal path from ARCHON to the goal node. Starting with ARCHON's position, all nodes surrounding the current step in the path selection process are evaluated and the node with the lowest value is chosen as the next node in the path. In case of a tie, a cost equation decides which node to use. As with the A* algorithm, we are guaranteed that the selected path is optimal in terms of the number of nodes in the selected path. Figure 5.7 shows the path selected. A special case algorithm has been implemented if a flag has been detected on the map between ARCHON and its next designated waypoint. If this special case is detected, path selection will always pass on the proper side of the detected flag.

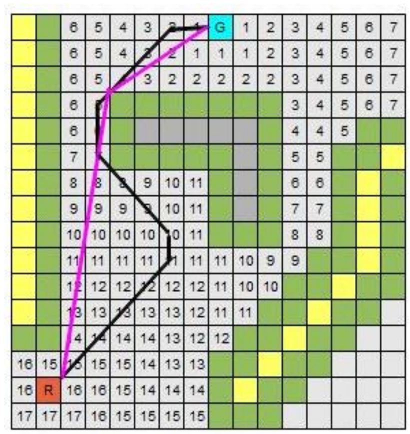

Figure 5.8: Smoother algorithm

Figure 5.8 demonstrates the path smoother. Path selection of the Waterfall algorithm is restricted to 45º and 90º turns. This limitation is overcome in ARCHON by a smoothing algorithm to “cut corners.” Smoothed paths will never take ARCHON across a node occupied by an obstacle. This process allows ARCHON to take a straight-line path whenever available, resulting in an optimal path as measured in real-world distances.

5.7. Control Decision

With path planning completed, *ARCHON* implements it's control decision. Speed is dynamically adjusted based upon the length of the first straight line segment of the planned path. *ARCHON* will travel at minimal speed when faced with nearby obstacles, speeding up as longer segments of clear space become available. This strategy ensures *ARCHON* has sufficient time to react while in tight quarters. Control decisions are output as separate serial speed commands for each servo. The speed commands are then processed by a separate micro-controller, which in turn provides an analog signal to *ARCHON*'s servos

5.8. Jaus

The coding strategy for JAUS is sophisticated since it relies heavily on high-level functions and capabilities of the C++ language. JAUS_NEIGHBOR is a user-defined class that is created to take care of new connections. The motivation for designing a class structure for JAUS comes from the high demands and the necessary tools that are included with the JAUS architecture. A class orientation seemed to be the most logical design. We have encapsulated the JAUS_NEIGHBOR class as a "friend" member within our primary Robot class. This serves a few purposes: (a) this design allows the JAUS protocol to have access to necessary data members within the Robot class, while still keeping these variables private and protected from exterior objects and functions – (b) implementing JAUS_NEIGHBOR as a friend class also ensures a clean and efficient coding implementation, potentially cutting down time spent on troubleshooting.

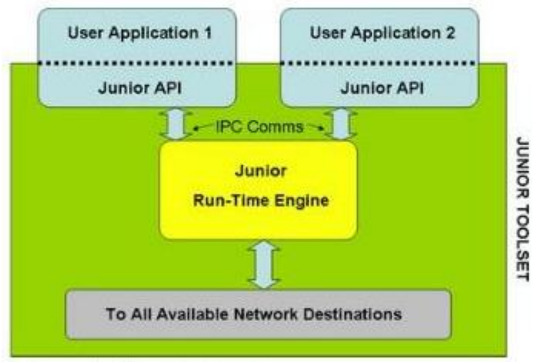

Figure 5.9: Junior Toolset

To assist in the implementation of JAUS, we are coordinating with an open source JAUS specific C++ set of libraries, called *Jr Middleware*™. These prebuilt libraries allow us to ensure accurate connections with a JAUS device, while also enabling our team to focus more time on tuning how the robot responds to these JAUS commands. Our implementation of *Jr middleware*™ permits preassembled tools to act as a "middle-man" between our robot and the JAUS device.

The *ARCHON* implementation of JAUS is unique in another way, however. With the advanced technology of multithreading, BSC has designed an implementation of JAUS that enables interoperability between autonomy and JAUS control. As our application enters into "navigate mode", we instantly start a separate thread of execution which constantly monitors for new JAUS connections. This allows the robot to navigate in autonomous mode seamlessly until JAUS connections are found, depending on the connection settings received from the JAUS enabled device. Once the JAUS enabled device is authenticated and requests control, our algorithm instantly switches from autonomous to JAUS controlled; once commands are issued via

JAUS, the robotic platform can switch back to autonomous mode and begin executing the commands. This design ensures accurate connections with JAUS-enabled devices, while still allowing the robot to perform in an autonomous manner – that is, our robot can now recognize, initialize, and configure new connections, receive commands, and return to autonomy without user intervention. This, we believe, is the ultimate goal.

5.9. Simulation

New simulation software has been developed for *ARCHON* which allows for the monitoring of *ARCHON*'s goal-setting and path-finding algorithms on platforms independent of *ARCHON*. All data used by *ARCHON* in its decision making process can be captured and analyzed in an easier-to-read format. In addition, user-generated maps can be constructed and tested using *ARCHON*'s goal setting and path-finding algorithms. This additional tool has proven invaluable in both troubleshooting and developing efficient algorithms. Owing to the secondary test base constructed for *ARCHON*, the software development team will be able to continue testing and refining the robot even when *ARCHON* itself is unavailable.

5.9.1. Software Innovation

Our software innovations are listed as four innovative algorithms in Section 3. The largest advancements in software innovation this year have come in the form of improved algorithm efficiency and reliability. Of particular note, *ARCHON*'s ripple algorithm has moved from a computational cost of $O(N^3)$ to $O(N^2)$. This increase in efficiency was achieved by moving from a brute force iterative solution to a much more efficient recursive solution. *ARCHON*s course navigation and waypoint navigation algorithms have been integrated into a single solution. In past competitions, course navigation and waypoint navigation had been treated as two discreet events. With the update to the IGVC rules, the two algorithms have been merged and both events are now treated identically.

Additional algorithms allowing *ARCHON* to detect and navigate between flags have been added to *ARCHON*'s camera and path selection algorithms. These algorithms will allow *ARCHON* to detect the special case of flags existing on the map between *ARCHON*'s current position and the next waypoint. In this circumstance, *ARCHON*'s normal path selection criteria are overridden and a path leading between the flags is given priority.

6. Predicted Performance

6.1. Speed

Given the vehicle's 14-inch wheels and 7:1 gear ratio, *ARCHON*'s motors are capable of theoretically driving the vehicle at 10 mph at their power-optimal speed of 1650 rpm. Vehicle testing has yielded results close to this estimate. In accordance with IGVC regulations, the maximum speed of the vehicle has been limited to 10 mph..

6.2. Ramp-climbing ability

According to IGVC regulations the vehicle must be able to climb a ramp-like structure with an angle of 15%. Given the QuickSilver motor specifications and the robot's weight, *ARCHON* will be capable of climbing the 15% incline at 5 mph.

6.3. Reaction time

The software program cycles through all procedures in less than 0.06 seconds. The SilverNugget motor controllers have programmable reaction parameters such as motor accelerations. Theoretically, the overall reaction time of the robot could be very fast. At the time of this report, the actual reaction times have not been set and measured.

6.4. Battery life

Table 1 lists the power consumed by the vehicle components under normal as well as worst-case operating conditions. Using these values, it is expected that the vehicle will be able to run for approximately 58 minutes under normal operating conditions and 55 minutes under the worst-case conditions.

Device	***Normal Operating Conditions***			***Worst Case Conditions***		
	Voltage (V)	Amps (A)	Watts (W)	Voltage (V)	Amps (A)	Watts (W)
Hokuyu	12	.7	8.4	12	.7	8.4
CSI Wireless DGPS Receiver and Antenna	12	1	12	12	1.5	18
Sony HandyCam Camcorder	8.4	.2	1.68	8.4	.6	5.04
Maretron Solid State Compass	12	.15	1.8	12	.15	1.8
Motors/Controllers	48	30.28	1453.44	48	31.92	1532.16
Total (Watts)			***1477.32***			***1565.40***

Table 1: Power

6.5. Distance at which obstacles are detected

The vehicle's Hokuyu unit is configured for a range of 30 meters. The camera is set up for a somewhat shorter range of 7 meters to eliminate glare and horizon effects.

6.6. Accuracy of arrival at navigation waypoints

With a differential beacon, the CSI Wireless DGPS gives an accuracy of two feet 67% of the time. This accuracy will most likely come within the one-meter circles at IGVC.

7. Safety, Reliability, and Durability

As with any product, it is not enough to perform well. One must also provide a strong and durable product that is capable of operating safely and reliably. *ARCHON* includes several features that not only contribute to its performance, but also increase its safety, reliability, and durability. Three E-Stop systems are implemented to ensure that the vehicle can be stopped safely, quickly, and reliably. These are the soft, hard, and remote E-Stops which are controlled by the propeller micro-controller, the manual mechanical button on the rear of the vehicle, and the remote control, respectively. The shelves are lined with a layer of paint to protect the electronic components from ground issues. All electrical circuits are carefully fused to prevent electrical damage. Furthermore, each device is fastened securely in order to ensure that no device becomes dislodged while the vehicle moves.

8.1. Costs and Sponsorships

Table 2 breaks down the team cost and Table 3 shows a list of sponsors with the service provided.

Description	*Retail Cost*	*Actual Cost*	*Comments*
Frame/Body	*$800.00*	*$0.00*	*Built by Students*
Motors/Controllers	*$4500.00*	*$4500.00*	*Purchased New*
Wheels	*$0.00*	*$0.00*	*Same Wheels from previous vehicles*
48 V DC Battery & 9 A Charger	*$1223.00*	*$1223.00*	*Purchased New*
Camera/lens	*$320.00*	*$0.00*	*Previously Used*
Hokuyu	*$5600.00*	*$5600.00*	*Purchased New*
DGPS & Antenna	*$3000.00*	*$1800.00*	*Previously Used*
Compass	*$700.00*	*$700.00*	*Previously Used*
Laptop	*$1300.00*	*$1300.00*	*Previously Used*
Extra Wires/Components	*$350.00*	*$200.00*	*Previously Used*
Total	*$17,793.00*	*$15,393*	**Savings of $2400.00**

Table 2: Team Cost

Sponsors	Materials
Smith Services	Aluminum for Competition Base, Allowed student to weld Aluminum on sight
Sexton Signs	Vinyl, Lexan and skirts
Lamb Machine	Machining of shafts and hubs
Conn-Weld	Donation of steel
CART Inc.	Funding of trips and materials

Table 3: Sponsors

8. Conclusion

The Bluefield State Robotics team is very proud of *ARCHON* this year. *ARCHON*'s performance in trial runs and tests are very promising. We expect that this year will be our best year yet!