IGVC DESIGN REPORT FOR ARES

Bluefield State College
Alex Enoch, Whitney White
Bob Riggins, Ph.D. Adem Ozyavas, Ph.D. <briggins@bluefieldstate.edu>

This report details the design process, electrical components, software, performance, and other aspects of the Bluefield State College Robotics Team's 2014 IGVC contestant, ARES.

INTRODUCTION

The Bluefield State College (BSC) Robotics Team would like to introduce their newest Intelligent Ground Vehicle Competition (IGVC) contestant, ARES. The team has redesigned our visual input system, converted the software platform to LabVIEW 2013, compartmentalized our internal systems, streamlined data acquisition, and improved both durability and safety. Using BSC's previous experience, combining features which have shown success in the past, updating both hardware and software of our sensor package, and improving serviceability; our team is confident that we have our best robot yet. With a strong versatile team backing ARES, we look forward to competing in this year's IGVC. Included on the right is Figure 1, a photograph of ARES.

Figure 1. ARES Photograph

TEAM

The ARES team consists of undergraduate students from the computer science, electrical engineering, and mechanical engineering programs. With the additional input of two faculty advisers, the ARES team has a diverse and robust skill-set which allows us to tackle many challenges. The team has logged roughly 1500 hours over the past year, and most team members received five credit hours of instruction in robotics this past year at BSC. The ARES team is pictured on the next page. A list of team members appears in Table 1, followed by a team picture in Figure 2.

Table 1: Team Members

Name	Role	Class
Douglas Reynolds	Co-Captain; Software Lead	Senior
Alex Enoch	Co-Captain; Electrical Lead	Junior
Jared Orlicki	Electrical	Senior
Whitney White	Electrical; Documentation; Graphic Design	Senior
Corey Nunn	Electrical	Senior
Andrew Smith	Computer Science	Senior
Hollie Fuller	Business	Junior
Levi Puff	Computer Science	Junior
Clayton McChesney	Computer Science	Freshman
Nathan Oaks	Mechanical	Senior
Brandon Tolley	Mechanical	Senior

Figure 2. ARES Team

DESIGN

In this section the design process, innovations, and physical characteristics of ARES are discussed.

Design Process

While regrettably unable to compete last year, the ARES robot that was designed by the 2012/2013 robotics team provided our team with a solid starting point with which to begin this year's project. We poured through IGVC records, noting the successes and failures of the past. We then brainstormed about how to improve performance and avoid pitfalls while investigating new concepts and innovations. Finally, the team decided to focus on software and hardware modularity, speed, and ruggedness for this year's IGVC entry. With these priorities in mind we disassembled the previous team's robot and reworked him from the ground up. We gave each internal component its own individual casing, added an internal rubberized mat for electrical safety and vibration cushioning, upgraded our sensory system, redesigned the software, and performed additional testing.

Design Innovation

Many of this year's design innovations center around serviceability, ruggedness, safety, software speed, and sensor accuracy. Furthermore, our sensory capabilities have been greatly increased with the addition of a high frame rate, high data transfer speed, Basler USB 3.0 camera. The modularity and design of our software has been improved by changing our development platform to LabVIEW 2013, discussed further in the software section. Finally, the software interface of the Hokuyo Laser Measurement System (LMS) has been completely reworked, allowing for much faster cycle times.

By removing all of ARES internal components and adding a non-conductive, rubberized mat underneath, we have increased safety and durability. This mat acts as an insulator shielding the frame of ARES from any possibility of an internal ground fault. It also provides a vibration dampening cushion which reduces stress on our components. In addition, each device's power connection in ARES has been individually fused and the mount for our LMS has been rebuilt to provide electrical isolation. Also, each system now has its own independent housing. For added protection, our laptop "brain" runs on an isolated power supply and provides independent power for our new Basler USB 3.0 camera. These features make ARES the most electrically robust of all BSC's robots to date.

With speed in mind, ARES has a new Basler camera. This camera is the first USB 3.0 camera ever used in a BSC robotics project, and it has a potential frame rate of over 100 frames per second (FPS). This allows a high rate of data capture which we hope will serve BSC robotics well into the future. Using white balance and gain adjustment features, our implementation allows the camera to operate in many lighting conditions with reduced glare and improves color recognition. Designed as a traffic camera, the Basler is very versatile in outdoor conditions.

Another innovation which helps ARES's speed is the redesign of the data acquisition from our Hokuyo. After a redesign utilizing the LabVIEW development environment, we have been able to reduce the time for one cycle of data gathering from 150 milliseconds to 25 milliseconds. We built a driver interface allowing ARES to capture data using fewer layers of programming. This new driver interface also allows ARES to take advantage of some advanced settings in this device which had been unexploited before. With our new programming techniques we are able to take advantage of speed enhancing parallel processing, as described in the software section.

Further speed increases have been achieved by using a Core i7-based laptop with 8 gigabytes of RAM and a solid state hard drive. This laptop's raw power has served our team well and provides the execution speed we need for our upgraded software.

Physical Characteristics

ARES is 66.7 centimeters wide, 179 centimeters in height, and 101.6 centimeters long. It weighs about 91 kilograms, including the 9.1 kilogram payload when fully loaded. These dimensions meet IGVC specifications, but tend toward the lower limit to give ARES more room to maneuver within the course. The ARES base is constructed using the frame, motors, and motor controller from an 1170 Jazzy electric wheelchair. This base has been modified to allow the top of ARES to be removed by pulling four pins and then simply lifting the top portion off. The main body of ARES was designed by students on the robotics team and constructed by a local business. It has ample internal space for components, easy access doors, a convenient control panel for operation, and a sleek look. Atop the main portion of the ARES body sits a mast which houses the GPS receiver, camera, and running lights. The combination of these three main components allows for portability, serviceability, and versatility.

ELECTRICAL AND SENSOR SYSTEMS

This section details the electronic components, sensor system, and student-built custom parts included in ARES

Electrical Systems

ARES uses two Optima Yellow Top 12 Volt-DC deep cycle marine batteries rated for 30 amp-hours apiece. The location of these batteries near the bottom of ARES' frame helps to provide a low center of gravity, which allows for greater ramp climbing ability. This is detailed in the performance subsection. These will power ARES' systems, under normal conditions, for nearly an hour at full speed; much longer at slower speeds. This 24 Volt power system runs two motors, a Pilot wheelchair controller, and a 24 to 12 Volt DC-DC converter. All other devices, except the laptop and camera (which have self-contained power) are powered by this converter through a central fuse box. A diagram of the power system is included in the Appendix: Power Distribution.

To ensure safety, most devices are separately fused providing over-current and ground fault protection. In addition, the central body of ARES is "carpeted" with an insulating mat, and each internal system has its own casement; this further reduces possibility of electrical damage or ground fault. These features also enhance durability by providing shock absorption and shielding the internal components from electrostatic discharge.

ARES features four independent emergency stop (E-stop) mechanisms. The first is a direct "kill switch" which disconnects the power to all sections of the ARES system. The second is a wireless version of the same device, allowing remote emergency shutdown. Third, ARES contains what we refer to as the "soft E-stop," a system which shuts down power to the motor controller while leaving other systems powered. The soft E-stop is used primarily for testing and troubleshooting purposes. Finally, a toggle switch removes the computer control from the ARES system, allowing a user to take immediate manual control of the robot using a backup wired joystick. It can also be activated from a convenient button on the remote control device.

Student-Manufactured Custom Parts

The wireless E-stop system is completely student-made. It operates using a 433MHz HAC-UM96 receiver and transmitter which have been hardware encrypted to overcome interference issues experienced during testing. It operates in parallel with the hard E-stop using relay-activated switches. Students also made a 16-Bit Propeller microprocessor system which relays laptop commands and remote control commands to the motor controller. Additionally, the overcurrent protection system and Hokuyo Laser Rangefinder power supply filter are both student-designed and manufactured.

Sensor System

ARES uses four sensors to provide information from the outside world: A Differential Global Positioning System (DGPS), a laser rangefinder, a camera, and a digital compass. Each sensor is mounted so that it can easily be removed and remounted. All of these sensors connect to our on-board laptop using USB, making them easy to connect and disconnect. With a fused USP hub, the laptop is isolated from any electrostatic discharge or power surge which might travel through the USB data connections. A brief description of each sensor follows.

Camera. A Basler USB 3.0 outdoor camera has been selected for multiple reasons. With a frame rate exceeding 100 FPS and high speed data transfer; this camera provides more than enough speed. Additionally, automatic white balancing, gain adjustment, and shutter speed control allow for excellent vision in any lighting condition. When combined with a horizontal 125 degree field-of-view lens having only 3% distortion, the ARES vision system has exceptional precision and versatility.

Laser Rangefinder. ARES uses a Hokuyo LMS scanner for object detection. With a 270-degree field-of-view at 0.25 degree increments and a detection range of up to 30 meters, the LMS provides extremely accurate object detection. It cycles at 40 Hz, allowing ample time for ARES to detect any obstacles in its path. The Hokuyo also features data clustering, specularity measurement, and adjustable resolution levels for maximum customization.

DGPS & Antenna. To obtain positioning data ARES uses a CSI DGPS system. This provides position, direction, and speed data, allowing ARES to track both its own position and those of user-defined way-points. The GPS antenna and the Beacon antenna used for differential corrections are housed in the same location, making it easy to mount on ARES. DGPS accuracy is discussed in the performance subsection.

Compass. A Maretron Solid State Compass assists in determining vehicle heading. Since the heading data provided by a GPS unit is less than reliable when the vehicle is still or moving at low speeds, it is supplemented with this compass. It provides an accuracy of 0.1 degrees, and updates at 10 Hz. to verify our direction. The Maretron compass is designed to function with pitch and roll of up to 45 degrees preserving its functionality on inclines.

SOFTWARE STRATEGY

In this section, software strategy including software development, signal processing, system integration, map generation and goal selection will be discussed.

Software Development

ARES has been redesigned in the LabVIEW 2013 software suite. This is a new software development environment utilizing graphical-based coding. This platform allows for easy visualization of code structure and also makes code very compartmentalized, allowing our team to easily view or change any one aspect of the software without changing other code structures. LabVIEW also allows the use of segments of C code as subroutines which provides legacy support for existing code and allows the ARES team to use C code when preferred. Additionally, LabVIEW executes code in an interesting and useful manner. It executes each piece of code as soon as the data inputs are available instead of executing all commands sequentially. This feature will allow for increased processing speed by allowing for greater distribution of processes between different cores. LabVIEW also provides direct support for much of our hardware allowing our team to focus on the path planning and mapping without having to deal with difficult data communications issues with the sensors. The ARES navigation software gathers sensor information, fuses this information together, generates a local map, selects a goal, plans a path, and makes control decisions. At this time it performs each of these tasks approximately every 50 milliseconds. Our goal is to reduce this cycle time to 25 milliseconds by IGVC.

LabVIEW is a great way for us to add software innovation allowing the ARES team to push its boundaries by reaching the hardware limitations of 25 milliseconds per scan and 270 degrees viewable angle with our laser rangefinder. It has also allowed us to process more pixels of visual information at a greater frame rate than ever before using a Basler USB 3.0 camera.

System Integration and Signal Processing

Sensor information from our four sensors, a Hokuyo Laser Rangefinder, a Basler camera, a DGPS, and a magnetic compass, is all integrated into a single data stream which eventually becomes our local map. Hokuyo LMS data is weighted to highest priority, since it is the most accurate of our sensors and collisions are particularly undesirable. Each nine pixel block on the raw camera data is averaged, analyzed, and assigned to either the white, blue, or red category. The camera data is filtered through a glare-reducing algorithm and red and blue areas are checked for size to confirm that they are flags, and not barrels. Areas to the appropriate sides of flags are also marked to ensure passing on the correct side. Camera data is integrated next, with white indicating course boundary lines and pot holes, red and blue indicating flags. All three colors are assigned values and added to the local map. The DGPS and magnetic compass data is used for ARES position and heading, and also used in the goal selection stage of processing.

Map Generation

The Ares local map is composed of 6400 cells making an 80x80 grid, which represents an 8x8 meter area, with each cell representing 0.1 meter by 0.1 meter. The upper left and lower right cells have a location of (0, 0) and (79, 79) respectively. ARES occupies cell (60, 40); which gives ARES a forward range of 6 meters, a sideways range of 4 meters, and a rear range of 2 meters upon which to plot its map. During map generation each open cell is assigned a value of 1000. This allows us to modify this value to represent locations to which ARES does or does not want to travel.

Sensor data is added to this map as it becomes available using the technique described above. ARES's map is then augmented by adding a layer of what we call “fat” around objects. This layer acts as a buffer zone to ensure that ARES does not collide with objects. It is adjustable to allow for fine tuning of the map and normally it provides a buffer of 0.4 meters to either side of an object. With ARES width being 0.66 meters, this should provide ARES with a clearance of 0.07 meters on either side in all scenarios. Included on the right is Figure 3, a conceptual drawing representing obstacles with “fat” added.

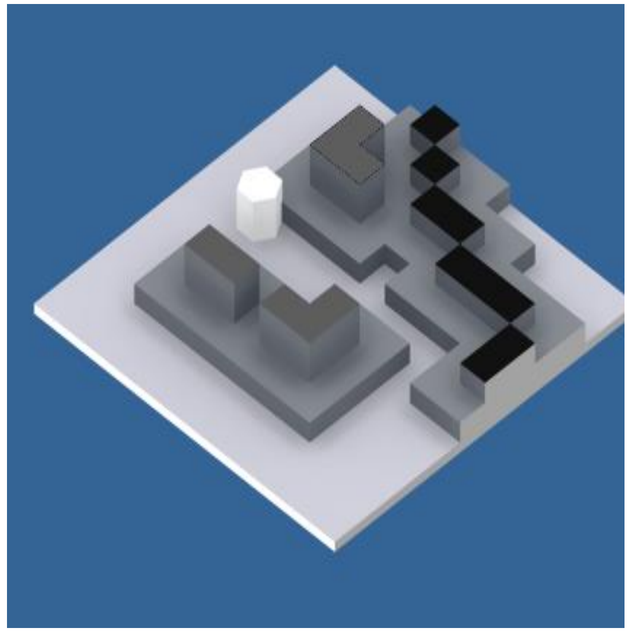

Figure 3. ARES Local Map With "Fat" Added

Goal Selection and Path Creation

Since ARES uses a local map which is much too small to encompass the entire course; provisional goals must be selected within the boundary of ARES’ maps. These goals are selected through a dynamic weighted equation (see below) using five parameters: straight, distance, gap, slant, and final way-point destination. Any of these parameters can be adjusted in the field. Since this equation can use all or some parameters, ARES can still make goal selection decisions on limited information.

$$Weight = (d \times P_d) + (a \times P_a) + (\beta \times P_\beta) + (S \times P_S) + (G \times P_G)$$

To select a goal ARES notices the tendency of the path to go in a certain direction and prefers a path with a similar bearing. Called “slant” (*S*), this is part of the strategy to navigate despite intermittent lines. Another component of the goal selection process, “gap” (*G*), instructs ARES to prefer the largest path within selected parameters. Since the maximum and minimum path sizes are known for IGVC, Ares will be instructed to prefer paths within these bounds. The other weights in this equation are distance (*d*), angle to waypoint (*a*), and bearing from

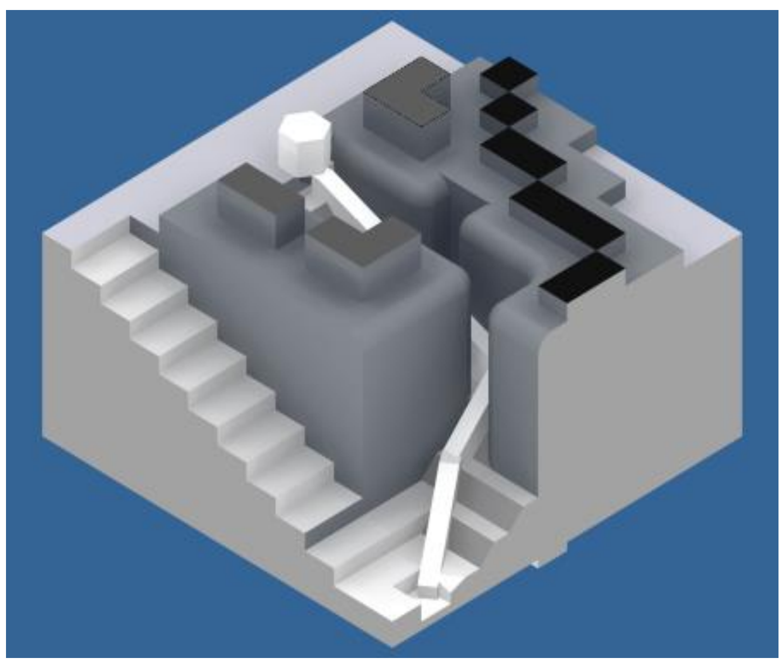

Figure 4. ARES Path Planning Example

ARES current direction (β). The goal is then selected by checking each map node with this equation and marking the lowest value as the goal. The goal is given a weight of zero, the lowest weight on the map. This process is depicted in Figure 4. The path selection process consists of three sub-processes, ripple, waterfall, and smoothing. Ripple assigns increasingly larger weights to map nodes as the distance from the goal increases. Waterfall creates a path for ARES by going "downhill." It checks each node from ARES to the goal and chooses the lowest number. Because of the weights generated by "ripple," the lower numbers will be closer to the goal. In the case of a tie, a cost equation is used. A special case algorithm has been created for use in the event of flags. Smoothing is needed because the waterfall is restricted to 90 and 45 degree turns only. It uses trigonometry to "cut corners" resulting in shorter path distances.

After path planning, the speed is determined by the length of the first straight line segment of the chosen path. This allows ARES to "open up" in clear areas, and "be careful" in close quarters. Using this path planning process, ARES determines both long and short term goals, allowing it to avoid traps and dead ends.

TESTING AND PERFORMANCE

This section will discuss software simulation, predicted performance, safety, and durability.

Simulation

By simulating ARES logic we are able to identify problems, examine behaviors, and troubleshoot under any imaginable circumstance. Our simulation is designed to mimic actual ARES behavior down to minute detail. All logic in simulation is exactly the same as the logic used in actual field performance; in fact it is the same software. Through using manufactured sensor data and then feeding this data into the actual ARES field program we are able to determine exactly how ARES will make decisions in regards to any obstacle. Furthermore, timers simulating sensor acquisition and additional response time needed due to ARES inertial dynamics are part of our program.

High Speed Operations

One of the ARES team's primary innovations this year has been to speed up processing by identifying and remedying bottlenecks in both our hardware and software. By including a timing function in our simulation testing we are able to identify which areas are the most critical to improving the performance of ARES. One area we were able to identify was the data acquisition from our Hokuyo LMS. By redesigning the software used to acquire data from this device we were able to reduce the cycle time from 150 milliseconds to 25 milliseconds; which is a significant improvement.

With the addition of a Basler USB 3.0 camera to our sensor suite, to our knowledge the first at IGVC, we are able to capture video at over 100 frames per second. The Basler camera is also equipped with a low distortion, wide angle lens, allowing ARES to use less processing time correcting for lens distortion. Furthermore, LabVIEW 2013 has capabilities to support parallel processing more efficiently than ever before. With these new features we are confident that our reaction times will be much higher than in the past. This will allow ARES to come much closer to the IGVC "speed limit" of ten miles per hour.

Predicted Performance

ARES current top speed is 6 mph, and it is able to climb a 25% grade with no reduction in speed while fully loaded. With software cycles around 0.05 seconds ARES is able to react very quickly to changing conditions. In fact it is our belief that ARES can react more quickly than human beings, whose average reaction times are around 0.21 seconds. Obstacles can be detected at long distances, but we are currently limited by the size of our internal map which caps our detection range at eight meters. Using the CSI DGPS Max system, ARES is accurate to within one meter 95% of the time, according to the product specifications. ARES will overshoot a GPS way-point by one meter to maximize the probability of coming within one meter of way-points.

Safety, Reliability, and Durability

ARES has a number of attributes which not only improve performance, but also make it more rugged and safe. ARES features four independent E-stops, two on-board and two wireless, as previously discussed. Our newest additions for safety and reliability are a solid state hard drive, rubberized padding, individual component housings, a fused power system, and chassis electrical isolation. The solid state hard drive now in our laptop will prevent disk damage due to vibration or rough terrain and increase performance in our laptop. The rubberized, non-conductive matting protects both ARES and others in the case of electrical failure. Each component is individually housed and securely mounted using non-conductive mounting; this further isolates the electrical system. Individual fuses provide a last line of electrical defense, burning out in the case of failure of the other isolation systems. The ARES system can be configured to run without many of its components. This allows the team to disable almost any component for testing and troubleshooting. ARES can even run under remote or wired control in the absence of its laptop "brain." In autonomous mode any sensor can be disabled and ARES will still continue, albeit with some loss of functionality. With these features ARES is the safest, most durable robot Bluefield State College has ever constructed.

ACKNOWLEDGMENTS

Sponsors

We would like to thank PEMCO for donation of welding services, Smith Services for aluminum, Conn-Weld for steel, and CART Inc. for providing our registration costs.

CONCLUSION

In this report we detailed the innovations included in ARES, the 2014 IGVC contestant from Bluefield State College. These innovations included added safety, reliability, reduced data acquisition time, and high speed vision.

APENDIX: POWER DISTRIBUTION