BLUEFIELD STATE COLLEGE

BLUEFIELD STATE COLLEGE ROBOTICS

VALKYRIE I

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Statement of Integrity:

I certify that the design and engineering of Valkyrie I by the 2021/2022 BSC robotics team has been significant and equivalent to what might be a senior design course.

Joseph Hazelwood, Faculty Adviser

1. Introduction

The Bluefield State College Robotics (BSCR) Team is proud to enter Valkyrie I into the 29th annual Intelligent Ground Vehicle Competition (IGVC). Valkyrie I is designed to autonomously navigate an obstacle course for IGVC. It is significantly upgraded and improved from previous designs from Bluefield State College. The main objective of the Valkyrie I system is to optimize modularity in its designs. With the use of sensors, the navigation software can adapt to a multitude of situations.

1.1 Organization

Bluefield State College Robotics Team consists of a coordinated group of students with guidance from faculty and alumni advisors. The team captain is chosen each year as the person with the greatest experience with the robot, including its electrical, mechanical, and software systems. The primary team leads are broken down to the three basic fields in robotics: electrical, mechanical, and computer science. Team leads are appointed by the team captain to mentor and manage required tasks for fellow members in their field of expertise. The remainder of team members are designated under their academic major at Bluefield State College and use their knowledge from the classroom to develop, design, fabricate, and maintain robotics projects. A total of 1,970 hours has been spent on the Valkyrie I project (Table 1).

Department	Team Member	Academic Major	Standing	MECH	ELEC	COMP	MGMT	Hours
	Jacob Clarkson (Team Captain)	(B.S) Mechanical Eng. Tech	Senior	X	X	X	X	745
Mechanical	CJ Buckner (Mechanical Lead)	(B.S) Mechanical Eng. Tech	Senior	X			X	85
	Kashif Alston	(B.S) Mechanical Eng. Tech	Sophomore	X	X			80
	Kateryna Dashevska	(B.S) Mechanical Eng. Tech	Sophomore	X	X		X	75
	Peyton Whitt	(B.S) Mechanical Eng. Tech	Freshman	X				10
	Samuel Bauer (Alumni Advisor)	(B.S) Mechanical Eng. Tech	Alumni	X	X		X	350
Electrical	Elisha McClary (Electrical Lead)	(B.S) Mechanical Eng. Tech	Senior	X	X		X	180
	Christopher Coleman	(B.S) Electrical Eng. Tech	Sophomore		X	X		75
	Theodor Schell	(B.S) Electrical Eng. Tech	Senior		X			50
	Casey Hazelwood	(B.S) Electrical Eng. Tech	Sophomore		X			35
Computer Science	James Cardwell (Computer Science)	(B.S) Computer Science	Senior			X	X	175
	Teddy Razafindratsima	(B.S) Computer Science	Sophomore		X	X		50
	Frederik Bau-Madsen	(B.S) Computer Science	Senior			X		60
							Total	1970

Table 1

1.2 Design Process and Assumptions

The design process for the BSC Robotics Team utilized a seven-step process as seen in Figure 1 (Bluefield State Robotics Team, 2018). The initial problem presented by the competition was to design and create a self-driving mobile robot that is capable of autonomously traveling to specific way points while navigating through an obstacle course. Valkyrie I's design process began immediately following the close of 2018's IGVC with an analyzation of the Apollo IV's performance and identification of the problems that it faced. After the analysis of the robot, the team assigned priority to each fail-point, with innovations concerning the areas of greatest failure taking the highest priority in the new design. Research was done to locate the causes of each problem and

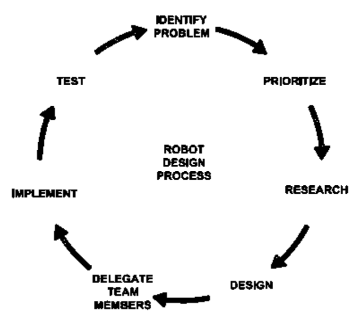

Figure 1

find the best solutions. Following the research phase, the team presented the findings of this research as a group and designs were created for each solution. After design and fabrication was completed, the next step was to establish the modifications to verify a functional system. If adjustments needed to be made at any stage of development, the design process was repeated.

2. Innovations

2.1 Light Weight Body

The newly designed body used in the Valkyrie I system is inspired by aircraft structures. This allows the body to have a minimal weight while maintaining a large storage volume. With previous robotics platforms the internal storage was limited and caused overheating of components. The enhanced volume allows for extra equipment to be implemented in future versions of the Valkyrie platform.

2.2 Modularity

All electrical components and software systems are designed to accommodate use within previous BSC robotics platforms, thus assisting future teams with the understanding of old as well as the development of new designs.

2.3 Additive Manufactured Components

Components were created with the use of additive manufacturing utilizing a Prusa i3 MK3S+ 3D printer. 3D printing has been implemented to a greater degree in the Valkyrie I than with any previous BSC robotics platform. As a result of this manufacturing process, new components can be prototyped with greater efficiency, and damaged components replaced with lower cost.

2.4 Cooling System

With previous BSC robotics platforms heat dispersion was a factoring problem on runtime since heat would be trapped within the main body of the robot. The newly developed cooling system acts as a forced air-cooling system. A 120mm fan moves the heat directly from electrical enclosures and forces the exhaust out the bottom of the body with the use of a 3D printed fan hood (Figure 2). This ensures all electrical components remain cool and functioning.

Figure 2

2.5 Payload Containment

While competing in the Auto-Nav competition, robots must carry a 20-pound payload (IGVC Rules Committee, 2022). Previous members of the team have made observations of multiple robots either losing balance due to the payload or having a run disqualified due to the payload falling off the robot. For the Valkyrie I, the batteries have been moved up into the interior of the robot, and the payload has been set in the chassis of the robot located between the wheels (Figure 3). Two robust drawer slides are used to slide the payload in place making it more accessible. This lowers the robot's center of gravity and increases its stability by keeping the payload in the direct center of the robot.

Figure 3

2.6 New Batteries

Previous BSC robotics platforms employed a set of 12V Optima YellowTop lead-acid batteries. These batteries, while being rated for 55 ampere-hour, experienced issues with power loss during runs. Therefore, the Valkyrie I system utilizes two 35 ampere-hour 12V deep cycle sealed lead-acid wheelchair batteries. These batteries maintain the same output voltage without draining at the same rate due to the streamlined electrical system.

2.7 Sound System

Electric vehicles (EV) feature an Acoustic Vehicle Alerting System (AVAS). This system warns people of an approaching robot. The Valkyrie I provides an onboard AVAS system that delivers sounds to warn of its presence which minimizes the risk of injury to pedestrians.

2.8 New Graphical User Interface

A new Graphical User Interface (GUI) was generated to provide ease of operation of the navigation software. The main goal in redesigning the GUI was to make information easy to access for users with limited software experience.

3. Mechanical Design

3.1 Overview of Mechanical Design

The Valkyrie I body focuses on increased stability, modularity, low weight, and ease of access to components. The Valkyrie I consists of a wooden and polymer body set on the base of a modified electric wheelchair. The body of the robot is covered with a vinyl covering for ease of access to internal components. The wheelchair motors have been modified to respond to commands directly from the control system. This allows the full capability of the motors beyond its design to achieve speeds for competition, which is limited to 5 mph. Another advantage of the modified wheelchair system is the zero-degree turning radius, allowing Valkyrie I to perform with high precision.

3.2 Structure Design

3.2-a Chassis

The Valkyrie I is set on top of a modified Quantum Q6 electric wheelchair base (Figure 4). Through multiple tests performed by the BSC Robotics team in previous competitions, it has been decided that a wheelchair base is the best option for an autonomous vehicle. They can achieve speeds well in excess of competition requirements and are capable of zero degree turns. The batteries, which normally sit down in the middle of the wheelchair base, have been moved into the body of the robot. This leaves a space which will snugly fit the payload required for competition (IGVC Rules Committee, 2022). Having the payload in the center, close to the ground, lowers the center of gravity of the robot, increasing stability in uneven terrain.

Figure 4

3.2-b Body

The body of the Valkyrie I is a wooden base with polymer framework (Figure 5). The lower part of the body houses a majority of the electrical equipment. Plywood and lumber were chosen due to low cost, light weight, and ease of fabrication. The upper shell is comprised of a set of ribs made from both high-density polyethylene (HDPE), a highly recyclable polymer used in most household consumables, and Delrin plastics, which have been cut on the OMAX MAXIEM 1530 water jet machine located in the BSC machine shop. These ribs are secured by way of two steel threads, as well as two sets of aluminum L-brackets on either end of the body. This upper portion of the body is secured in place with the use of wooden dowels, so that it can be removed and aligned with ease. This allows for easier access to the electronic components of the robot. Furthermore, the HDPE ribs utilize vent holes on either side to allow for the addition of a cooling system for the electronics housed within the body. The rear end of the body has a window to allow the operators to see the interior laptop which runs the robot during operation. The body is protected with a vinyl cover. This cover protects the electronics from inclement conditions without adding much weight to the body. The mast is fabricated from segments of 2-inch PVC pipe, with connectors to accommodate the compass, camera, and GPS antenna. PVC has been used for many of the BSC robotics team's mast-heads, primarily because of the ease with which it can be used. Mounting brackets have been 3D printed for the camera, compass, and GPS. This allows for parts to be replaced easily, should anything break.

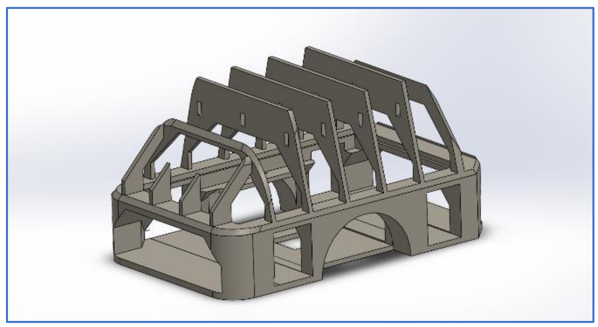

Figure 5

3.2-c Suspension

There is limited travel in the suspension employed in the design of the Valkyrie I compared to other BSC robots. The suspension that is incorporated in the design of the wheelchair base remains in use. The team believes that this suspension design is optimal for paved environments such as the competition course. For the mounting point between the chassis and the body, a set of silicone gel shock absorbers have been added to absorb the force produced when the robot rocks to either side. The front shocks are made with a denser silicone than the back. This produces a rigid shock absorber, which is meant to minimize vibrations.

3.2-d Weather Proofing

The main weather protection for Valkyrie I comes from the vinyl cover (Figure 6). The cover is fitted over top of the polymer ribs and is secured with Velcro strips around the perimeter of the body. This cover protects the electronic systems from the elements. The fuse box and power systems are further protected in a water-resistant enclosure within the body of the robot.

Figure 6

4. Electrical Design

4.1 Overview of the Electrical Systems

The electrical system of Valkyrie I has maintained the same basic systems as previous BSC robotics platforms, this was decided to aid the future goal of complete modularity of electrical components among all robotic systems created by BSCR. Valkyrie's new fuse box has exterior access to the individual component power switches for convince and safety. In addition, the fuse box incorporates a comprehensive color-coded wire system. An enhancement from previous designs to the fuse box is the robust cooling system, to ensure the reduction of overheating components. Valkyrie I uses a DC-DC voltage regulator to lower the voltage to desired output voltage. The original wheelchair control system was removed, and a completely new control system was used. The Valkyrie I control system consists of an X-Bee wireless transceiver, Parallax Propeller 8-core microprocessor, and a Sabretooth 2 x 60 motor controller. All these components remain completely compatible to former BSC robotic platforms. During the design process safety was highest priority. Later considerations focused on reduction of wasted power to increase range, and to prioritize modularity with previous systems.

4.2 Power system.

The Valkyrie I power system possesses an increased range compared to previous robotics platforms, due to advancements in battery technology. Two 35 ampere-hour 12V deep cycle sealed lead-acid wheelchair batteries are used to power all onboard systems. The two batteries are connected in parallel to provide 24 volts to the motor control system. The other components are regulated to 12 volts with the use of a DC-DC voltage regulator. The fuse box receives the power from the DC-DC voltage regulator and restricts the amount of current through the sensor systems. A useful feature of the newly designed fuse box allows for users to power each component separately with the conveniently color-coded switches mounted to the back window of the robot (Figure 7). The new fuse box provides extra safety and clarity with the easy-to-follow color coded wires (Figure 8). Each sensor system is connected to the fuse box with the use of quick connectors. Each sensor connector has a unique color and shape to prevent severe damage to electrical components.

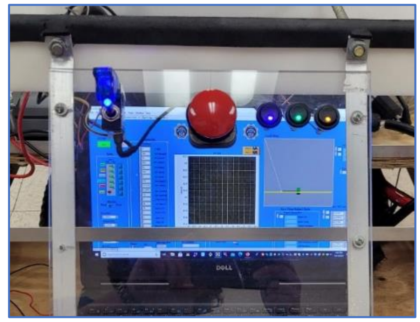

Figure 7

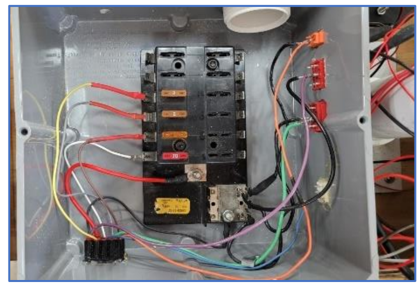

Figure 8

4.3 Control System

The Valkyrie I control system was replaced from a wheelchair control unit to a system developed by BSC Robotics students. The control system built around the Parallax Propeller 8-core microprocessor in conjunction with a Sabretooth motor controller. Opto-isolators were used between the Sabretooth and microprocessor to physically separate the two components since they operate on different voltages and currents while maintaining the operation of the brakes. Similar to previous designs, a ferrite core toroid on the motor wiring harness was used to reduce transients from reverse voltage of the motors. With keeping the same basic components as previous robots, the microcontroller unit is completely interchangeable with previous BSC robotics platforms with minimal changes to software. An onboard laptop computer runs student developed navigation software. The microcontroller relays information via Universal Serial Bus (USB) to the onboard laptop computer, which commands direction and speed of the motor control system.

4.4 Sensor Systems

Valkyrie I utilizes four main sensors: Light Detection and Ranging (LIDAR), camera, Global Positioning System (GPS), and compass. Each of these sensors are used to collect data from Valkyrie I’s surroundings and act accordingly. The sensors were selected by the team for their established accuracy from previous robotics systems. Maintaining similar sensor configuration optimized further modularity with previous BSC robotics systems.

4.4-a Hokuyo UTM-30LX-EW LIDAR

The Valkyrie I system uses a Hokuyo UTM-30LX-EW LIDAR (Figure 9). This is used for obstacle detection on the course. The Hokuyo offers a multitude of customization options such as adjustable resolution levels, data clustering and specular measurements. The Hokuyo LIDAR sensor provides a 270-degree field-of-view at 0.25-degree increments with a range up to 30 meters. (HOKUYO AUTOMATIC CO., 2014) The LIDAR system provides Valkyrie I with high precision information at high speeds, with cycles running at 40 Hz. This allows sufficient time for the navigation software to react to approaching obstacles.

Figure 9

4.4-b SJ4000 Camera

The main vision sensor system in the Valkyrie I is an SJ4000 Camera (Figure 10). This was selected due to the ease of connectivity with the use of a micro-USB that communicates directly with the onboard computer. The frame rate of 30 frames per second allows for high-speed data transfer to the navigation software (SJCAM, 2017). The SJ4000 camera provides rapid automatic white balancing, gain adjustment, and shutter speed controls. These features are exceptional in outdoor environments with varying light qualities.

Figure 10

4.4-c Hemisphere GPS

Valkyrie I uses a L1, GNSS, L-Brand Hemisphere GPS in conjunction with an A21 antenna (Figure 11). This system provides data for the position, direction, velocity, and tracking of user defined waypoints. The onboard GPS unit runs at 20 Hz. This ensures that Valkyrie I is capable of navigating the course at maximum speed while maintaining its exact location (Hemisphere, 2018).

Figure 11

4.4-d Compass

The Maretron SSC200 Solid State Compass acts as a supplementary device to the GPS in determining vehicle heading (Figure 12). The addition of a compass allows for greater accuracy of direction due to the GPS unit having less accuracy when the system is stationary. Maretron Solid State Compass allows for a high accuracy within 0.1 degrees. The data sent to the navigation software updates at 100 Hz to authenticate the direction of the system. An

Figure 12

additional feature to the Maretron Solid State Compass is to detect pitch and roll of the platform up to 45 degrees, which the Valkyrie I platform uses to ensure stability on inclines. (Carling Technologies Inc., 2022)

4.5 Safety Systems

The Valkyrie I system is equipped with a multitude of safety systems. The systems ensure the safety of pedestrians that Valkyrie I might encounter. Many of these systems allow a user to immediately stop the robot with a push of a button. Other features warn oncoming pedestrians of its location and what mode the Valkyrie I system is operating.

4.5-a Emergency stops (E-STOP)

Three emergency stops are located onboard the platform. Two physical switches are located at the rear of the robot. First the blue toggle switch disconnects power from the entire system via the fuse box (Figure 13). Second is the large red push button which acts as a soft E-stop, this commands all systems to stop. The third onboard emergency cutoff is in the upper portion of the platform. All three safety switches act to completely disconnect power and communication to all systems.

Figure 13

4.5-b Wireless E-stop

A wireless Emergency Stop (Figure 14) sends stop commands to the X-bee wireless receiver located within the microcontroller enclosure. The maximum range well exceeds the minimum requirement of 100 feet for IGVC (IGVC Rules Committee, 2022) (Digi International Inc., 2022). By activating the large red button, it will stop the robot should the system go off course or to prevent dangerous situations. For added safety, if the signal is disconnected from the wireless E-stop, the system will engage the mechanical breaks within the motors and stop all operation within 100 milliseconds, this ensures the maximum amount of safety. A Nintendo Wii Nunchuk is used to communicate with the robot and control the robot manually. By pressing the “c” button on the Nintendo Wii Nunchuk enables Valkyrie I to travel in autonomous mode; exit the mode by pressing the “z” button.

Figure 14

4.5-c Indicator Lights

As required by IGVC, four blue LED light bars are placed around the base of the body which is secured with the use of 3d printed enclosures (Figure 15) (IGVC Rules Committee, 2022). These lights allow people to visually see whether the system is in autonomous mode by flashing the lights, or if it is being

Figure 15

controlled by a user when the lights remain solid. Through field testing the light indication is clear in a multitude of lighting circumstances.

4.5-d Acoustic Vehicle Alerting System (AVAS)

Acoustic Vehicle Alerting System (AVAS) is a newly added safety device which acts as a Pedestrian Warning System (PWS) warning pedestrians of an oncoming electric vehicle (Fortino, Eckstein, Viehöfer, & Pampel, 2016). The Valkyrie I onboard AVAS system is used to minimize risk of injury especially for the blind or visually impaired who rely on sound stimulus to notice and realize a vehicle is near (Figure 16). These features are commonly being implemented in the electric vehicle industry due to newly established regulations. The AVAS system provides ample sound quality to warn of its presence and allows for customization of sounds to suit the robot's environment.

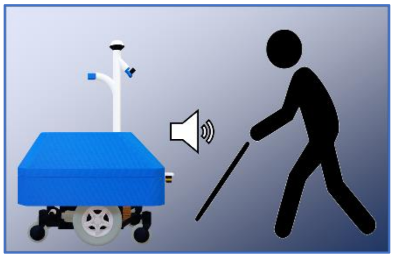

Figure 16

5. Navigation Strategy and Software Design

5.1 Overview

The Valkyrie I navigation software is developed using LabVIEW. Using LabVIEW allows users to easily create a sophisticated graphical user interface that makes it simple for them to debug software, monitor and change data using the new main Graphical User Interface (GUI) (Figure 17).

Figure 17

5.2 Obstacle Avoidance and Path Planning

The Valkyrie I uses a path planning algorithm that utilizes the mapping sensor data to an 80 x 80 2D grid of weighted nodes that represent an area surrounding the vehicle. The LIDAR locates obstacles, and the camera vision system detects lines. Subsequently, sensors send their information to the onboard computer which maps the data and graph of nodes previously mentioned.

5.3 Map Generation

Location and heading information received from the GPS and compass are used in tandem with the obstacle data in the graph to select a goal on the map, so that the robot will move to the next waypoint while navigating around obstacles.

5.4 Goal Selection and Path Generation

The path planner is then used to create a safe path to the end goal using the weighted shortest cost path planning method. Finally, the software determines the commanded heading and speed of the robot, which ensures a smoother path (Figure 18).

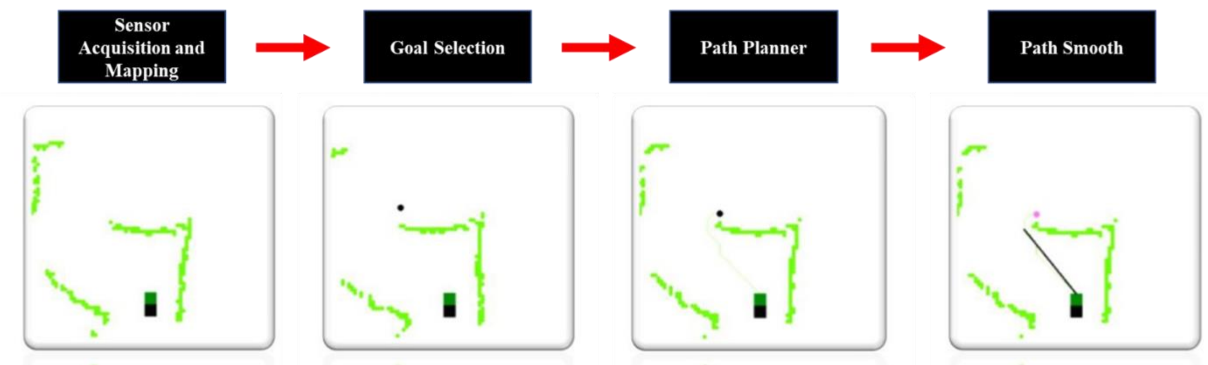

Figure 18

6. Failure Points and Resolutions

6.1 Vehicle Failure Modes and Resolutions

The Valkyrie I system often selects unsuccessful navigational choices due to logic errors in navigation system. A resolution to this failure was to enhance global mapping software. The Valkyrie I exterior dimensions were not fully defined in the navigation software; thus object avoidance was comprised. Resolution to this error was to add additional parameters in the navigation algorithm to fit new design elements.

6.2 Vehicle Failure Points and Resolutions Strategies

Previous robotics platforms have a imbalanced center of gravity. The solution to this problem was the newly designed body and centered payload containment system which provides a low center of gravity. To ensure the safety of the body, multiple tests were performed driving down the steep hills around campus. The heavy weight of previous robotics platforms limited the locations and increased the amount of assistance required to transport. The resolution to this problem is the new lightweight body construction. The Valkyrie I system can be transported and lifted with less difficulty. An added feature to the body is it does not require disassembly for transport. Unacceptable movement in the mast caused vision complications; therefore, a wooden plate was created to support the mast. The internal laptop computer was not secured inside body. A laptop holding bay was constructed to prevent damage to the computer. The team's strategy to reduce the voltage drain and overheating, was to implement a new streamlined electrical system, along with exterior access to switches prevented overheating, along with a forced air-cooling system. With the knowledge acquired from the failures the team has overcome these issues and will adapt for future designs.

6.3 All Failure Prevention Strategy

Valkyrie I is designed to accommodate a modular robotic system, with the ability to adapt to numerous situations with ease. The design has both physical modularity and software modularity that will work among other BSC robotics platforms.

6.4 Testing

Due to the pandemic, the team was unable to perform an adequate amount of physical testing. Therefore, the team relied on LabVIEW simulation conducted by the computer science team.

6.5 Vehicle Safety and Design Concepts

Valkyrie I incorporated safety designs which are found across the entire system. The electrical system incorporates a multitude of safety features such as the emergency stops, lights, and sound systems. The physical body of Valkyrie I is designed with light weight flexible plastics which greatly reduces the possibility of injury. The navigation software detects the general area around the robot and adjust for inaccuracies of the sensors and stops the system if errors occur.

7. Simulation System

Valkyrie I is equipped with an onboard simulation within the LabView software (Figure 19). This system allows for the creation of customized courses and tests how the navigation software reacts in different scenarios. LabView simulation systems provide invaluable data for software development since it is much easier and faster to create a virtual course. Furthermore, much of the data collected on Valkyrie's performance has come from simulation due to the Covid-19 pandemic creating difficulties with physical testing. The system runs on a user generated course. Different colors are used to represent different objects. The blue triangle is the Valkyrie I

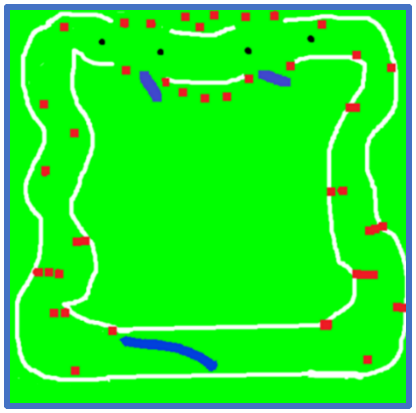

Figure 19

current position while the blue line is the path that the robot has taken. Black circles are waypoints and red objects are obstacles such as barrels.

8. Performance Testing and Assessment

Catigory	Analysis method	Predicted preformace
Speed	Tested	5 mph
Ramp climbing ability	Tested	30% slope
Reaction Time	Limited by software cycle time	25 milliseconds
Battry life	Calculated and tested	7 to 8 hours depending on use
Distance at which obstacles are detected	Software limits range	7 meters
Accruacy of waypoint navigation	Tested	70% chance within 2ft.

Table 2: Testing and Assessment

Valkyrie I has an estimated peak current draw of 10 amperes. The new batteries are rated for 35 amp-hours. The calculated battery life is 3.5 hours. Physical runtime was tested through a strenuous course running at full spend for extended lengths of time. The results of this test were quite surprising in that the battery system held a strong charge for over 7 hours which would in turn mean that our average current draw is closer to 5 amperes. The new motor system does not draw as much current due the lightweight robot body along with the more efficient power system.

Run Time = Battery Energy / Peak Current Draw = 35 / 10 = 3.5 hours

Run Time = Battery Energy / Tested Average Current Draw = 35 / 5 = 7 hours

9. Summary of Performance and Assessment

The initial performance tests and simulations of Valkyrie I have shown that the robot performs satisfactorily using the improved electrical and mechanical systems. The Valkyrie I system is prepared to operate minimal tasks such as line detection and object avoidance. The autonomous function has performed to date and continues to improve as fine tuning of software continues. The team is proud of the tested performance of the system along with the new advancements in the robotic platform. The team is confident that the new innovations and designs of Valkyrie I will impress the judges of IGVC.

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