Design Rationale

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***Abstract*—The Kennesaw State University Autonomous Underwater Vehicle (AUV) Team built and designed this vehicle, in accordance with the SABAC rules and regulations, with the intent to modify and enhance it over seasons to come. Developed over the course of this past year, the AUV's motor setup and control systems run in parallel with common technology used in aerial drones. This vehicle utilizes a PixHawk flight controller, functioning as both a motor controller and a gyroscopic sensor. The communications between the dual camera system and the aforementioned flight controller govern the movement of the AUV. The work done to successfully create an AUV entails communication between team members across myriad disciplines.**

Dry Weight	20.37 kg	Thruster	6 x BlueRobotics T200 Thruster
Dimensions	65.90 cm x 66.71 cm x 20.42cm	Camera	Zed 2K Stereo cam and Logitech Web Cam
Degrees of Freedom	Surge, Sway, Heave, Roll, Pitch, Yaw	Motor Driver	Afro ESC 30amp

Figure 1: Specification Table

I. DESIGN STRATEGY

For each competition year, this team sets a goal to design our AUV to perform at least slightly better than it performed the previous year. Because our 2015 AUV cleared the start gate by dead reckoning, we aim to accomplish that objective more reliably in addition to touching a buoy and navigating the channel. To accomplish these tasks, we needed to design accordingly: vision capabilities, and an effective system for movement.

In order to accomplish the vision related tasks, the start gate and the buoys, we implemented a dual camera system: a ZED camera facing forward and a camera facing downward, both of which communicate with a Jetson to process images. The ZED helps with image processing with its ability to identify not only specific colors, but as it is stereoscopic, depths and distances as well.

For our motor placement and system, we took inspiration from unmanned aerial vehicles (UAVs) in both mechanical and electrical aspects. While we began with the idea of creating an underwater quadcopter, we in the end placed six Blue robotics motors on the AUV, four of which act in angles across the XY plane, and two act vertically, as demonstrated in Figure 2. These motors communicate with a PixHawk, normally used in UAVs, which controls both motors and telemetry.

Figure 2: SolidWorks assembly of the AUV

II. VEHICLE DESIGN

A. Mechanical

The team chose to manufacture the AUV's exoskeleton, which holds together the main body, camera housing, and motors, out of four beams of 8020 aluminum in two sizes. This material choice, although simple, allows for minimal machining in addition to being inherently useful for attaching necessary motors and waterproof housings. Making use of this latter property, we created custom mounting plates for the six motors and the cylindrical camera housing; these connectors attach directly to the frame and were cut with a waterjet directly from sheets of aluminum.

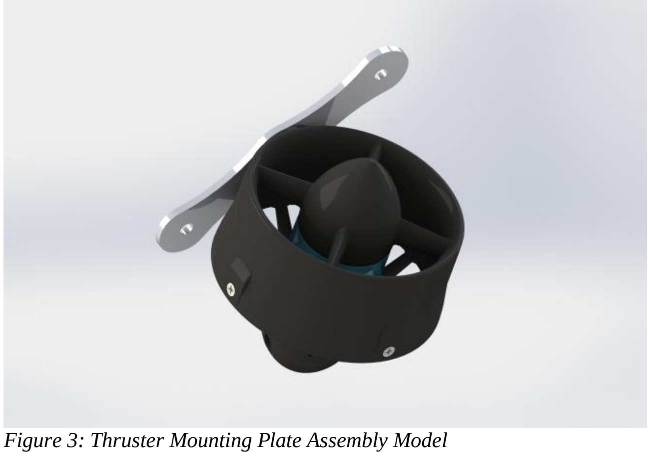

Figure 3: Thruster Mounting Plate Assembly Model

We chose to house the electronic components inside a polypropylene Pelican case. Inherently watertight, it provides a simple and ideal method for enclosing water sensitive items within. In selecting the Pelican 1450 case, our team noted numerous qualifications: the Ingress Protection system rating of 67 requiring a resistance to dust and water (IP67), military certifications regarding waterproofing, stacking, and reusability (MIL C-4150J), and certifications that require testing done via vibrations, impact, and temperature, both (STANAG 4280), and (Def Stan 81-41). The dimensions of our chosen case ended up being 41.8 centimeters long, 33 centimeters wide, and 17.3 centimeters tall. Such measurements coalesce into an internal volume of 0.015 cubic meters. The abundance of volume within the Pelican case allows for ample space to place electronic components, while having built in buoyancy. At the time of this essay's writing, we are redesigning the mounting of the Pelican case to the exoskeleton.

We designed the AUV's inner structure, which is the support structure for the electrical components located inside the waterproof housing, to facilitate quick access to the electronics. The team designed a shelved structure in which one can move a shelf vertically to adjust for space requirements and horizontally to access certain components without withdrawing others. We manufactured the sides and the shelves from sheets of 5052 and 6061 aluminum cut via waterjet, and opted to 3D print the corner pieces and connectors. Kennesaw State University provided the 3D printer we used to create these pieces. We chose these materials, not only because they are strong enough to support weigh but and not heavy enough to counteract the vehicle's buoyancy, but because they also function well as a heat sink for the heat sensitive electrical components. For the inner design to operate effectively, our team had to drill into the Pelican 1450 case to create a path for the wires to travel. First, we started with an aluminum template that allowed us to drill with a uniformed pattern while also keeping the structural integrity of the Pelican 1450 case. After drilling into the case, we moved to waterproofing the wires with 6 mm cable penetrator from BlueRobotics. Out of fourteen holes drilled, we will be using nine holes. The unused holes will be plugged with cable penetrator blank from BlueRobotics and used at a later date.

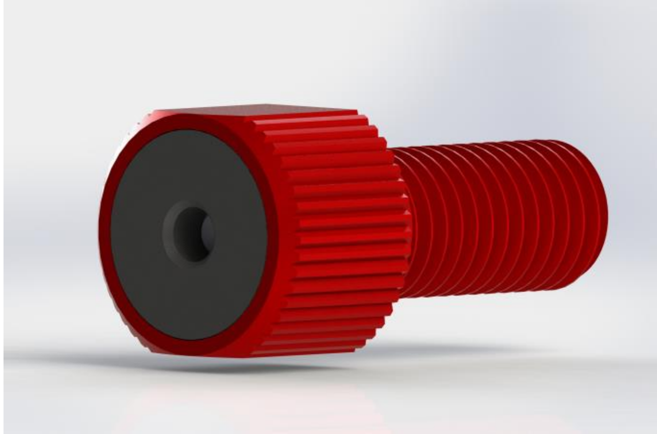

Figure 5:BlueRobotics Cable Penetrator

While it allows for simple waterproofing, the Pelican case, alas, is opaque and therefore should not contain the two camera system. We solved this problem by enclosing the both the ZED camera and Logitech webcam in a 4 inch diameter watertight enclosure made by BlueRobotics. This is an ideal housing because it was already made for AUV competition. The watertight enclosure will be mounted with two half circle tied with a nut and bolt. We sealed the ends of the tube using O-rings and watertight end pieces. We implemented the same BlueRobotics 6mm cable penetrators to allow necessary cables to pass into the housing. Much of the challenge of our task rested in figuring out how to keep two cameras from moving back and forth in the cylinder. After a series of debates, we decided to make a design that utilizes friction fitting. We used the same O-rings from the AUV 4 inch enclosure to friction fit inside the tube. The O-ring fits around a 3D printed design that held the two cameras 90 degree to each other. Noting that the 3D part would be hard to place all the way through the tube, we decided to split the part in half. Both parts utilize friction, fitting while meeting in the center of the tube to hold both cameras.

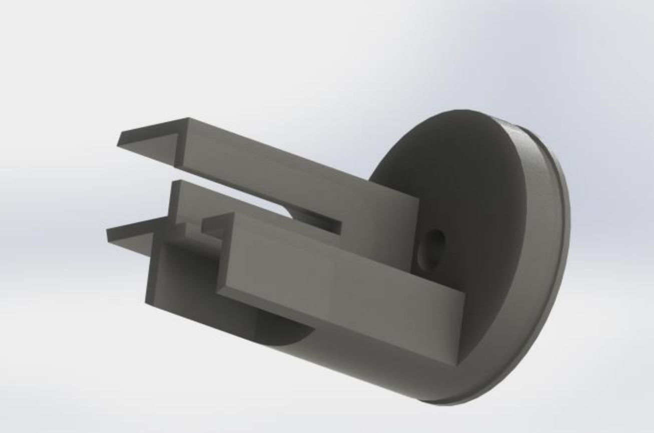

Figure 4: Camera Housing Inner Structure (One Half)

The team encountered a number of unforeseen mechanical difficulties, the most notable of which being our manufacturing staples, a waterjet and 3D printer, falling out of order during prime manufacturing time. Thus, this situation brought the building process to a halt, and the delay put the completion of the AUV’s mechanical aspects well behind schedule. We were able to bounce back by contacting a third party manufacturer named Dinamec Systems LLC.

Although the 2016 competition has not yet occurred, we are already planning ahead for mechanical design improvements to make after. In our continual aspiration to improve at least slightly each year, we decided to undertake the torpedo dropping mission. Therefore, we have already designed a dropper attachment that we will add to our AUV for the upcoming competition. While the decision to craft the frame from 8020 serves us well this year, we selected it largely due to limited time to design and manufacture a more custom frame. Hence, we plan to invest a great deal of time into the frame design during the upcoming year.

B. Electrical

In order for the sub to complete multiple tasks, it has an array of sensors on board ranging from accelerometer, gyro, compass, current, voltage, and pressure sensors. Also, the electrical and software teams decided to utilize a stereoscopic camera call ZED. The help of all these sensors enables the AUV to accomplish all of the tasks we attempted.

The sub power systems divide into two primary categories: computer and sensors, and propulsion and task. Separating these systems into two categories simplifies power distribution and reduces noise and cross talk for electrical components. Seven lithium polymer batteries power the sub. Each pack is 14.8 volts and with a total of 10000mAh, a peak discharge rating of 20c for 10 seconds, and a continuous discharge of 10c. A voltage and current sensor module monitors each battery pack. These modules connect to an Arduino to calculate and send information to the main computer.

The sub utilizes ten BlueRobotics cable penetrator connectors and one 8 pin MacArtney Subconn Micro connector. The 8 pin MacArtney Subconn Micro connector will be used for communication to and from the sub. This 8 pin connector is rated at 300 V from 5 to 10 amps and with a pressure rating of 700 bar. The connecter will be wet mateable, which will save time when uploading new code.

The sub utilizes six BlueRobotics thrusters, brushless DC motors encased in ABS plastic housings, for maneuverability. These thrusters produce a peak forward thrust of 5.1 kilograms of force at 16V and a peak reverse thrust of 4.1 kilograms of force at 16V. Six electronic speed controllers (ESC) control and regulate the speed of the thrusters. The ESCs receive instructions by pulse width modulation from the PixHawk. The ESCs give users the ability to control the rotational speed and direction of the thrust.

The mean power switch comprises a magnetic sensor called a hall effect sensor, which can be commonly found on door sensors for home security systems. When a magnet is brought close enough, the hall effect sensor varies its output voltage in response to a magnetic fieldwill. The sensor then hooks up to six power relays that can handle 30 amp. The power relays connect between the batteries and the voltage and current sensor module monitors. When the relay is in the off position, no current can pass through the relay. We chose a hall effect sensor in order to reduce the number of possible places the vehicle could leak. A magnet can be attached to a brightly colored handle so the safety diver can quickly de-energize the vehicle in the event of an emergency.

The number and type of sensors utilized correspond to the events the team chose to compete in; as such, we currently set the sub up in a simple configuration. It has two cameras: one facing forward to locate and work through the challenges, and one facing the floor to handle line following for the movement to each successive challenge. We made the decision to use “off the shelf” parts for the cameras, i.e. webcams, to minimize expenses and design complexity. One of the cameras is a Logitech brand web cam and the other is a ZED 2K Stereoscopic Camera. The pressure sensor that we chose was the Measurement Specialties MS5837-30BA, which can measure up to 30 bar with a depth resolution of 2mm. The pressure sensor keeps the submarine within the proper range of the pool floor, ensuring the sub does not breach the surface unexpectedly. The Inertial Measuring Unit (IMU) detects changes in the vehicle’s orientation in three major axes: pitch, roll, and yaw.

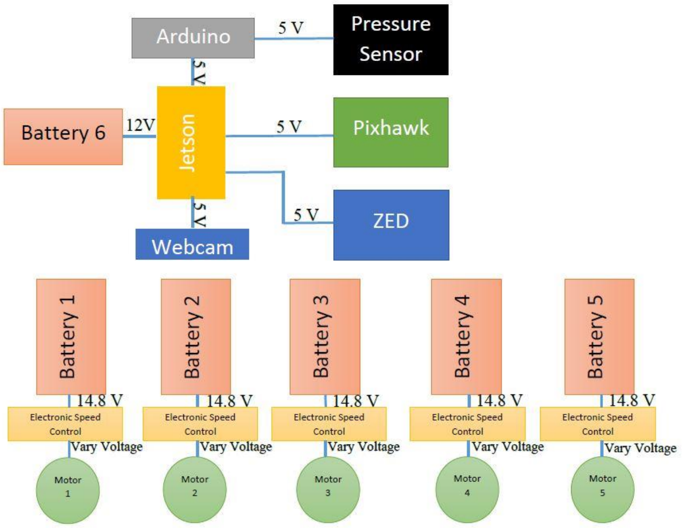

Figure 5: Electrical Diagram

C. Software

We created the code simply for efficiency and ease of use; we based our AUV on the Robot Operating System (ROS) framework to easily communicate between different programs, or “nodes”. Each node is an independent program. These nodes communicate with ROS and coordinate with each other.

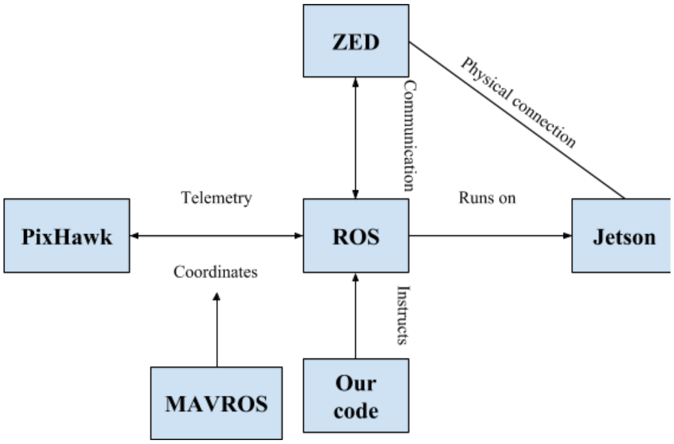

Figure 6: Movement Flowchart

As demonstrated in Figure 6, our code runs within ROS as a node to interact with the rest of the programs. It listens to the outputs of the ZED, a camera node which translates image into a color laser chart. Our code searches for specific colors, such as the Blaze Orange of the start gate.

The PixHawk (Figure 7), a motor autopilot with a built in compass and gyroscope, controls 6 motors as well as telemetry. From that point, our node then sends an initial inquiry to the PixHawk to identify the current location of the AUV.

Figure 7: PixHawk Flight Controller

From there, our node provides information on where the AUV should be going, and the PixHawk then instructs the motors to go along this direction. This loop is constantly updated until the ZED provides information that the objective has been reached.

The team selected C++ in which to write the code because of its ubiquity and its compatibility with ROS. The open source nature of ROS allows for easy documentation and troubleshooting with a widely known framework and coding language.

ROS runs on top of Ubuntu 14.04. Because of the open source operating system, it allows for our team to customize the code in a way unavailable in a similar operating system such as Windows or OSx. For example, we are able to program a robot administrator to execute our code and to be able to turn off the graphical user interface (GUI) to conserve processing power and for our hardware to not generate an image. ROS and Ubuntu are run through a Jetson Tegra K1 (Figure 8).

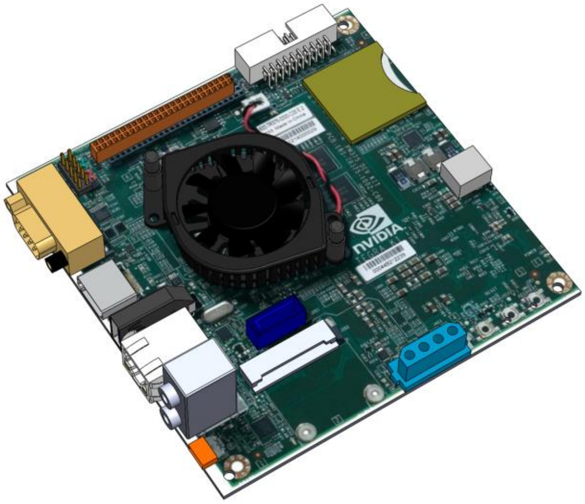

Figure 8: Jetson Tegra K1

Some of our challenges in programming involved getting the programs to properly communicate with each other as well as memory constraints in the hardware. With regards to navigational computing, we experienced a minor challenge because we are using a flight computer for underwater navigation.

We plan to improve upon our current model by upgrading from a step by step program to a learning system to which we can give a task that it will eventually understand how to do as well as adapt to any new modules that we put onto it, such as more sensors.

III. EXPERIMENTAL RESULTS

As of this document's completion, we tested the waterproof housings, the pelican case and the acrylic camera housing, to determine buoyancy; additionally, we plan to perform a stress and deformation simulation test on the portion of the pelican case on which we drilled holes. We tested for buoyancy by bringing the housings to a pool and gradually adding controlled amounts and distributions of weight until they began to sink. Through this testing, we were unable to sink the Pelican case, concluding that it will remain positively buoyant. Pelican rates the case's buoyancy at 13.6 kilograms. The camera housing sinks when carrying 1.45 kilograms.

IV. ACKNOWLEDGEMENTS

The team would like to acknowledge our advisor, Dr. Kevin McFall. We would like to thank the KSU Alumni Association for providing us with much of our budget, and Pelican for generously donating a second Pelican Case to the team. We would like to acknowledge GitHub, BlueRobotics, SolidWords, and VideoRay which were integral to our design process. We thank Scuba Lesson Atlanta Divers' Shop in Marietta, GA for allowing us to test on their premises. We thank team alumni Jason Wilkins and his workplace, Dinamec Systems LLC, for aiding us in manufacturing.

V. APPENDIX—OUTREACH ACTIVITIES

The team appeared at the Maker Faire Atlanta event in October 2015. While there, we not only discussed our previous year's AUV and answered questions about our work, but we demonstrated an underwater remotely operated vehicle (ROV) that we built; this ROV facilitated our discussions with the attendees, particularly children who were interested in controlling it.

Additionally, our team and a high school underwater robotics team established contact. In early June, the young team toured our laboratory, inquired about our approaches and the differences in our competitions, and requested advice. We offered to advise the team wherever we can be helpful.