Design and Implementation of Texas A&M Women in Engineering (WE) AUV for entry into the AUVSI RoboSub Competition

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***Abstract*— An Autonomous Underwater Vehicle (AUV) is being designed and fabricated to compete in the annual AUVSI Foundation International Robosub Competition. This research project is divided into three subdivisions: Electrical, Mechanical, and Programming. The electrical subdivision entails the power efficient design of the overall electrical system of the AUV while the programming subdivision requires the smart interfacing of sensors with the electrical system. The mechanical components include the small form factor design of the frame and hull, smart waterproofing of various sensors and cables, and ensuring the entire structure is watertight.**

I. INTRODUCTION

The Robotic Engineering Aggie Females (REAF) team's main goal is to design, fabricate, and program an efficient Autonomous Underwater Vehicle (AUV) that will compete in the 2016 AUVSI International RoboSub Competition. The purpose of the AUV, named Ula, is not only to complete the obstacle course, but also to provide women in the College of Engineering at Texas A&M University with an opportunity to develop engineering and leadership skills as a part of a supportive team. The team was split into three sub teams; Electrical, Programming, and Mechanical. This year, the team will complete the first portion of the obstacle course with our first AUV.

A. Design Strategy

This year, the team plans to complete the first half of the competition, including Scuttle Ship (touching buoys and pulling a ship under the water) and Navigate Channel (navigating over/through an obstacle). The vehicle has been designed and programmed for these tasks. The team decided to focus on the first portion of the obstacle course to obtain maximum reliability instead of complexity. For general functionality, Ula has four thrusters to propel it with three degrees of freedom, two Lithium Polymer batteries that will serve as a power source, and code that will incorporate attitude and heading information to keep the vehicle upright. For the Scuttle Ship challenge, the AUV has been equipped with two cameras (one forward facing and one downward facing) and programmed with image processing codes. A hook will be attached to the front for pulling the ship underwater. For the Navigate Channel challenge, the vehicle will use another image processing code to identify the obstacle and appropriately avoid it. The vehicle has been designed to be compact so that it will easily avoid the obstacle. While the design is compact, it is also very sturdy. The team decided to ensure that the vehicle would be able to withstand all of the forces that it may face rather than focusing on making it hydrodynamic.

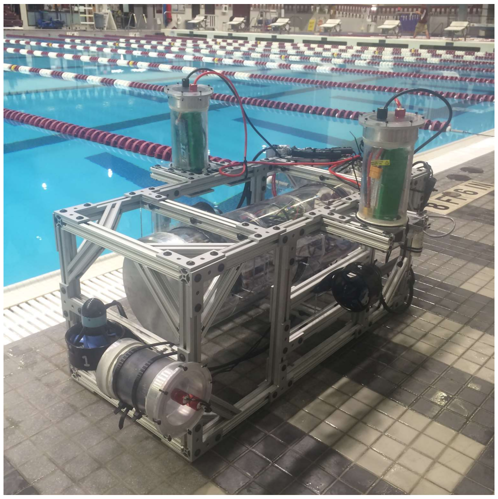

Figure 1: Ula

B. Design

B.1. Mechanical Design

Ula's mechanical system consists of the electronics housing (main tube), the outer frame, watertight housing for outer electronics, and thrusters. Each of these components was connected to the main tube, and all connections were sealed to be watertight. The mechanical system was designed with Solidworks and Inventor.

B.1.1. Electronics Housing

The main electronics housing consists of polycarbonate tubing and custom machined aluminum endcaps. The polycarbonate tube has an 8 in. outer diameter and 7.75 in. inner diameter. The clear polycarbonate tube was chosen due to the clear view of the main electronic components and ability to withstand the necessary pressures. The end caps to enclose the tube were machined out of 6061 aluminum. The team chose to use 6061 aluminum because of its strength-to-weight ratio, corrosion resistance, and cost. It was decided that one of the end caps for the main tube would never be removed, so it was epoxied directly to the tube using Loctite marine grade epoxy. For the other end, the team fabricated a collar that would fit over the end of the tube. The team laser cut a circular plate from an acrylic sheet. Holes were added to this plate for BlueRobotics cable penetrators so that the cables that needed to enter or exit the main hull could be passed through and exchanged fairly easily. The plate has been attached to the collar along with an O-ring as in [1] using ten bolts. The final product is shown in Fig. 2.

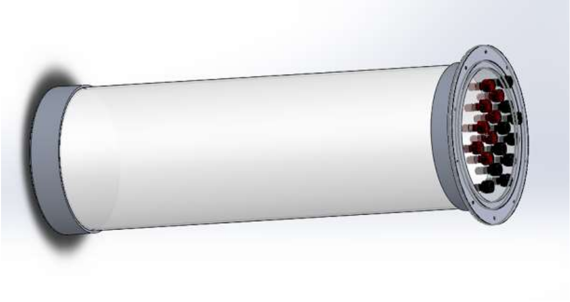

Figure 2: Electronics Hull

Electronic Trays

The interior circuit racks were designed so that part placement was not fixed for optimal adaptability. Two circuit racks were implemented within the hull along with four circular frames to hold the racks in place. Both the frames and racks are composed of 0.22 in. thick acrylic. Acrylic material was chosen because of its reasonable cost and ability to be laser cut quickly. The main ideology behind the interior design was to have circuit trays with holes throughout the tray. Each rack is 21 inches long. The upper rack is composed of both 0.25 in. and 0.50 in. diameter holes and a 4 in. gap while the lower rack possesses only 0.25 in. holes. The small holes on the upper rack are for the electronic parts while the larger holes are to allow for wires to be passed between the two racks. The gap at the end is to allow wires from the exterior to go to the bottom rack. The lower rack is comprised of only small holes because it holds the power components that the top components are fed through the holes to reach.

The frame created to hold up both trays was fitted to the tube with slits cut for the trays. When creating the tray, there were several issues that needed to be addressed. The acrylic sheet that was initially used was too thin and was not strong enough to hold the tray up properly. The original design had to be modified, and more frames were added.

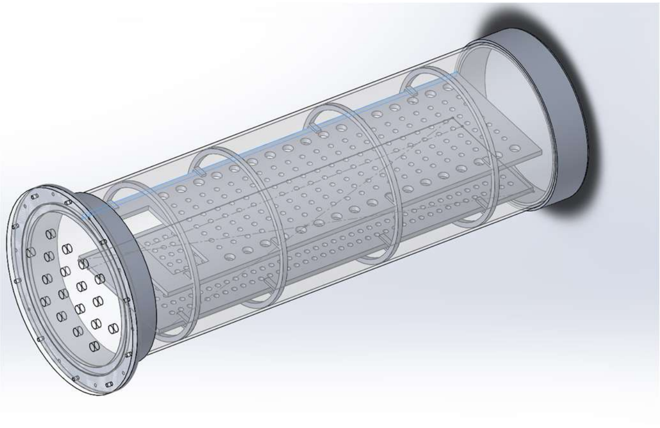

Figure 3: Trays and Frames

The first idea for attaching the electrical components to the trays were thin platforms with pegs to go in the holes of the trays. These platforms would be custom made in the 3D printer for each board size. With this design, each component would be allowed to be placed anywhere along the rack and could be easily moved. The design of the platforms with pegs took multiple attempts as the 3D printer often created inaccuracies or warped pieces. This idea was dropped for this year's robot because of the extensive amount of time that would be required to implement it. The team decided to use zip ties to attach the components to the trays instead because they are cheap, easy to remove, and can be used at different lengths.

B.1.2. Outer Frame

The external frame is made from 80/20 extruded 6061 aluminum. The team chose to use extruded aluminum because it allowed the creation of a modular design that could be built and adjusted quickly. The frame, shown in Fig. 4, weighs 25 lbs.

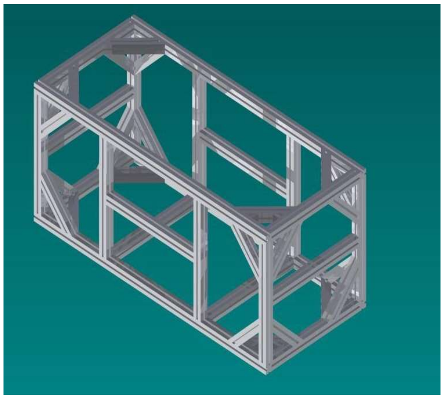

Figure 4: External Frame

Tube Suspension

The team originally attempted to attach the electronics housing to the frame with aluminum straps. This quickly proved to be an extremely ineffective method when the team first placed Ula into a pool. The straps allowed the tube to move too much, constantly changing the center of mass and center of buoyancy of the vehicle. To fix these problems, the team implemented a new harnessing method that consisted of laser cutting acrylic and attaching it to a piece of extruded aluminum. A strip of rubber was then super glued to the circular edge of the acrylic. Two of these structures were placed on top of the tube, and one was placed on the bottom of the tube.

Figure 5: Tube Holder

B.1.3. Watertight Outer Electronics Housing

Several electrical components that needed to be placed outside of the vehicle were not watertight when purchased. This was because of lack of availability or extra cost for watertight components. The team used several methods for making these components watertight including creating watertight housings similar to the main tube, PVC pipes filled with epoxy, and 3D printed structures filled with epoxy.

Watertight vs. Waterproof

One of the utmost design concerns when constructing an AUV is keeping the interior of the vessel free of water. In everyday terms, watertight and waterproof can be used interchangeably, but this is not the case when it comes to the construction of AUV's and other marine structures. When purchasing materials and designing components, it is important to note that waterproof means the majority of water is kept out of the area being protected, while watertight ensures that no water at all is able to enter the area. When dealing with sensitive electronics and sensors, it is critical that all seals and casings be watertight.

Battery Housing

The battery housing design was inspired by the main tube design. It is essentially a smaller version of the main tube with only two holes with cable penetrators. Two battery housings made of clear polycarbonate tubes and aluminum end caps were made. The outer diameter of each of the tubes is

3.5 in. with a 0.125 in. wall thickness and a length of 7.5 in.

The battery housing is meant to be opened and closed to switch out batteries, so the end caps were fabricated using a lathing machine to allow easy access to the inside of the tube as well as a simple way to seal the tube to the endcap. Aluminum 6061 was used for these endcaps. The ends caps are shown in Fig. 6 and Fig. 7. This was made similar to the endcaps of main electronics housing. An O-ring was used to provide a watertight seal.

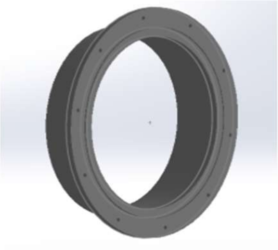

Figure 6: Static end cap, Figure 7: Collar of the removable end cap

These tubes will be attached to the top of the AUV using a system similar to the main tube's harnesses.

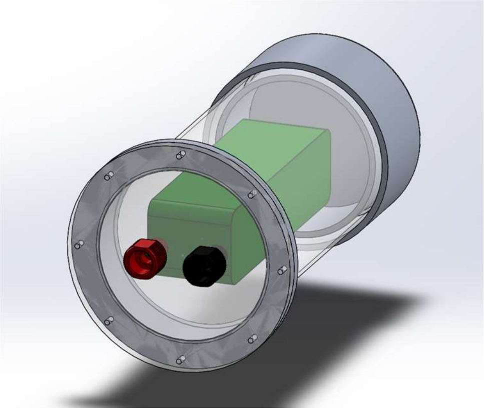

Figure 8: Battery Housing

Camera Housing

The camera housing is similar to the battery housing except for the length. The camera housing was made shorter because the cameras require less space than the batteries. It was extremely important that the tube for the cameras was perfectly clear and free of scratches to provide the best image quality.

Pressure Sensor Housing

The pressure sensor that the team purchased was not watertight, so a housing had to be fabricated to protect it in the water. The first attempt to create a housing for the pressure sensor consisted of 3D printing a case and endcap to hold the pressure sensor. This strategy was quickly dropped when the team realized that 3D printed parts were not watertight. The final solution was to epoxy the pressure sensor in a piece of PVC pipe. The main challenge for this method was ensuring that the wetted parts did not get any epoxy on them.

Kill Switch Housing

The kill switch connections were soldered by the electrical team and covered with heat shrink. To ensure water tightness, the team created a resin 3D printed kill- switch housing consisting of two parts. One part covers three of the four lateral sides of the switch and has tabs with holes that extend to the side for easy attachment to the frame. The second part is the fourth side. This side is printed separately to allow the team to place the switch (which has a top lip that is wider than the rest of the switch) inside of the housing before closing it off. This housing, shown in Fig. 9, will then be filled with epoxy on the side with the soldered electrical connections.

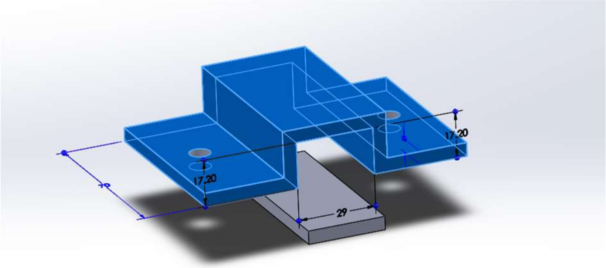

Figure 9: Kill switch Housing

B.1.4. Thrusters

The vehicle will be propelled through the water using four BlueRobotics T-200 brushless thrusters. These thrusters were selected because of their low price, watertight seal, and compact design. They also each provide an impressive maximum thrust of 7.8 lbf or 3.55 kgf in the forward direction and 6.6 lbf or 3.0 kgf in the reverse direction at 12 V (the voltage they will be provided with).

Figure 10: BlueRobotics T-200 Thruster [2]

The vehicle will have two thrusters facing forward and two thrusters facing up to provide three degrees of freedom, as shown in Fig. 11. The programming team will run the thrusters at varying speeds to go in all necessary directions (up, down, left, right, forward, and backward).

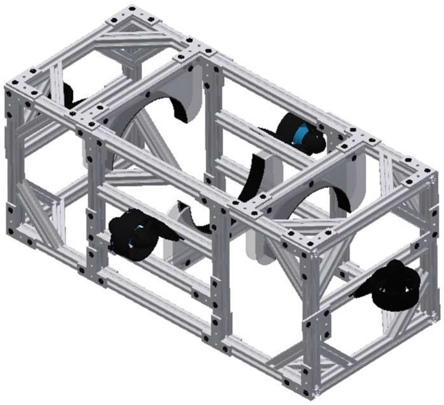

Figure 11: Frame with Thrusters

B.2. Electrical Design

Ula's electrical system consists of power distribution, sensors, and data transfer. This system is comprised primarily of purchased parts with the exception of the custom power distribution Printed Circuit Board (PCB) and thruster data transfer PCB. The electrical system also features wire management that is achieved through the use of zip ties.

B.2.1. Power Distribution

The power distribution system provides power to all of the electrical components of the vehicle. It consists of batteries, an ATX power supply, and a custom PCB (Printed Circuit Board) shown in Fig. 12.

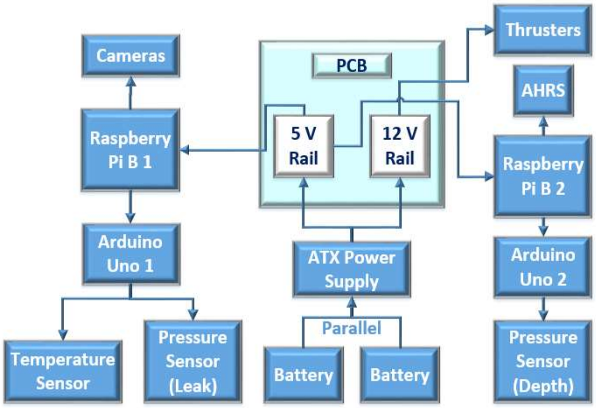

Figure 12: Power Transfer Diagram

Batteries

The vehicle utilizes two Multistar Lithium Polymer 14.8 V 10,000 mAh batteries that have been placed in parallel using a battery parallel Y-Harness. The team chose Lithium Polymer batteries because of their reasonable cost, energy density, and size. 14.8 V was the selected voltage because it was the most commonly found voltage that was higher than the maximum required voltage for any of the electrical components. The batteries were placed in parallel to double the maximum available deliverable current to 20 A. At constant maximum current consumption from all of the electrical components, this current will allow the vehicle to run for at least 30 minutes. This is more than the expected run time of each vehicle listed in the competition manual of 15 minutes.

ATX Power Supply

The power from the parallel batteries is connected to an M4-ATX power supply from mini-box as described in [5], which will maintain voltage rails at various levels including the +5 and +12 needed for our electrical components. The ATX will also keep the rails from experiencing any spikes or drops in voltage, which could affect the performance and health of the electronics. The voltage rails from the power supply are connected to a custom made PCB. The power and ground from the battery parallel Y-Harness connect to the power and ground terminals of the ATX. The wire that connects to the kill switch power in terminal is connected to the power terminal of the ATX as shown in Fig. 13. The power out terminal of the kill switch is connected to the ignition terminal of the ATX.

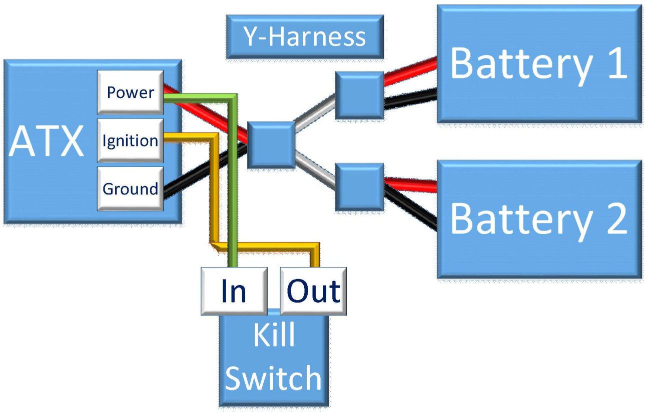

Figure 13: Kill Switch Implementation

The DIP (dual in-line package) switches on the ATX can be set for several different uses. For our vehicle, the power supply is set to setting P1, which gives a 5-second off-delay and a 1 minute Auto Latch.

Custom PCB

The custom PCB, shown in Fig. 14, was designed by the electrical team leader using EagleCAD and manufactured at the Texas A&M EIC (Engineering Innovation Center), one of our sponsors. The PCB was originally designed for use with RCA underwater cameras. Issues with sending the camera data to the Raspberry Pis resulted in the team opting to use two USB webcams which would be powered by USB connection with the Raspberry Pi. The PCB had already been fabricated when this change was made, so there was no time to make a new design. The team also decided that the PCB should have extra connections for certain voltages in case any components were added after PCB fabrication.

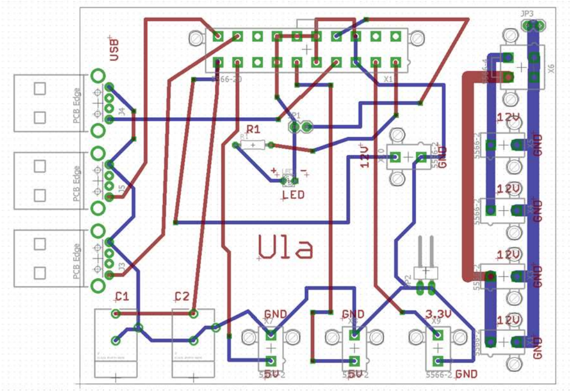

Figure 14: Power PCB Design

B.2.2. Sensors

The vehicle uses various sensors to provide input to the code so that it can maneuver autonomously. These sensors are an AHRS (Attitude Heading Reference System), pressure sensors, temperature sensor, and cameras.

AHRS

Ula uses a VectorNav VN-100 that was donated to us by VectorNav to gather information about the vehicle’s attitude and heading. The VN-100 is a high-performance Inertial Measurement Unit (IMU) and AHRS. It uses the latest solid-state Micro-Electro-Mechanical Systems (MEMS) sensor technology. It was selected because it includes a set of 3-axis gyroscopes, 3-axs accelerometers, 3-axis magnetometers, a barometric pressure sensor, and a 32-bit processor. Another reason that it was chosen for Ula is that it has a built in microcontroller that runs an Extended Kalman Filter. Not having to program the Kalman Filter saved a large amount of time.

Pressure Sensors

The vehicle utilizes two Measurement Specialties US300 pressure sensors. One is for detecting leaks in the main hull. The other is for measuring the depth of the vehicle in water.

Temperature Sensor

The temperature sensor’s purpose is to ensure that the temperature in the main electronics housing does not get too high.

Cameras

Originally, the team planned to use two SS Aqua Cams for the vehicle’s vision. The cameras worked perfectly on their own. However, problems with reliably converting the data from the camera to a format that the Raspberry Pi could use proved to be too time consuming and difficult. The team tried using RCA to USB converters, but none of the converters that were ordered provided good quality video. The team also tried processing the video through the Arduino video experimenter shield to the Raspberry Pi, but the team could not find any way to send video from Arduino to Raspberry Pi. Ultimately, the team decided to use USB webcams to provide the necessary images to Ula. The vehicle utilizes two Logitech C270 720p 3-MP Widescreen HD Webcams. One camera faces down to see the path markers. The other camera faces forward to detect buoys and obstacles.

B.2.3. Data Transfer

Ula's data transfer system is the key to making programming the vehicle possible. Without data transfer between components, the vehicle would not be able to be autonomous or run at all. Data transfer is achieved by using both USB A and USB B connectors along with custom made connectors for other sensors including a custom PCB for thruster data. The data transfer method, shown in Fig. 15, also determines the placement of the components on the electronic trays within the main tube.

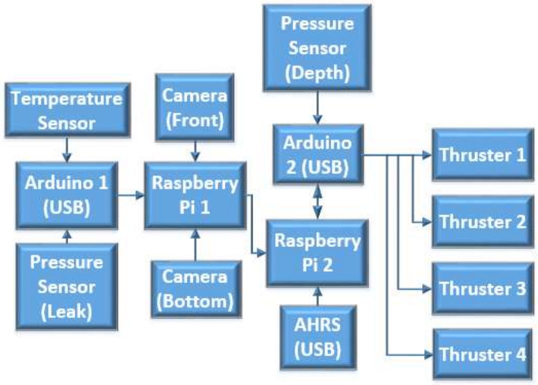

Figure 15: Data Transfer Diagram

Heat Distribution and Board Placement

The electrical components were placed according to power and data distribution as well as heat production. The bottom tray houses the power distribution boards including the Power Distribution PCB and the M4-ATX. One of the reasons that the M4-ATX was chosen was that it is designed to not produce a large amount of heat. The PCB is placed in the back of the AUV near the fixed end cap so that it may use the cap as a heat sink. The majority of the components are housed on the top rack including two Raspberry Pi Bs, two Arduino Uno's, the thruster data PCB, the AHRS, and the pressure sensor. To absorb some of the heat to allow for a better functioning board, two heat sinks were placed on each Raspberry Pi with thermal adhesive tape.

While heat distribution played an important role in board placement (shown in Fig. 16), the most important factor was data transfer. Boards were grouped and placed near each other in the order that they were to be connected. The Raspberry Pi that controls the thrusters and processes orientation information was placed at the back of the tube with the Arduino that runs the thrusters, the thruster data PCB, and the AHRS. The Raspberry Pi that controls the cameras was placed at the front of the tube because the camera cables are the shortest cables and most difficult to extend.

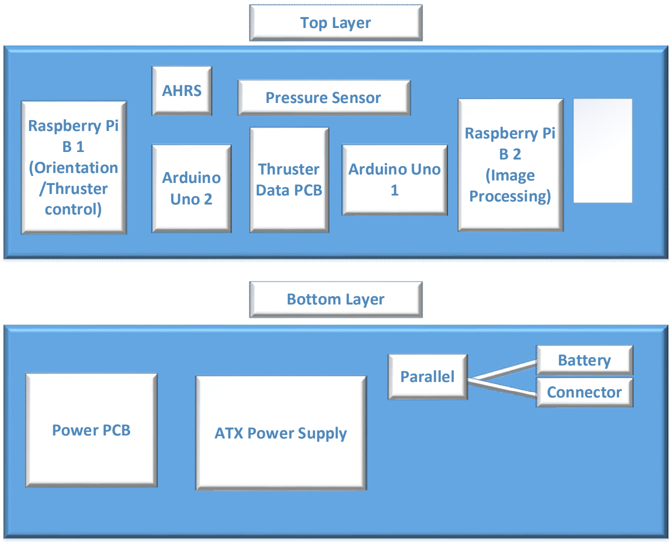

Figure 16: Board Placement Diagram

Thruster Data

The thrusters are run using I2C. The team assigned each thruster with a unique I2C address so that all of the thrusters could be run with only one set of signals from the Arduino Uno. It was decided that the best way to send the signals to all of the thrusters was to create a custom PCB as shown in Fig. 17.

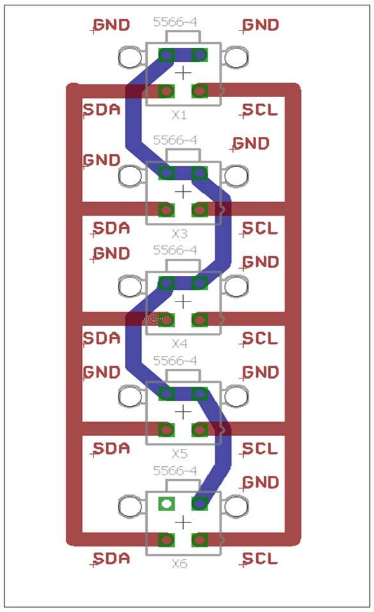

Figure 17: Thruster Data PCB

B.3. Programming Design

Ula's software system performs several functions. It communicates with various sensors and other electrical components to gather information about the AUV and the environment surrounding it. It also analyzes this information in order to decide how the AUV should behave next depending on the task it should be performing. Finally, based on its analysis, the software system controls the thrusters to make appropriate adjustments to the AUV's position in the water. The software system also displays and stores the data it collects in order to assist with the testing phase of the development of the AUV.

The software that the AUV runs is spread out across several microcontrollers. The programs on the Arduino Uno microcontrollers that are connected to sensors continuously receive input from the sensors and output this data to the Raspberry Pis. The Arduino Uno that is connected to the thrusters does this as well as the reverse – it receives data from the Raspberry Pis that tell it which thrusters to turn on or off. The programs on the Raspberry Pis are more complicated. One of the Raspberry Pis is connected to two cameras. This Raspberry Pi takes the video from the camera and runs it through an open-source image processing library called OpenCV. Any information determined by this image processing is then sent to the other Raspberry Pi. The second Raspberry Pi collects all of the data from all of the other microcontrollers and stores the data in a file. It then takes the data and analyzes it to determine which task it should be performing and how to change the thruster speeds in order to complete this task.

B.3.1. Thruster Control

The thrusters are controlled through the combined operation of an Arduino Uno microcontroller and a Raspberry Pi B as shown in Fig. 18. The Arduino Uno is connected to a pressure (depth) sensor as in [4], which collects information about the surroundings and state of the robot and sends it to the Arduino Uno. The Arduino Uno receives the data and transfers it to the Raspberry Pi for data analysis as in [3]. Serial communication exists between the Arduino Uno and Raspberry Pi via USB. The Raspberry Pi utilizes programming language Python 2.7 to interpret the data received from the sensors through the Arduino. Based on the data process, the program formulates a plan of action for the thrusters. These commands are then transmitted from the Raspberry Pi to the Arduino Uno, which outputs the instructions to the thrusters that control vertical movement. The thrusters then send information about their temperature, the speed at which they are currently running, voltage being received, and current being received. All of this information is then sent to the Raspberry Pi B for data logging and thruster maintenance. This is an iterative process, so that the vehicle is able to constantly adjust to its surroundings.

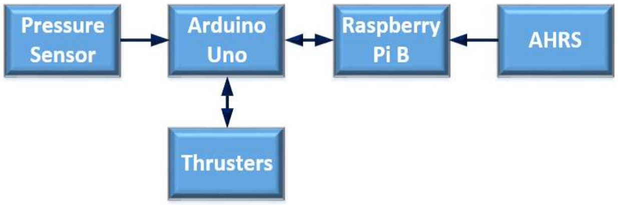

Figure 18: Thruster Dataflow Diagram

The AHRS is plugged into the Raspberry Pi via USB. The Raspberry Pi uses the information from the AHRS to control all four thrusters to keep the vehicle balanced and upright. This Raspberry Pi is also connected to the Raspberry Pi that receives input from the cameras. It uses information from the other Raspberry Pi to control all four thrusters to move toward or away from (depending on the task) the object that is being detected. This is also an iterative process like the one depicted above.

B.3.2. Image Processing

The vision subsystem provides crucial information for target tracking and course navigation. Two Logitech HD Webcam C270 cameras, one facing forward for course navigation and the other facing downward for path marker identification, were placed on the frontal section of the vehicle. A software module for image processing and computer vision was built utilizing Intel's Open CV 2.4 library as in [6], [7], and [8].

In order to achieve real time target tracking based on color detection, first, the upper and lower boundaries of the desired color in the HSV color space are predefined. The frame is resized to have a width of 600px. Downsizing the frame allows for processing the frame faster, leading to an increase in FPS (due to less image data to process). The frame is then blurred to reduce high frequency noise and allow focusing on the structural objects inside the frame. Finally, a conversion from the frame to the HSV color space is done. On the other hand, to determine the distance from the vehicle to a known object, triangle similarity index is utilized. By working collaboratively with the color detection module, the AUV is able to identify objects based on color and estimate distance with respect to AUV's location. Necessary data analysis is executed in order to maneuver the vehicle to the correct position.

C. Experimental Results

The team has primarily tested the robot through simulations and in-water testing. All watertight containers were tested first in a bucket of water and then in the Texas A&M Student Recreation Center Pool at 9 ft. deep. Thickness for all tubes was decided by researching and simulating pressure on various thicknesses at 16 ft. As of the writing of the technical report, the AUV has not been tested as a whole with programming. This will begin the day after the technical report is submitted and continue until the vehicle is shipped.

D. Conclusion

As stated before, the team was divided among three sub teams in order to optimize solutions for the tasks at hand and successfully resolve the technical challenges. While the mechanical sub team specialized on the design, construction, and assembly of the hardware components, the programming sub team concentrated on the design and development of the software elements, and the electrical sub team focused on power distribution and sensor selection. This being our first year in the competition, extensive research on autonomous underwater vehicles was done throughout the initial phase of the project. The team now has extensive knowledge of AUVs as well as technical expertise that was gained by taking volunteer classes at the EIC (Engineering Innovation Center) at Texas A&M. During the implementation period, many conceptually proven ideas became inefficient and required redesigning. The team continuously learned and adapted to unforeseen circumstances as needed.

The primary objective for our team was to effectively navigate through water and utilize vision processing as a movement reference system. We plan on competing next year and have many improvements that we plan to add to the vehicle. We will add a robot arm for picking up and releasing markers, a torpedo launcher, and a hydrophone array for obstacles with a pinger. The Electrical Subteam plans to create a more advanced PCB system with a backplane and implement a Doppler Velocity Log (DVL). The Mechanical Subteam plans to design a more hydrodynamic frame and body. The Programming Subteam plans to reorganize the code and add portions for the new sensors.

E. Acknowledgements

The R.E.A.F. team would like to thank the following sponsors for making the design and fabrication of Ula possible: The Texas A&M Women in Engineering program, the Engineering Innovation Center, VectorNav, and 80/20 Inc. The team would also like to thank Carl Hayden High School's RoboSub team for their advice when the team was first starting out and continued support via email throughout the year.

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