WHALE TECH TECHNICAL DOCUMENTATION

TONY BROZOWSKI [CEO] [12TH]
MICHAELLA HOPFNER [CFO, ELECTRICAL ENGINEER] [11TH]
TYLER POLD [COO, DESIGN ENGINEER] [10TH]
GARRETT LANAHM [MECHANICAL ENGINEER] [11TH]
GAVIN OSTERLOH [MECHANICAL ENGINEER] [11TH]
LIAM RICHEY [MECHANICAL ENGINEER] [11TH]
GRAHAM JOONSAR [SOFTWARE ENGINEER] [11TH]
PHAELAN PEARSON [MECHANICAL ENGINEER] [10TH]
JACOB BANTA [SOFTWARE ENGINEER] [10TH]
IAN OSTERLOH [MECHANICAL ENGINEER] [9TH]
CHARLIE BOLES [ELECTRICAL ENGINEER] [9TH]

MENTORS

GEOFF GARDENER
ROCCO LEACHE

300 N PAULDING DR # 6675, DALLAS, GA 30132

ABSTRACT

WhaleTech has responded to the MATE Foundation's request for proposals for the design and construction of the newest member of the Whale Armada, Whale III. This Remotely Operated Vehicle (ROV) operates in various aquatic environments, from Lake Titicaca's heights to the ocean floor's depths and everything in between. The Whale III has numerous components and payloads that allow for such versatility. With six T200 Thrusters mounted for omnidirectional movement, combined with a three-function manipulator, the ROV is enabled to precisely manipulate the surrounding environment for swift completion of tasks given by MATE, such as installing a floating solar panel array and treatment of diseased coral. Three cameras are used, not just for the visualization of the surrounding environment but also for autonomously completing tasks, from 3D modeling coral reefs and searching for infected specimens to piloting Whale III into a docking station. These components, along with additional non-ROV devices, enable the Whale III to effectively address the tasks given by the MATE Foundation and assist in the united, worldwide effort to complete the UN Sustainable Development Goals as a part of the UN Decade of Ocean Science for Sustainable Development. This technical document will cast light upon not just the specifications of Whale III but also the design and troubleshooting processes and the internal mechanisms of WhaleTech during its pursuit to combat the issues our world and its climate are facing.

Figure 1: WhaleTech Robotics Team Members

TABLE OF CONTENTS

ENGINEERING DESIGN RATIONALE

Design Evolution

Throughout 2022 and 2023 WhaleTech produced its third adaptation of a manufactured remotely operated vehicle, the Whale III. This year, the company faced a few problems, such as new member growth and a loss of available workspace. To overcome these issues, the company made adjustments to its overall structure. Each department of production, such as electrical, mechanical, software, and payloads, was divided into groups to brainstorm and design their respective responsibilities before pitching the ideas to the company and deciding on a final course of action. From there, prototyping for each department began. Rough model prototypes were developed using materials such as plywood for the frame and cardboard for the control board housing mockups. These items were used for dimension and layout evaluation, significantly improving the company's confidence in the designs' functionality and performance potential. After deliberation amongst the engineers, the decision was made to reuse mechanical and electrical components salvaged from past North Paulding Robotics ROV builds. The principal issue facing the company was that the company could not afford to purchase all new equipment with the proposed budget allowed for the new ROV. There is an inherent risk associated with reclaimed electrical components. With this in mind, each part underwent extensive testing to ensure its functional integrity before allowing it to make its way into the ROV. Various testing devices were constructed with simple wiring techniques and a test code to run and evaluate the components in question for usage (see Testing and Troubleshooting Techniques).

Safety remains one of the company's main priorities throughout the production and testing processes. The ROV has integrated features that keep wildlife and team members safe in and out of the water. For example, the surface side control box houses the main power switch for the ROV. It is easily accessible to the pilots at all times and can cut power to the ROV within moments if components malfunction. The company also conducts regularly scheduled safety checks to optimize safety within the workspace and when the Whale III is in use. For example, examinations of the ROV occur daily for corrosion of vital equipment that could lead to failure and for maintaining all surfaces to remain free of abrasions or sharp materials.

Figure 2: Whale III

Mechanical Rationale

WhaleTech strives to produce ROVs capable of accommodating the needs of various clientele and being adaptable to complete any number of directed tasks. The frame is engineered to maneuver through waterways efficiently with minimal drag. It was precision cut with a CNC machine out of neutrally buoyant, high-strength, low-density material and designed for ease of movement through the water. Three high-definition underwater cameras with low latency are strategically placed in operational positions to provide the broadest range of visibility available. One of the cameras is placed atop the front "face" of the ROV to navigate bodies of water and examine ocean floors for reef organisms or evaluate the condition of deployed machinery. Six thrusters are intentionally placed at the corners and midsection of the ROV to maximize maneuverability. They allow for omnidirectional propulsion letting the Whale III easily traverse a variety of ocean topography. Each of the four horizontal motors is mounted at a 45-degree angle compared to the midline, allowing for both lateral and rotational movement of the ROV. The two remaining thrusters are placed facing vertically for ascension and descension. Mounted to the interior baseplate is a manipulator arm and claw. Constructed to operate like a human arm, the manipulator can complete a wide range of motion for various tasks, from replacing floating solar panels to installing cameras in aquatic machinery.

Several decisions regarding components of the Whale III were weighed in comparison to one another, with mechanical and electrical engineers alike, before a course of action was taken. The six-inch control box enclosure was adopted over two separate three-inch enclosures, as seen on the Whale II, for its larger interior volume, aiding in the prevention of overheating of the electrical equipment. In addition, software and electrical departments met to discuss open-source electronics platforms. These departments ultimately settled on the use of an Arduino Mega and Raspberry Pi. The Arduino and Pi were chosen to complement each other, splitting the software load to match each board's respective abilities (See Software).

Troubleshooting and Testing Techniques

WhaleTech worked to develop new forms of testing and troubleshooting within the company to guarantee that Whale III became and remained an effective ROV.

In anticipation of recycled ROV components being implemented on the Whale III, company engineers sought a means of testing them before warranting their integration into the production process. As a result, mock circuit boards consisting of a power bus, an electronic speed controller, and a step-down transformer were wired up to provide a reliable thruster testing device. This allowed for the status of each electrical component in question to be tested individually. A test code with simple task information was provided and hooked up to piloting joysticks to run each device as if they were mounted to an ROV and ready for use.

While waiting for parts and materials to arrive, the company wanted to be able to test parts of the control code and troubleshoot any issues that arose. The testing rig for determining the operational status of the reclaimed thrusters was explicitly repurposed for this task. Six thrusters were hooked up to a mock circuit board to test the up-down and side-to-side functions of the control code and communication to fundamental devices such as the control joysticks. The same method of testing was used for each part of the code that needed to be in operative condition and for any obligatory troubleshooting on both the equipment and programming sides.

Basic troubleshooting procedures were followed throughout the production process when rapid assessment and solutions were needed, namely in the electrical department. Blue Robotics thrusters and Electronic Speed Controllers (ESCs) make their current condition apparent using beeps when power is switched on in the ROV. The beeps provide information on the ESC status and make troubleshooting more efficient by immediately pointing out an issue. The first step taken is to check for continuity between all wiring of the ESCs and the thrusters, ensuring that there are no breaks in the circuit. If two wires are found suggesting an open circuit, the break is discovered and repaired, or they get replaced. Often if the ESC does not make a final initializing beep, it is not receiving the operation signal or is not receiving the correct 1500 microseconds, and the problem is in the Arduino or control code. The same basic assessment techniques can be used for all electrical components on the ROV, providing a rapid diagnosis necessary for repairs.

MECHANICAL COMPONENTS

Frame

The Whale III's frame had to support the necessary components, which have an intuitive construction, and allow the ROV to complete tasks requiring swift maneuverability. The design needed to be durable, intentionally providing protection and support to defend the inner components of the vehicle. It also had to be hydrodynamic to avoid drag and turbulence while maneuvering underwater.

WhaleTech's process focused on designing a frame that would meet these criteria using efficient and purposeful methods. First, optimal placement had to be determined to provide protection for the most vital components, such as the onboard control box, manipulator, and thrusters. The vertical thrusters mount to the top plate and reside within the vertical "wings" of the frame. They are located on the upper portion along its side-to-side midline. The thrusters sit partially inside and partially outside the frame. This allows the Whale III to maintain stability while moving up and down through the water as well as keeping a compact design. It also offers protection to the thrusters by not having them mounted entirely outside of the frame. The top plate has integral thruster guards that surround the portion of the thruster that is outside of the frame. This addition means any side impact to the thruster guards will distribute more evenly across the whole frame. For the onboard control box, a dedicated area was taken out of the top plate to accommodate the diameter of the control box housing. The resulting placement of the box lies partially above the top plate and the rest below to lower drag caused by its flat face. The open spaces around the control box allow water to flow more freely as the vehicle moves in any direction, therefore reducing drag.

The frame fits together using a mortise and interlock design. This allows the frame to fit together like a puzzle piece and has multiple overlapping vertical and horizontal sections. This joinery technique spreads out the physical stress across individual parts of the frame. This improved usability because of how the pieces fit together without the exclusive need for screws if the frame had to be repeatedly assembled and disassembled or if inner components required maintenance. Stainless steel M4 hex head bolts secure the individual pieces together and add to the rigidity of the frame. The "handle" shape resulting from the room allocated for vertical thrusters on the wing design is also intentional for ease of handling and lifting when moving the vehicle. Additionally, it provides extra protection for the thrusters from anything that could impact from above.

The lower portion of each of the wings was designed to have integral feet. This allows the baseplate and other equipment to be above the sea floor if the Whale III descends to the sea bottom. It also provides stability when while out of the water, preventing it from being knocked over in the same way that the bottom of a cup is concave in the center. If the ROV needs to operate on the sea floor in sand, silt, or soil, the internal components remain elevated above where the feet sink in.

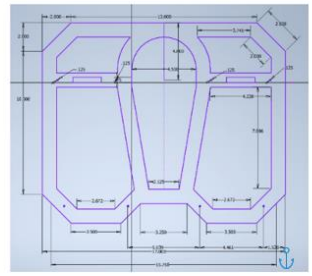


Figure 3: Inventor drawing of frame

Figure 4: Wooden model of

Figure 5: Frame design

The baseplate has two 20cm by 5cm sections carved out for better water flow when moving up and down the water column. Another 20cm long slit has been cut 4.5cm to the left of the center of the base plate in order to mount the manipulator. It is mounted in this manner because the tilt device for the arm is designed to operate with the arm off-center of its mounting plate. The slot in the baseplate allows for the arm to be stowed away during travel but also be easily slid into place for underwater operations. Another 4.5cm hole was cut into the rear of the baseplate to mount the camera in position to view the transect line and other objects below the ROV. This allows pilots to keep an eye on environmental features underneath the ROV to avoid damage to both the ROV and the surrounding environment. The hydrodynamics of the ROV was considered throughout all stages of design to configure the frame so that water could flow through the thrusters freely and avoid turbulence. The frame is less like a wall and more like a skeleton or web in the way that it is open to allow the water pushed by the thrusters to escape the underside of the ROV and incoming water to flow without much resistance.

The frame itself was cut from 9.53mm High-Density Polyethylene plastic, also known as HDPE. This material was chosen for its high strength-to-density ratio, making it very durable and light. The entire 45.7cm x 45.7cm x 35.6cm frame weighs 3.3kg without thrusters. The convenience of this lightweight material means that the ROV will not need large amounts of buoyancy to counteract the frame's weight. The design was planned extensively, with drawings, digital mapping, and 3D modeling with well-thought-out and calculated measurements using Inventor (Figure 3). Two plywood iterations came before a final product to physically map out the placement of the six thrusters and fine-tune the components' dimensions, angles, and relative placements (Figure 4). After several changes, a final design was cut with the CNC machine to the specifications modeled in Inventor. Using Inventor, along with the precision of the cutting ability of the CNC machine, created a greater opportunity to use mathematical reasoning in the frame design (Figure 5).

Propulsion

Six 3-Phase T200 Blue Robotics brushless motors propel the Whale III. WhaleTech selected its thrusters due to its extensive relationship and experience with Blue Robotics products and their capabilities. The consistency and reliability of outsourced propulsion is unmatched. Specifically, within the Blue Robotics brand, the T200s' superior thrust force of a maximum of 3.7 kg/f when provided with 12V, as opposed to the T100's maximum of 2.36 kg/f of thrust in the same conditions, was the driving factor in the decision. Although there is a higher cost associated with purchasing T200 thrusters over the T100s, the T200s produce noticeably higher thrust using the same voltage and amperage. They provide the propulsion force necessary for quick and accurate movement across mission fields, such as the transect of Lake Titicaca and the Coral Reef Modeling, as well as the lift capacity to bring debris to the surface.

The Whale III achieves omnidirectional movement due to the thrusters' orientation at each corner of the ROV. These thrusters are offset by 45 degrees with respect to the front and back centerline of the ROV. This was done to ensure that the front-to-back and side-to-side components of the force produced by the thrusters were equal so that the robot could move in any direction with equal speed. These components of the thrusts are proportional to the sine of the angle and cosine of the angle, respectively, and the only angle with equality between those is 45 degrees. The remaining two thrusters are oriented to thrust vertically on the top plate's broadsides. This offers a third axis of movement to the ROV. They are placed just on the inboard side of the horizontal thrusters' path so as not to interfere with the path of the horizontal thrusters' water movement. This also allows for the vertical thrusters' water path to be unobstructed and provide powerful vertical thrust. These winged thrusters allow WhaleTech to swiftly retrieve and bring down mission objectives such as the E-DNA extractor and fry box.

With spinning blades and the rapid influx of water into the thrusters to generate the propulsion needed to move, the thrusters can pose a significant risk to small species of marine life and risk to the robot if debris or marine life comes in contact with the blades. Shrouds were custom designed specifically for the T200s to form a barrier in which water can pass but foreign objects cannot, thereby limiting the risk of injury or damage. The shrouds are 3D printed with slotted joints so that individual faces of the shrouds can join together on either side of the thruster. Each shroud face has a slotted "female" channel on one side and a "male" slide on the other. The slotted channel is 9.4 cm wide with a 4.57 cm channel, and the "male" slide is 4.57cm wide and slots into the channel, as mentioned earlier. Both sides are epoxied together to create a rail system that further secures the shrouds to the thrusters (Figure 5).

Figure 6: T200 Front and Back view of thrusters with custom shrouds and measurements.

Buoyancy

One of the benefits of our onboard control boxe is that it serves as our main source of buoyancy. By having an airtight tube spaced out on top of the ROV, the ROV will have a relatively flat source of buoyancy that keeps it upright. Using Archimedes' principle along with the measured volume of the ROV, the calculated buoyant force was 124.25 N. Since the ROV only weighs 114.6 N, it had to add an additional 9.78 N of weight to make the ROV neutrally buoyant.

Total ROV Volume	.01276m^3
Density of Pool Water	992.72kg/m^3
Total Buoyant Force of ROV	124.25N
Total Buoyant Force of Onboard Control Box	54.13N
ROV Weight	114.6N
Added Weight	9.7865N
Added Mass	998.62g

Table 1: Buoyancy calculations to determine how much weight needed to be added to ROV frame.

ELECTRICAL SYSTEM

Topside Control System

Most of the Whale III's control systems are housed in the onboard control box, allowing the surface control unit to be more compact. All components of the surface control box fit into a Monoprice weatherproof hard case. The case's dimensions are 55.88cm x 35.56cm x 20.32cm. The interior of the surface box contains a top panel work surface that accommodates the laptop used to control the Whale III. This workspace is also large enough to house other necessary components such as the power switch, network interface, multi-function voltage monitor, and the buoyancy engine receiver with its display screen. A compartment under the top panel houses all of the surface-side electronics, keeping them safe from the elements. The case's durability provides safe storage and transport of the surface box even in less-than-ideal conditions (Figure 7).

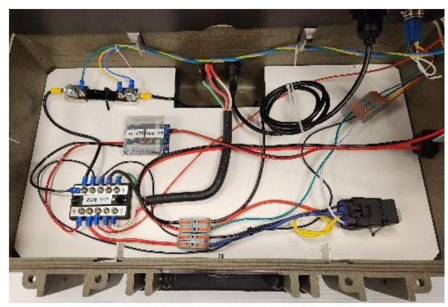


Figure 7: Underside of control system

The surface control unit consists of three subsystems: the power supply system, the control system, and the radio receiver system. The power supply system supplies electricity to the entirety of the Whale III, its subsystems, and the GO-BGC float radio receiver system. The control system is in charge of sending commands to the Whale III. The radio system is responsible for receiving signals from the buoyancy engine and displaying it on an LCD screen. The power supply system starts at the power switch. The flush-mounted power switch is both a utility and a safety feature. It offers a single point to instantaneously turn on and off power to the ROV. While at the same time, its flush-mount design keeps it from being depressed and accidentally turning on or off the vehicle. When pressed on, the power switch activates a 30amp relay switch, which, once bridged, supplies 12 volts to the entire system. From there, the power is sent through the bus bar and distributed to various other electrical components. One such component is the LCD screen that displays the transmitted signal from the GO-BGC float. A 5V step-down transformer is used to power this screen, which also provides power to the radio receiver. When it surfaces and transmits the data, this receiver receives the transmission from the GO-BGC float. Power is sent to the Whale III directly through the tether, which is attached by an industrial four-pin waterproof power connector. This connector allows the tether to disconnect and increase mobility during transport. This surface box also utilizes a multi-function electrical display that allows pilots to monitor voltage and amperage in the system. This feature can assist in troubleshooting and signaling the need for immediate power shutdowns should a malfunction occur (Figure 8).

Figure 8: Topside control system

The topside control system consists solely of a Lenovo laptop that receives input from the pilots. The laptop runs Whale III's control code and sends commands to the robot through the tether. It is also responsible for connecting to the two Logitech Extreme 3D Pro joysticks used to pilot the Whale III and receiving their input. The laptop connects to the tether through a flush-mounted RJ45 connector on the top work surface. The tether also has a disconnectable waterproof connector that allows the tether to be completely detached from the surface box for transport (Figure 9).

Figure 9: Tether restraint control box side

Onboard Electronics

The Whale III's onboard control system is encased by an airtight cast acrylic enclosure that is part of the BlueRobotics 6-inch enclosure series. A fifteen-hole aluminum output plate is used to allow wiring to enter the housing via epoxy-potted cable penetrators. The output plate hole number was calculated at the beginning of the production process, considering the number of wires going to and from the control box. Chosen for its interior dimensions, the 6-inch housing provides sufficient space for maintenance while decreasing the probability of overheating equipment. In addition, using the 6-inch enclosure was a cost-effective decision, having been donated to the company in a past season by the Mate ROV organization (Figure 10).

Figure 10 : BlueRobotics 6 inch cast acrylic enclosure

An AC-to-DC bench power converter supplies the control box with 12 volts of power through four 14AWG (American Wire Gauge) power and ground wires. A 25-amp fuse is mounted inline to provide overcurrent protection. Voltage limits are set according to Mate regulation, and fuse calculations are engineered to establish the required current to safely operate the electrical components on the Whale III (See FUSE CALCULATIONS). Input voltage is directed to a power bus bar that distributes 12 volts to six Electronic Speed Controllers (ESCs) and two step-down transformer/voltage regulators. The BlueRobotics basic ESCs are necessary to regulate the speed and direction of any three-phase brushless motors, such as the

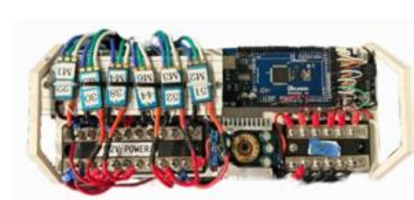


Figure 11: Onboard electronics

T200 thrusters employed on the ROV. The first step-down transformer is a DC-to-DC voltage regulator that converts the 12 volts supplied into the 7.4 volts required to power the Savox waterproof digital servos. Communication with the Whale III is established through both a Raspberry Pi 4 microcomputer, responsible for autonomous missions and camera input, and an Arduino Mega 2560, responsible for control code (See SOFTWARE). A second voltage step-down converts the supplied 12 volts into 5 volts to supply power to the Pi safely. This step down is necessary to limit interference caused by powering the pi off the Arduino's pins. Each device stays in communication with the programming laptop through a Cat5e industrial ethernet cable, permitting both micro-computers to communicate with the ROV's components. Each device (thrusters, servos) is allotted its own Arduino pin number, allowing for signal correspondence between the written program and the action taken (Figure 11).

Certain elements were designed to ensure the onboard control box was accessible for constant maintenance throughout the ROV production and testing processes. The electronics base plate was cut from refurbished whiteboard material to both repel moisture and cut costs, while a custom housing structure was 3-D designed and printed to increase the accessibility of the electrical board. In addition, gray A-key way electrical connectors bridge all output wiring before exiting the housing, enabling the board to be easily detached from the ROV. Detachable wiring within the housing is utilized for its efficiency, allowing the control box to be worked on in diverse locations.

Tether

The Whale III has an Onboard control box (bottom side) and a surface control box (top side) that are required to stay in constant communication, transmitting power and data back and forth. A 15-meter tether effectively enables this imperative communication.

The component cabling is safeguarded in woven polyethylene terephthalate (PET) sleeving, otherwise known as Tech Flex. This abrasion-resistant material offers protection from kinking, and exposure to serrated objects inflicts less harm on the cabling. Kept afloat by buoyant and flexible polyethylene foam, the tether rests on top of the water as the Whale III makes its advances, keeping away from marine species and machinery. In addition, the tether is no longer at risk of becoming an obstacle for the ROV when running, mitigating any risk of entanglement or damage. The tether is fixed in place by robust restraints on both the top and bottom sides, presenting relief in two common areas of strain. A waterproof RJ45 panel mount connector and a 4-pin waterproof power connector are installed on the surface side control box. These connectors allow the box and tether to disconnect from one another. As a result, it is easier to transport and maneuver the two systems independently of each other. Before entering the onboard control box, the tether is guided through two U-bolts, or hose clamps, fastened to the control housing. This protects the electrical components from harm by keeping a firm grasp of the tether during snags. A similar setup is used at the surface control box, providing all elements of the ROV with protection in case any obstruction or snagging of the tether was to occur. The tether consists of two separate cables that connect the surface control box and programming laptop to the onboard control housing. Power to the ROV is supplied through an Automation Direct flexible power cord with four conductive 14AWG (American Wire Gauge) wires. Two power and two ground wires were implemented in place of a single power and ground wire to avoid the voltage drop experienced in past designs. In addition, a continuous flexing Category 5 enhanced (Cat5e) industrial ethernet cable provided by

Automation Direct connects the programming laptop to the Raspberry Pi microcomputer within the control box. This model of ethernet cable was chosen over both Cat5 and Cat6 for having the capacity to transmit data at a faster and more reliable rate than that of the Cat5, and for the companies' purposes, using a Cat6 cable would be redundant and needlessly more expensive to use where the Cat5e is adequate. Continuous flexing cabling was chosen in anticipation of the user continually wrapping and bending the tether for transportation and maintenance, offering more resistance to damage. Both cables are braided together within the sleeve, forcing the electromagnetic fields to alternate and thereby reducing any remaining electromagnetic interference (Figure 12).

Figure 12: Whale III tether

Tether management protocols are enacted in operation to ensure proper deployment, usage, and storage of the ROV's tether. The tether is coiled orderly around a refurbished spool previously used to store cabling purchased by the company, providing a means of safe transportation and storage of the tether. When in operation, specified personnel are responsible for managing the tether's deployment into the water and guiding it along as the ROV moves through the water. This process ensures that the tether remains out of both the ROVs and harm's way while avoiding contact with marine life.

SOFTWARE INFRASTRUCTURE

The software infrastructure of the Whale III is responsible for reading input from the joysticks and the keyboard, displaying images from the cameras on the ROV, controlling the motors and manipulators of the ROV, and performing autonomous tasks. The software manages two main pieces of hardware: The onboard control box and the surface control unit.

These two systems communicate over ethernet through sockets, using bi-directional communication on a network. This way, the laptop sends control data to the onboard control box, which then sends images from the cameras to the laptop.

Topside Control Unit

The surface laptop, a Lenovo Thinkpad E590, runs a program that gathers and processes input data into microsecond values for the servo motors and thrusters and runs performance-intensive calculations for the autonomous programs.

The software reads the pilot input from two Logitech Extreme 3D Pro joysticks, one controlling the ROV propulsion and the other controlling the manipulator. Each joystick has three axes of movement, controlling the ROV and manipulator's direction, and 12 possible buttons corresponding with running certain autonomous programs, switching between different cameras, and several miscellaneous auxiliary functions. One of these auxiliary functions is a button that halves the speed of the thrusters, allowing for the pilots to make more precise movements during delicate missions.

In order to transmit data between the surface and the ROV, the software uses an open-source library named NumpySocket. This library transmits numpy arrays, which are interpreted as sequences of motor data or images, over socket connections. Because the data is sent over sockets, all that the Whale III needs connected to the surface is ethernet and power.

Onboard Control Unit

A Raspberry Pi 4 is located onboard the ROV and controls the ROV according to the microsecond data it receives from the surface laptop. The raspberry pi acts as a middleman between the surface control unit and the hardware, delegating the movement of the motors and manipulator to an Arduino Mega 2560. The Arduino is used to directly control the motors and servos because it is made explicitly for controlling peripheral hardware and can interface with the ESCs that control the ROV's motors. This separation of tasks allows for simpler and more extensible code.

The images received from the ROV's cameras are displayed using OpenCV, a library that specializes in image manipulation and computer vision.

CODE MANAGEMENT

The code management is designed with abstraction in mind. Using the python programming language's capacity for object-oriented programming, the surface laptop's software uses an object to represent the robot in the code. The benefit of this is that it allows developers to add features to the program without having to know how the whole system works, only needing to know how to interact with the interface. Whaletech's codebase also makes use of the version control system Git/Github, which can store code online and provides the ability to look at past versions of the codebase, an invaluable ability when debugging. Git/Github also increases the ability for collaboration, as multiple programmers can work on different forks of the codebase at the same time, then assimilate their changes into the main codebase through pull requests that other programmers can review. The Code went through various versions, each one fixing bugs and improving efficiency over the last.

Vision system

The visual system of the Whale III consists of three ExploreHD 3.0 cameras. These cameras were selected for their high detail and resolution, advantageous viewing angle, low streaming latency, strong connection, and high IP rating. A large portion of the budget was used for purchasing these cameras. However, the camera's fast, reliable, and effective visuals during mission tasks more than justify the added expense (Figure 13).

Figure 13: Sideview of Explorer 3.0 Camera

The cameras are also compatible with USB connections, which is ideal for communication between the surface control unit and the ROVs visual systems. The cameras' latency is also an essential quality-of-life improvement for pilots. The latency of these cameras, 35ms (+/- 20ms), is near-instant, meaning autonomous functions on the ROV can complete mission tasks without mistakes pertaining to improper timing and maneuvering.

The visual range of the ExploreHD 3.0 cameras is 150° diagonally; because of this, pilots are able to observe a wide area at one time and fully capture the ROVs' surroundings. In addition, the quality of the image and frame rate; (1920 x 1080 and 30fps, respectively), as well as the color-graded visual output for underwater use, ensure the pilots receive an accurate, fast, and detailed understanding of the environment and provide a better source image for generating 3D models of environmental features, such as coral heads.

The cameras were placed in three different locations on the ROV, providing pilots with a wide range of vision for coordinating the manipulator, maneuvering, and observing the environment. The first camera is mounted to the front of the ROV to assist pilots in maneuvering the ROV properly to complete tasks. A second camera is positioned overlooking the manipulator to receive a visual confirmation when executing precise movements for the operators when completing tasks. The third is mounted within the baseplate of the ROV facing the sea floor to observe the environment for data collection. Specifically, its placement is optimized for the transect line counting frog species along the bottom of Lake Titicaca.

To increase the performance of the cameras, multithreading was used in combination with only reading from two of the cameras at the same time. When the raspberry pi executes the code that reads a frame from one of the cameras, it takes longer than a normal piece of code because it must wait for outside input from the camera. This time delay is reduced by employing multithreading, which allows the code to read from multiple cameras at the same time while also performing other tasks. The reason only two cameras are used at a given time is that the bottom facing camera and the manipulator facing camera are only used in certain situations and never at the same time, so it is more efficient to switch between them rather than both at the same time.

TOOLS

Air Bag

Figure 14: Whale III Air Bag

The lifting bag consists of two main pieces, a buoyancy container, and a dual action hook attachment. The hook attachment has a one-way locking safety latch. Once engaged, this latch ensures that the hook and lift device remains attached to the object throughout retrieval. The main body of the buoyancy container is a 4258.59 cubic centimeters size round plastic container. The container remains opened on one end, which prohibits the container from building up pressure of any type. When the container is inserted into the water, the prop specialist fills it with water so that it is neutrally buoyant. This allows the Whale III to attach the container to the object easily and not be pulled to the surface by it. Once securely attached, the lift device is made buoyant by manually pumping air into the container using a hand pump at the surface. The pump delivers air through quarter-inch pneumatic tubing, which connects to the lifting device by fitting into a custom 3-D printed base plate. This baseplate is attached below the container but centers the open end of the pneumatic tubing directly under the container. As air exits the tubing, it is captured by the container and displaces the water inside through the opening in the bottom. Once enough air has been captured, the buoyant force of the container is enough to raise the object to the surface. The safety hook is attached to the buoyancy container by strong and flexible paracords ensuring that the weight of the heavy container does not snap the connection between the container and the object. Once the entire system is raised to the surface, the Whale III can then safely pilot it to the water's edge (Figure 14).

eDNA Extraction Device

The eDNA extraction device uses several components to retrieve the eDNA effectively. Quarter-inch pneumatic tubing is connected to a manual pump for the suction. The tube is then connected to a recycled twisted bottle as a collection reservoir. The tubing end is connected to a hard plastic "straw" with a 12.7mm inner diameter. The straw is equipped with a PVC endcap to assist in positioning the straw. Once the manipulator places the endcap on the sampling location, the claw will leave the endcap on the extraction point and feed the straw through the endcap into the eDNA. A prop specialist will then use a manual pump at the surface to extract an eDNA sample. The sample travels through the tubing to the collection reservoir at the surface. Once the prop specialist has determined a large enough sample has been collected, the reservoir containing the eDNA sample can be removed and put into the analyzer container for inspection (Figure 15). Through testing, we were able to simplify and rework the design into this cost-effective and facile design.

Figure 15: eDNA extraction Device

Manipulator

The Whale III is equipped with a custom-built 3-function manipulator, capable of performing a range of tasks with precision and efficiency. Some tasks include removing biofouling from wind turbines, ensuring that they continue to operate at their peak capacity, transporting fish in a specialized container to a safe environment, and a variety of other tasks requiring object manipulation. Overall, the manipulator is essential to WhaleTech's pursuit of preserving and protecting the underwater environment using the Whale III.

The manipulator's arm has two axes of movement, tilt and twist, and a claw that can open and close. The tilt function works using the torque of a servo linked to a set of two gears on an aluminum bar, which the manipulator rests upon. The twist function operates with a servo mounted upon the aluminum bar, connected with a 3D printed endcap to a 22cm section of 1" PVC pipe. This pipe acts as the body of the device, with the claw mounted on the other end of it (Figure 16). The decision to 3D print the endcap piece offered us customization in terms of dimensions and design, as opposed to a typical PVC end cap which does not offer a needed flat surface to mount the servo horn.

Figure 16: Manipulator and tilt mechanism

The open/close function, attached to the PVC section, uses a servo rotating a gear attached to one pincer; the gear has 90 degrees of teeth connecting it to an identical gear, ensuring that the rotation of the first creates identical and opposite movement in the second. The two gears then work in tandem to open and close the claw to grip anything necessary (Figure 17). In testing the manipulator, problems with over-stressing the servos on the claw arose, causing them to overheat. To fix this issue, we added two set close distances for the claw and lowered the voltage on the servos so they would not overheat as quickly if anything were to go wrong.

Figure 17: Claw mechanism

Fry Release Cage

To restore the native population of Northern Redbelly Dace, WhaleTech designed a container compatible with the Whale III to transport Dace fry and safely release them into a suitable new habitat. The device is used to store the fry within the confines of the container while the Whale III transports it using the manipulator, which holds two slanted bars at the top of the container (Figure 18). The device was designed internally, as it was cheaper to build than to purchase something like a third-party silicone net, which would also be too large for this purpose. Building it also allowed the company to alter the container to be compatible with the ROV and uniquely meet the needs of the mission.

Figure 18: Fry Release cage

The ROV holds the container by two slanted bars protruding from the top. These bars are also part of the mechanism to open the container. The fish are held in the container by two 3D-printed plates that are attached to the two metal bars using L-brackets. A modified door hinge allows the bars to move and open the bottom plates (Figure 19).

Figure 19: Bottome side of Fry Cage to show base plates.

The bottom plates stay closed with a thin strip of Velcro that can be detached or undone when the manipulator pinches the top of the two metal bars. When the top of the metal bars is pinched, the Velcro disconnects, and the doors swing open for the fry to swim out. Once acclimated, the doors open, and the fish are released to be introduced to their new habitat. After all of them have left the box, it is pulled back to the surface by a rope that is attached to the top of the container. The design has several safety features; it lacks sharp edges and a net inside to prevent predation during transport and prevent dace fry from escaping. During testing we experienced an issue where the fry got caught between the bottom plates and the sides of the container. To overcome this plastic sheeting is used and netting along the sides to ensure that they do not get caught in release.

Coral Modeler

WhaleTech's photogrammetry algorithm is designed to use a single top-down photo of the coral to generate a 3d model, showing the diseased and healthy areas of the coral, along with the width, height, and total area of diseased coral. Using the top-down photo, the coral is identified with OpenCV by masking out all the red sections in the image and, finding the section with the largest area, then calculating the radius and position of the smallest possible circle around that area. Over time, the range of color that was used to detect to coral was fine tuned so that the program would accurately detect the coral, and only the coral. A depth map is then generated by approximating the circle to a semi-sphere by knowing that points closer to the center of the circle are closer to the camera. Finally, Open3D is used to combine the depth map and the image taken by the pilots into a 3D model. An additional program is then used to find the

Figure 20: Simulation of 3D model of coral

dimensions of the coral by manually measuring one of the diseased sections by opening the claw to a known length and deducing the size, comparing the two. Then by drawing lines of the dimensions required, measurements are found by using the ratio of the known length to pixels. The measurements of the lines drawn are then displayed alongside the 3D model (Figure 20).

UV Light Simulator

The simulated UV light is a 5V LED that is sealed with epoxy to be waterproof. A plastic cone surrounds the light to direct the light to the diseased coral head. The cone keeps the UV light from escaping and blocks the ambient light from entering. An aluminum T-track extrusion is attached to the frame and serves as a mounting location for the light arm. The LED is attached to a right-angle bracket, which is attached to the T-track using two cam clamps. By connecting it in this method, the payload can slide in and out to change from a stowed away to a deployed position along Whale III's horizontal profile. The LED is powered by one of the Arduino Mega's digital pins and toggled on and off through the press of a button on one of the pilot's joysticks (Figure 21).

Figure 21: UV light simulator

Autonomous Docking Code

WhaleTech's autonomous docking algorithm enables the Whale III to dock itself without requiring any human intervention. The algorithm analyzes the front camera feed from the ROV to locate the docking station's button, which needs to be pushed for the ROV to be securely contained in the docking station (Figure 22). The algorithm uses the OpenCV library to isolate the red in the image by subtracting green and blue values from the red values and then finds the largest area of red in the camera feed, indicating the position of the button. Once the algorithm has identified the button's position, it adjusts the ROV's position and orientation to align it with the button so that the manipulator is in line to press it. The ROV's position is adjusted by writing the motors to move opposite of the camera's center position relative to that of the button's. The algorithm behind autonomous docking undergoes iterative development and extensive fine-tuning to ensure a reliable and high-quality experience. Real-world and simulated tests provide data for refining the algorithm, enabling it to adapt to various docking scenarios and environmental conditions.

GO-BGC Float

The Barnacle is an autonomously functioning buoyancy engine capable of wirelessly transmitting information to the mission station. It is composed of three systems, a control system, a drive train, and a hydraulic cylinder. All three systems work together to ultimately pull in or push out the cylinder's water, changing the Barnacle's density below or above that of water, causing it to sink or float, respectively.

The cylinder, a D40050DT-MC donated by Automation Direct, has a volume of 1608.7 cm^3. While capable of operating hydraulically, the decision to modify the cylinder by boring the inside of the cylinder's rod to use the mechanical advantage begotten of threads.

The drive train consists of a NEMA23 (KL23H286-20-8B) stepper motor. The stepper motor, while in a bipolar parallel configuration, grants a holding torque of 3 NM at just 4 volts and 2.4 amps and a moment of inertia of 840 g/cm^2. The torque the motor produces is then transferred into linear motion by twisting an all thread up and down a nut welded just before the bored hole.

The control system is set upon a 3-D printed, electronic shelf housed within a Blue Robotics 3" series acrylic tubing. The housing being reused for numerous years had proven to be highly successful in being a cost-effective way of keeping contents dry, even when purchased new. The control system consists of two subsystems: motor control and communications. Both systems start at two 4 AA battery holders wired in parallel, supplying 6V and before running into a 5-amp fuse within 5 cm in accordance with MATE regulations. Both power and ground are then spliced, one path powering a TB6600 stepper motor controller and the other two a 6V to 5V buck before powering an Arduino Uno. The Arduino, programmed to drive the motor forward and back based on a timer, then sends the appropriate digital signals to the stepper motor controller. Supplied with power and signal, the stepper motor controller then sends the proper current to the proper phases of the stepper motor in order to drive the cylinder. The communications subsystem splits from the control subsystem at the Arduino. A receiver is wired to the Arduino that communicates the time from the Arduino's internal clock to its partner receiver located in the surface control box. This time is then displayed on an LCD screen that the pilots can see.

SAFETY

Company Safety Philosophy

WhaleTech's first priority is the safety of its employees. The company follows policies set by the Job safety analysis, which provides the rules and proper procedures to ensure a secure workspace and encourage a productive environment. WhaleTech's personnel are fully trained on the proper safety protocols and to apply them from start to finish of the construction and operations of the Whale III. All members are trained to identify hazards and unsafe work practices, remove known obstacles to prevent accidents, and contribute to our ongoing efforts to create a safe workplace free from accidents and injuries.

Training

WhaleTech's personnel are educated on the proper procedures to use the appropriate tools and PPE for their tasks. Most importantly, they are instructed on exactly what to do if an issue occurs. Furthermore, members dealing with electrical equipment and soldering are trained on the correct operating conditions, damage control procedures, and basic first aid in the case of an incident. In addition, all employees must keep food and drink away from computers, motors, chemical adhesives, electronics, and other workstations. Finally, personnel must set up their workstations neatly and position cords in an organized fashion to minimize flame and trip hazards.

Vehicle Safety Features

Regulations were considered carefully during the design process of the Whale III to comply with MATE guidelines for safety. It was equipped with several safety features to complete tasks efficiently while maintaining the safety and integrity of the Whale III, its operators, and the environment. These ensure the well-being of the crew, work environment, and ROV during operation and testing. Warning labels have been attached to all moving parts and components, mitigating the risk of accidental injury or damage (Figure 23). In addition, the surface control box has a power switch that powers off the ROV if necessary (Figure 24). Components within the onboard control box have been labeled to be easily identifiable if the ROV encounters issues (Figure 25).

Figure 23: Warning labels on all moving parts.

Whale III's power supply is equipped with a 25amp fuse to prevent onboard systems from exceeding the maximum operating value (Figure 26). The onboard control box is housed in a 6-inch clear acrylic tube with watertight end caps, meaning any visually apparent abnormalities are immediately detectable (Figure 27). The Whale III is also free of any chemical contaminants that pose a risk to the environment; for example, the epoxy used for attaching shrouds and sealing penetrators is not water-soluble. To ensure the ROV has very little or no unintended impact on the environment with which it interacts, the Whale III is devoid of sharp edges or hazardous points on the frame and components, preventing flora from damage and aquatic animals from injury. The six T200 thrusters are also fitted with shrouds that prevent the entry of objects and larger organisms into the spinning blades.

Figure 24: Emergency shut off switch

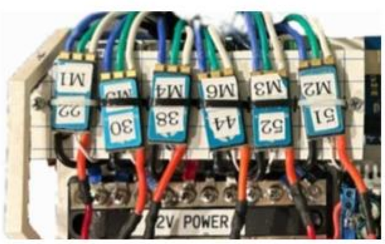


Figure 25: Labelled onboard control box for maintainence

Figure 26: A 25 Amp

Figure 27 : All pentrators are waterproofed with epoxy

Operational and Safety Checklist

The operation and safety checklist describes the proper procedures for PPE, wiring, electronics, setting up workstations, and incidents (See Appendix 1). All operators are aware of when the ROV is being powered on/off and when machinery is being operated in their area. These precautions significantly decrease the opportunity for unexpected injuries or general inattentive behavior because members are fully aware of their surroundings while others work.

Lab Protocols

The company employees maintain clean working environments by returning all tools to their specified housing, removing all trip hazards, and keeping all food and drink away from workstations. WhaleTech's job safety analysis (JSA), an overview of regulations and safety rules, provides the guidelines for the specifics of the company's protocols. WhaleTech's Job Safety Analysis is available to be accessed by all employees.

The company employees maintain clean working environments by returning all tools to their specified housing, removing all trip hazards, and keeping all food and drink away from workstations. WhaleTech's job safety analysis (JSA), an overview of regulations and safety rules, provides the guidelines for the specifics of the company's protocols. WhaleTech's Job Safety Analysis is available to be accessed by all employees.

Figure 28: Member demonstrating safety protocol.

During maintenance or manufacturing processes of the Whale III, company employees must conduct themselves professionally and are required to wear appropriate clothing and safety devices. Inappropriate workshop clothing includes open-toed shoes, loose-fitting clothing, long hair that is not tied up, and large accessories. While working with chemicals, such as adhesives, company employees must work in ventilated areas and wear gloves and safety goggles (Figure 28). In addition, no fewer than two members are permitted to operate machinery simultaneously.

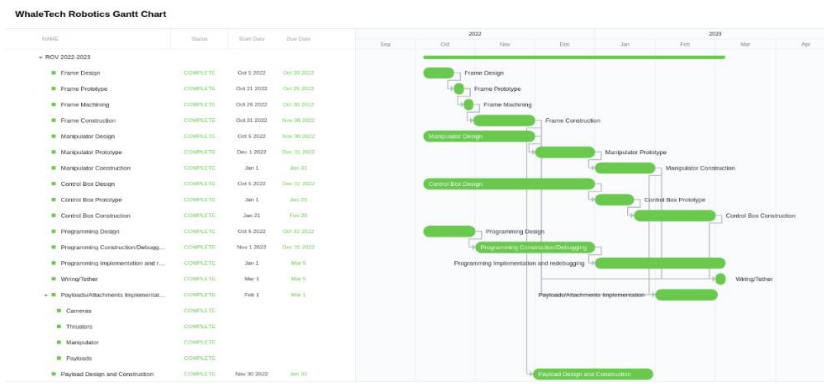
TEAMWORK

Project Management

Communication and organization inside the company were paramount to effectively managing the projects necessary to build the Whale III and its accessory devices. WhaleTech has organized its operations into three distinct departments - Mechanical, Electrical, and Software - to ensure maximum efficiency through the specialization of departments. Each department operates independently but communicates regularly with the others regarding timelines for completing individual parts and necessary components for successful integration. This approach ensures that day-to-day operations run efficiently, with each department working in tandem. The company itself consists of eleven members between 9th and 12th grade. At the top are Tony Brozowski (CEO) and Michaella Hopfner (CFO). Mechanical functions were delegated to engineers Garrett Lanham, Phaelan Pearson, Gavin Osterloh, and Charlie Boles. Electrical engineering was performed by the Michaella Hopfner and electrical engineer Ian Osterloh. The software team consisted of software engineers Graham Joonsar and Jacob Banta. Tyler Pold (COO) was responsible for design engineering.

WhaleTech utilizes both Google Drive and Google Calendar to keep track of important documents and dates, allowing team members to instantly share documents, photos, and 3D models while being able to see dates and times for our meetings. To track our deadlines and dependencies, we created a Gantt chart. This chart ensures we finish a particular component on time to ensure the completion of other elements of the ROV.

Employees were assigned a number of tasks to complete towards the development of the ROV in areas in which they had proven to be adept. As an extension of North Paulding High School, two classrooms held equipment, machinery, and meetings. Employees regularly met weekly for two and a half hours at a time. Beginning in January, meetings outside of school were organized on Saturdays, lasting between four and eight hours each. Less frequently, meetings were conducted in a conference room within a local business to discuss progress, documentation, and project logistics. Deadlines were discussed and set every few meetings in order to plan what future progress needed to look like.



Budget and Projecting Costing

At the beginning of the design phase of the Whale III, WhaleTech prepared an estimated budget of $6,500 based on prior project costs of North Paulding robotics companies. This outline provided the company with a structured schedule to follow regarding company spending, not to exceed the allotted funding. The projected cost included company expenditures ranging from hardware costs, transportation, lodging expenses, and advertising/technical materials.

A mix of employer costs, fundraisers, and donations supplied WhaleTech with an initial fund of $6,000, of which $3,500 were set aside for Whale III expenses, leaving the remaining available for costs such as prop builds, company meals and other miscellaneous items. Through methods including an annual company Christmas Hot Chocolate sale and supporting local businesses through the marketing of consumer goods, WhaleTech raised an additional profit of $4,500 to support the company's growing expenditures. Sponsor positions were also made available to companies willing to donate to WhaleTech's mission for a returned promise of recognition on company shirts and banners. A total of five sponsors' generous donations enabled the company to spend an additional $1,750 on the production of the Whale III, each given the decision between four tiers of various degrees of sponsorship.

One of WhaleTechs sponsors, Automation Direct, supported the company through additional means on top of sponsor money, including free and unlimited access to their company's products. This support gave WhaleTech the opportunity for free materials such as the Cat5e ethernet cable and the cylinder used in the Buoyancy Engine, saving the company an approximate total of $850 in spending. The company's decision to reuse specific components after intensive testing was another method for saving money during the Whale III's production, yielding an extra $975 in the company budget.

The current project cost of the Whale III is $5,168, taking into account money both gained and lost throughout the manufacturing process. This means the company spent $1,332 under the estimated budget, an updated measurement to be used in future WhaleTech productions. The costing spreadsheet can be found in APPENDICES 4. Since securing a spot at the world competition, more fundraisers are in the works to help raise funds to cover transportation and hotel costs for mentors. Estimated costs for two mentors will be $1,400 for flights and $2,400 for rooms. Shipping costs for the ROV are not necessary as some team members will transport the ROV in their personal vehicles. The company will give these individuals $300 to help cover the cost of gas along the way.

CONCLUSION

Challenges

Changes in the company and authority structure resulted in a decrease in funding, loss of available workspace, and decrease in available mentors for WhaleTech, which the company was unprepared and inexperienced for. Work schedules were administered to individual employees ahead of time to provide a definite structure for the company to abide by, and the company's chief executives reinforced affirmative communication. In addition, WhaleTechs financial circumstances pushed the company to develop new means of revenue, including the 6+ fundraisers held in support of the company and the reprocessing of mechanical components on the Whale III that gave the ROV budget more leeway.

Lessons Learned and Skills Gained

WhaleTech took every opportunity for critique as a method of improvement and development within the company and its engineers. Despite the company being goal oriented and focused on producing the Whale III, an overarching mission is to develop each engineer's abilities and soft skills. Skills such as problem-solving, innovation, leadership, and interpersonal communication were amplified and built upon within the company due to continuous barriers and the need for improvement.

Problem-solving and innovation are often seen to go hand in hand. Mechanical and electrical engineers alike put Whale III's components through several stages of testing and troubleshooting in order to manufacture an efficient ROV. One big source of issues the company faced revolved around the fabrication of 3D-printed parts. As the Whale III is the company's third rendition of a remotely operated vehicle, WhaleTech has learned not to 3D print joints that are in vital areas around the frame or that take a lot of buoyant force when in operation. The company's mechanical engineers innovate and design around this gained knowledge. However, 3D printing still plays a heavy role in production as rapid means for developing parts such as thruster shrouds or housing brackets. WhaleTech's design engineer and the 3D modeler have had to adjust to the meticulous demands of the 3D printer, needing detailed and precise 3D models for the prints to be effective without fail.

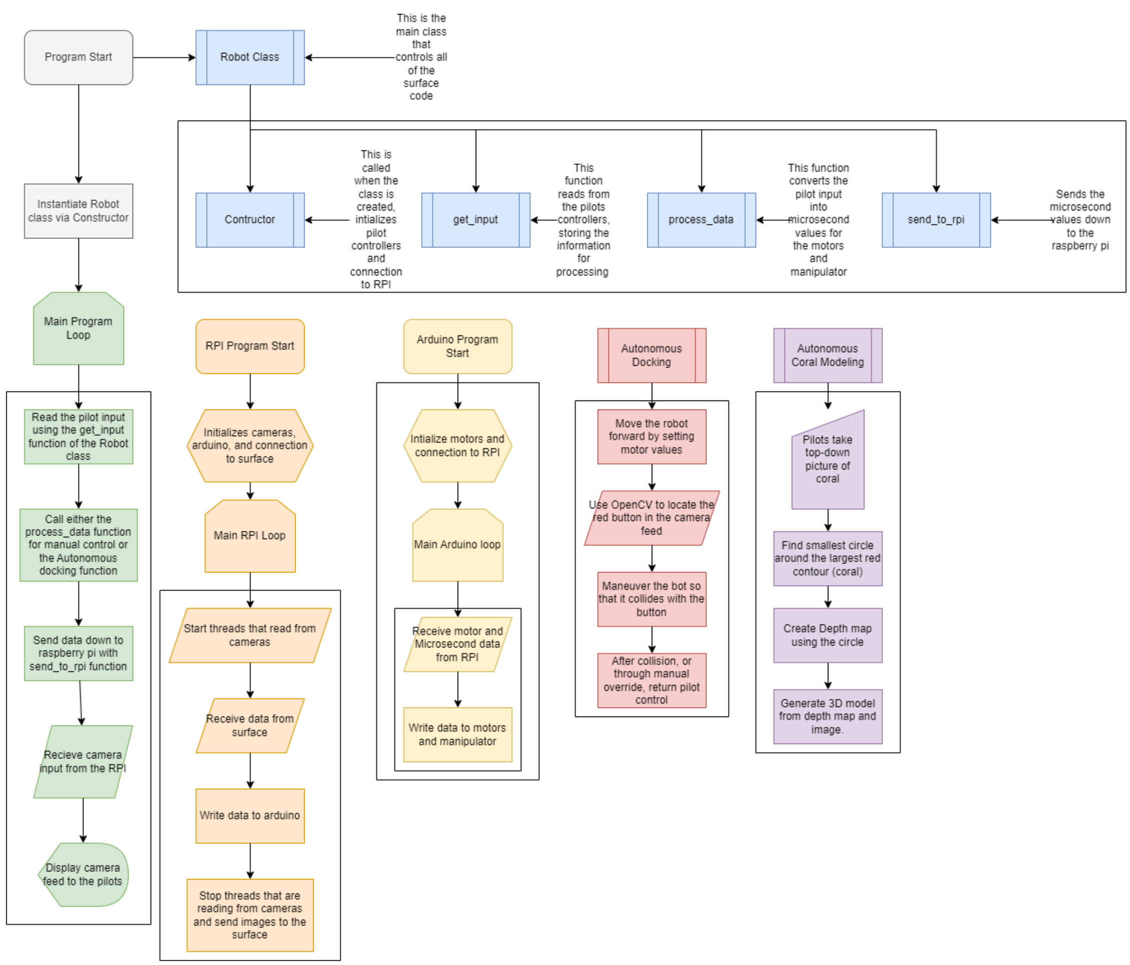
Additionally, WhaleTech's associates each developed leadership and teambuilding skills within the workplace, some being promoted into leadership roles based on prior performance and others becoming naturally team-oriented. With the company facing organization issues throughout the production stages of the Whale III, many individuals stepped up or learned to tackle issues on their own with other company engineers that previously would have required outside input.

APPENDICES

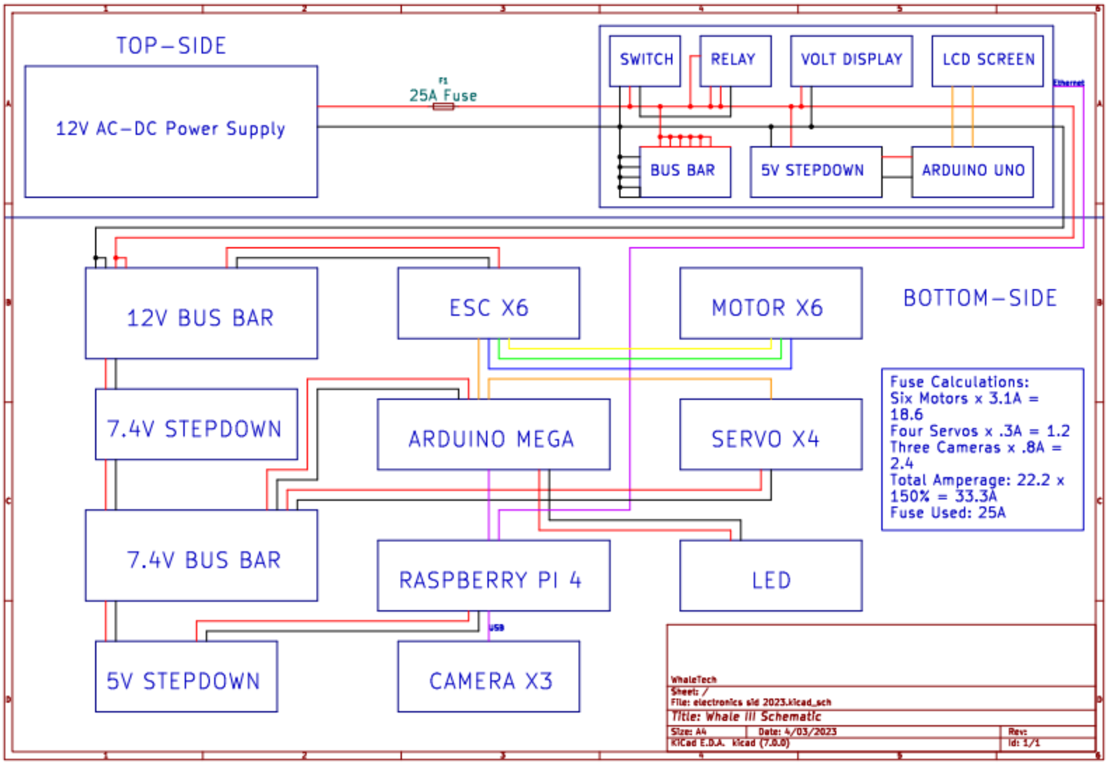
APPENDIX 1: OPERATIONS AND SAFETY CHECKLIST

PROCEDURE	CHECK
Surface control kill-switch is accessible and functional	
Loose clothing secured, long hair tied back, and close-toed shoes - (Members in appropriate attire)	
Wires are properly managed and other trip hazards removed, cords protected	
Operation of machinery is under adult supervision and only by a member who has been trained how to operate the machine	
Using PPE during the use of corrosives, adhesives, power tools, and soldering irons; as well as in the presence of the ROV	
Electronics are at a reasonable, large (5ft+) distance from water	
All team members alerted when the ROV or NRD is powered on/off	

APPENDIX 2: SOFTWARE SCHEMATIC



APPENDIX 3: ROV SCHEMATIC



APPENDIX 4: PROJECT COSTING FOR 2022-2023 ROV BUILD

Project Costing **WhaleTech**
North Paulding Robotics

CEO: Tony Brozowski
CFO: Michaella Hopfner

TOTAL BUDGET $6,000.00

SPENT	GAINED
$4,801.81	$8,212.00

REMAINING $3,410.19

EXPENSES:

Date	Vendor	Type	Category	Description	Spent	Earned	Original Cost	Running Total
10/18/2022	Employee	Funding	Donation	Company Dues	$0.00	$5,225.00		$5,225.00
10/20/2022	BlueRobotics	Electronics	Re-use	T-200 Thrusters, Electronic Speed controllers	$0.00	$0.00	$1,016.00	$5,225.00
10/21/2022	BlueRobotics	Hardware	Re-use	6" and 3" Series Housing Parts	$0.00	$0.00	$565.00	$5,225.00
10/22/2022	Amazon.com	Hardware	Re-use	Tech Flex, U-Bolt Restraints, White-Board	$0.00	$0.00	$35.00	$5,225.00
10/23/2022	Servo City	Hardware	Re-use	Arm Tilt Kit, Claw Kit, Camera Tilt Kit	$0.00	$0.00	$65.00	$5,225.00
10/24/2022	BuyPlastic.com	Materials	Purchased	HDPE Plastic Sheeting, PVC sheeting	$441.38	$0.00		$4,783.62
10/25/2022	AutomationDirect	Hardware	Donation	Continuous Flexing Cat5e Cable	$0.00	$0.00	$99.60	$4,783.62
10/26/2022	AutomationDirect	Hardware	Donation	Continuous Flexing 4-part Cable	$0.00	$0.00	$407.40	$4,783.62
10/27/2022	Amazon.com	Tools	Purchased	Caliper, Screwdriver, Dremel Bits, Sockets, wrench	$119.23	$0.00		$4,664.39
10/27/2022	Amazon.com	Electronics	Purchased	Jumper wire, Charger, Raspberry Pi 4	$111.65	$0.00		$4,552.74
10/28/2022	Amazon.com	Electronics	Re-used	Bus Bars, Step-downs, Arduino 2560	$0.00	$0.00	$122.10	$4,552.74
11/5/2022	Amazon.com	Tools	Purchased	Labels, Tapes, Keypad, M3 screws, nuts, washers	$224.37	$0.00		$4,328.37
11/11/2022	Home Depot	Tools	Purchased	Prop Supplies, 4x8 ply wood, screwdriver set	$681.52	$0.00		$3,646.85
11/15/2022	Kroger	Funding	Fundraiser	Boston Pork Butt Sale	$0.00	$1,937.00		$5,583.85
11/25/2022	Doner	Funding	Donation	Conrad Perry, Joonsar Family, Cobb EMC	$0.00	$1,050.00		$6,633.85
11/27/2022	Northern Tool	Tools	Purchased	Screwdriver set, Plier Set	$61.81	$0.00		$6,572.04
11/30/2022	Deep Water Explore	Hardware	Purchased	Explore HD 3.0 Underwater ROV/AUV Cameras	$778.80	$0.00		$5,793.24
12/1/2022	Amazon.com	Hardware	Purchased	Weatherproof case, switches, potentiometers, resisters	$265.50	$0.00		$5,527.74
1/6/2023	Amazon.com	Tools	Purchased	Center punch, deburring tool, acorn nuts, epoxy	$113.24	$0.00		$5,414.50
1/11/2023	MateROV	Miscellaneous	Purchased	Mate Registration	$250.00	$0.00		$5,164.50
1/22/2023	Amazon.com	Electronics	Purchased	Photorisistors, LCD screen, Voltage Regulators	$27.53	$0.00		$5,136.97
1/25/2023	Amazon.com	Hardware	Purchased	Caribiner, Battery Holder, syringes, plastic frogs	$30.75	$0.00		$5,106.22
1/25/2023	Amazon.com	Electronics	Purchased	5v Relays, Potentiometers, resistors, USB-A Cables	$101.65	$0.00		$5,004.57
2/3/2023	Amazon.com	Electronics	Purchased	Adjustable power supply, servo tester, USB 4 pin	$97.32	$0.00		$4,907.25
2/3/2023	Amazon.com	Hardware	Purchased	Savox Waterproof Digital Servos	$385.64	$0.00		$4,521.61
2/10/2023	Amazon.com	Hardware	Purchased	Standoffs, Test Tubes, Threaded Brass Rod	$69.65	$0.00		$4,451.96
2/14/2023	Amazon.com	Electronics	Purchased	Switches, cat5 patch cable, pcb board, 5v Leds	$104.78	$0.00		$4,347.18
2/15/2023	Amazon.com	Electronics	Purchased	Arduino Uno, USBc adapter, HDMI to USBc, step down	$227.02	$0.00		$4,120.16
2/24/2023	Amazon.com	Hardware	Purchased	liquid tape, 10-24 6inch tap, anderson connectors	$64.09	$0.00		$4,056.07
3/2/2023	Amazon.com	Electronics	Purchased	Breadboard, 18AWG wire, 30amp relay, 4-pin connectc	$80.95	$0.00		$3,975.12
3/9/2023	Amazon.com	Materials	Purchased	Gray 1.75 PLA, White 1.75 PLA, Orange 1.75 PLA	$79.47	$0.00		$3,895.65
3/11/2023	Amazon.com	Hardware	Purchased	Stepper Motor, Tubing, Aluminum End Cap, Driver	$138.35	$0.00		$3,757.30
3/12/2023	Amazon.com	Hardware	Purchased	RJ45 panel mount, RJ45 port/extension, npt tap	$43.56	$0.00		$3,713.74
3/16/2023	Amazon.com	Electronics	Purchased	100ft wire, 50pc lever connectors, 50ft 12AWG wire	$79.96	$0.00		$3,633.78
3/16/2023	Amazon.com	Tools	Purchased	Srep drill kit, tap and die kit, cam clamps, t-track	$111.17	$0.00		$3,522.61
3/22/2023	Fusion 3D	Hardware	Purchased	Printer Extrusion Head, Z-axis leveler	$112.42	$0.00		$3,410.19

REFERENCES

Blue Robotics Co. Website (2023, February 24). Retrieved March 2, 2023, from https://bluerobotics.com/

DeepWater Exploration Co. Website (2023). *Deepwater exploration*. Retrieved March 2, 2023, from https://dwe.ai/products/explorehd

MATE ROV Competition Website. (2023). Retrieved March 2, 2023, from https://materovcompetition.org/thechallenge

AutomationDirect Website (2023). Retrieved March 2, 2023, from https://www.automationdirect.com/adc/home/home?gclid=CjwKCAiAr4GgBhBFEiwAgwORrSDsTXMDE71JUr8CDTL088v9Isz5PE4s70s7XC2MsDnYDe3pdfizjRoCYJAQAvD_BwE#bodycontentppc (n.d.). Retrieved March 2, 2023

ACKNOWLEDGEMENTS

As we have prepared for the 2023 competition, individuals and businesses have provided support to our team by donating money, time, and expertise. WhaleTech Robotics would like to thank the following for their continuous help and support.

- MATE Center and Gray's Reef National Sanctuary for creating the 2023 missions and organizing the competitions.
- MATE sponsors (Marine Technology Society, Marine Technology Society ROV Committee, National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), Oceaneering, Marine Technology Society, Teledyne Marine, Martin Klein, Eastman Foundation, BlueRobotics, Bulgin, Kingsport, Eastman foundation, Global Ocean Biogeochemistry Array, Niswonger Foundation, Fritz Stahr and Erin Moore, Blue Trail Engineering, and Motorola Solutions Foundation.
- Huge shout out to our Bronze Team Sponsors for helping support our program for the 2022-2023 build year.
- Thank you to our sponsors for their generous support
- Brenda Morris for sponsoring our team shirts.
- Geoff Gardener and Heather Brozowoski for providing us with their time and team management skills.
- Our Families for their encouragement and support throughout the year.
- Mentors - Glenn Lewis and Rocco Leach.