ORION
TECHNICAL DOCUMENTATION

MATE ROV 2019

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1. ABSTRACT

M.I.A. Robotics is a 21-person company of interdisciplinary students from Alexandria University. This being its sixth year at the MATE ROV Competition, the company has accumulated expertise in the field of underwater robotics along the years. With a steady pace towards improving the performance of each ROV, the company devised new solutions to tackle this year's tasks.

In response to the MATE Organization and Eastman Foundation Request For Proposals, M.I.A designed Orion with the Boone dam area in mind. With more powerful thrusters and better imaging system, this year's design was tailored to perform dam inspection and repair, monitor water quality and restore fish habitat, and recover sunken artifacts using a lift bag. It has been manufactured from high-quality components and machined using modern manufacturing techniques like Computer Numerical Control (CNC) milling and 3D Printing.

Orion comes with a compact peripheral, the Micro-ROV, that enables it to explore parts where
navigation is limited, offering an HD video feed that is displayed on the Topside Control Unit (TCU) next to the main ROV's feed.

The following technical documentation records the process of designing Orion from blueprint to finish along with the challenges, lessons learned, and reflections from the company's seniors and mentors.

Figure 1. MIA ROBOTICS team members

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2. DESIGN RATIONALE

A. DESIGN EVOLUTION

At M.I.A Robotics, we strive to manufacture ROVs that are stable and efficient. This year, we started by studying previous designs, extrapolating their advantages and limitations, and putting great importance on reusing parts that are still operable. The result is an ROV that encompasses many years of research and development.

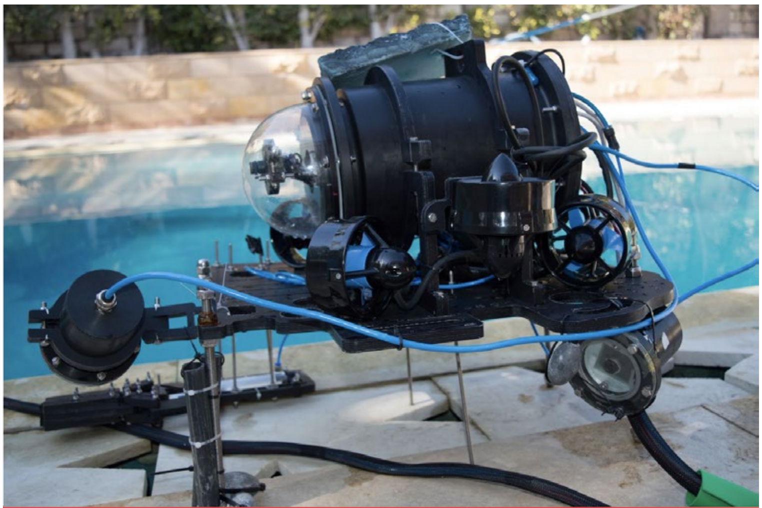

Figure 2. Orion

With the introduction of the baseplate, more mechanisms and tools can be installed on the ROV. This aided greatly in mounting the cameras, mechanisms, and electronics housing. Since speed is a key factor to the success of an ROV, Orion's four horizontal vectored thrusters and two vertical thrusters have been upgraded to provide higher speeds, more degrees of freedom, and better maneuverability.

Software development continued this year by implementing computer vision techniques to tackle this years' mission tasks. Orion's software utilizes OpenCV libraries to perform more intensive computer vision and image processing algorithms than the ones implemented in the past years. Since real-time processing is essential for this year's missions, we had to optimize our software such that it employs multithreading techniques to capture and process frames with high speed and low latency.

An additional improvement to the electronics system is the new arrangement of circuit boards. With the help of 3D visualization software, Fusion 360, the electronics team envisioned the boards early on and devised the optimal arrangement. The new arrangement is 20% more serviceable and efficient, allowing for putting more control boards in a smaller housing. The introduction of the micro-ROV enabled Orion to explore and inspect pipes that are inaccessible due to its relatively larger size.

B. MECHANICAL DESIGN

● Frame

The frame (Figure 3.) was designed to offer high reliability and functionality upon carrying out all tasks and missions in addition to offering lightweight, serviceability, and ease in assembly of the vital ROV components.

The frame is made of HDPE specifically chosen for its cost-effectiveness, high machinability, and its non-corrosivity and conductivity. It also excels in having a density of (970 kg/m^3) which achieves better stability and buoyancy effects.

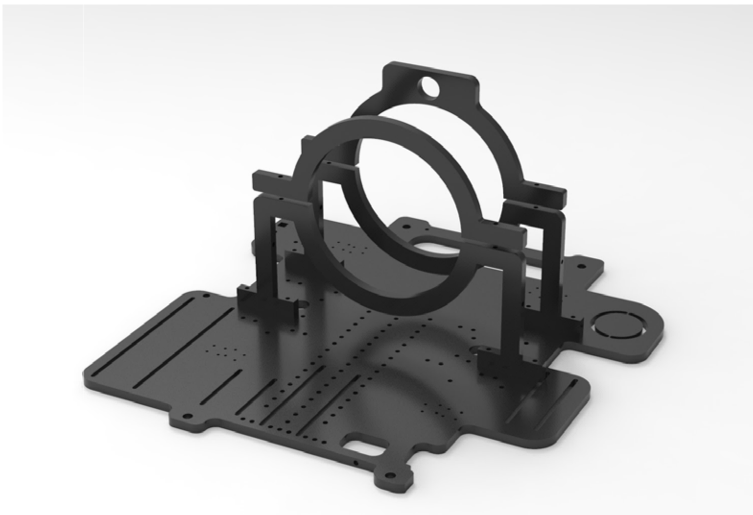

Figure 3. Frame

Two main caps exist on the top deck of the frame which aid in maintaining the electronic housing in position. The left and right sides of the caps hold the vertical thrusters. The caps are mounted on the main base using (M5) bolts. The main base rests on four main (M10) rods of length (17.5cm) with the purpose of facilitating the installation of mechanisms and providing them free desirable space to operate in ease.

The slots within the baseplate aim to facilitate the installation of the various types of the pre-designed mechanisms required for the tasks. In addition to the fixation of four thrusters, camera holders and the Micro-ROV housing.

CFD

Computational Fluid Dynamics study has been applied to the ROV for visual examination of the flow field features along the domain enclosing the body of the ROV, test the endurance of the vehicle to the pressure forces acting on the body due to the sudden conversion of kinetic energy into pressure energy, and to estimate the drag and lift forces. (Figure 4.) shows the pressure distribution along the vehicle which illustrates the advantage of using a semi-sphere as the first part facing the flow, this leads to a significant decrease in drag as the streamlines flow smoothly alongside it. (Figure 5.) is a flow visualization of the streamlines and illustrates the velocity variations throughout the flow domain of the ROV. The solution computed shows that the drag force is (25 Newtons) and the lift force is (-7 Newtons) which interprets the need of a flotation system to counter the negative force acting to sink the ROV. The solution to this problem is illustrated at the buoyancy section. (Look at Buoyancy section) (The case is solved for the ROV moving with (0.6 m/sec)).

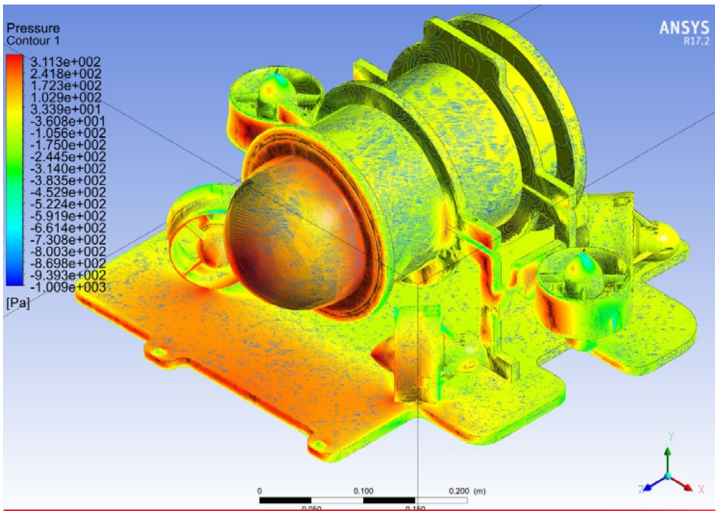

Figure 4. Pressure Distribution

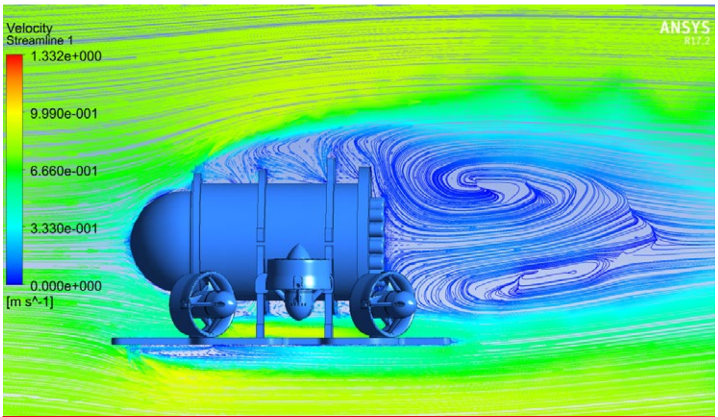

Figure 5. Streamlines Visualization

Propulsion

Ten Rule 1100 GPH bilge pumps were utilized to actuate Osiris - the predecessor of Orion. Despite their simplicity and low-power consumption, they did not offer sufficient thrust force to drive the ROV, especially in the vertical direction.

With a drastic reduction in the number of thrusters, Orion is powered by six T-200 brushless thrusters from Blue Robotics . This reduction has proven to have a significant effect on the ROV performance and maneuverability since the T200 thrusters have a higher thrust-to-physical size ratio than those of the bilge pumps, providing a stronger advantage towards the accomplishment of more free space that allows the installation of the mechanisms required for the tasks.

However, the T200 thrusters suffer a disadvantage of high-power consumption, yet this is only considered at high-speed operations. This is concluded from the equation of drag (D=2σAV^2Cd), that shows that drag force is directly proportional to the square of the velocity, and hence does not hinder Orion's operation, as the maximum speed required is of a safe region considering the drag force interruption.

Achieving better maneuverability and introducing lateral translation, four equally spaced thrusters are placed on a common plane and are vectored at 45° angles in the corners. Two vertical thrusters are placed on the vehicle's fore and aft sides. Thus, the vehicle can achieve four degrees of freedom (DOF) translations (Surge, Sway, Heave, Yaw). This configuration allows the thrusters to contribute the power efficiently towards better propulsion and minimizes the flow interference, taking into account overcoming drag interrupting the vehicle and the drag of the tether.

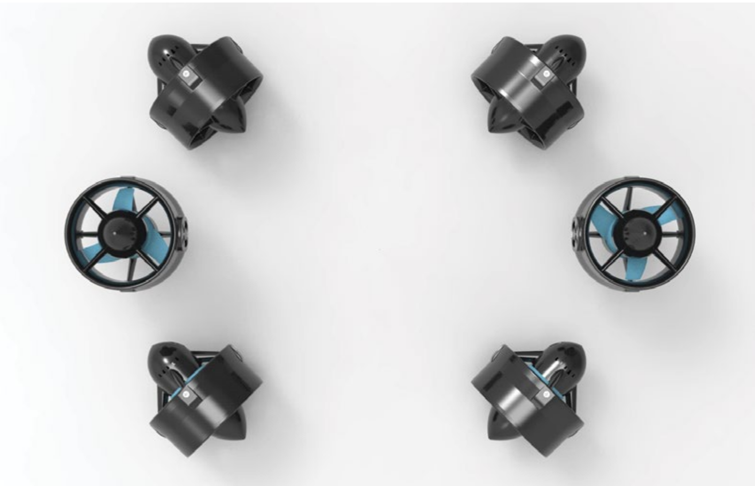

Figure 6. Thrusters Configuration

Buoyancy and Stability

One of the major challenges that have faced the mechanical team was the stability configurations. Our goal is to achieve smooth suspension of the vehicle in water for better navigation, obtaining neutral buoyancy underwater, and making the buoyancy force slightly higher than the vehicle weight as this will directly affect safety and maintenance issues. This is key, since the vehicle has to be slightly floating if the power turns off suddenly for any reason.

To achieve the main design consideration for the product vehicle which is the accomplishment of all required tasks. The outcome of this consideration is the design of a number of mechanisms (also taking into account the frame and electronics housing) which occupied a considerable amount of space in addition to their weight. The final design mass of the ROV after assembly was equal to (19000 grams). The mass of the displaced water (which causes the negative buoyancy effect) was (16200 grams). This variation in the vertical forces' components and the tendency of the heavier than water materials to counteract the buoyancy effect shall lead to the sinking of the vehicle.

Several solutions were introduced, the company employed several fixed flotations and constructed a ballast system. The flotation material that should maintain its form and resistance to water pressure at the anticipated operating depth. The company settled on using a lightweight foam which is a rigid polyurethane foam chosen for its low-density, excellent insulating value. They are made in high volumes at a density (29.96 kg/m3) and are reasonably inexpensive. Their stiff, brittle consistency and their propensity to shed dust (friability) when abraded can serve to identify these foams.

Static stability is achieved by placing the flotation at the top. This keeps the Center of Buoyancy (CB) above the Center of Gravity (CG). For ballast configurations, the company chose to use a system of modular lead weights

Quantity	Part Name	Displaced Volume (cm3)	Mass Outside Water (gm)	Total Mass Inside Water (gm)
4	Caps of Frame	139.24	540	379.4
1	Electronics Enclosure	6800	3970.15	-2829.85
1	Grout Mechanism	420	520	100
1	Lifting Mechanism	340	348.27	8.27
1	Main Base of Frame	1860	1979.14	119.14
1	Manipulator	350	370.05	20.05
1	Micro ROV Docking Mechanism	850	1024	174
6	Thrusters	1005	1950	945
Total		11764.24	10701.61	-1083.99

Figure 7. Buoyancy Effects

manufactured in house. The lead was chosen for its high density and low cost.

The previous table (Figure 7.) studies the buoyancy effects of some of the main parts of the ROV in the form of a comparison between its mass outside water (dry mass) and the volume it displaces when immersed. These parts tends clearly affects the buoyancy but their effect is countered by the other heavier than water materials in the ROV as nuts and bolts.

C. ELECTRICAL SYSTEMS

● Tether

Orion’s tether transports the necessary signals, power, and pneumatics’ tubes from the TCU to the ROV. For cable management purposes, black braided sleeving was applied to the lightweight tether (2.8kg) to avoid entanglement, tripping near the pool, and to ensure the safety of the tether technician.
The tether contains two Category 6 Ethernet (Cat6) cables, two 16-American Wire Gauge (AWG-16) DC power cables, and one 4mm pneumatic cable.

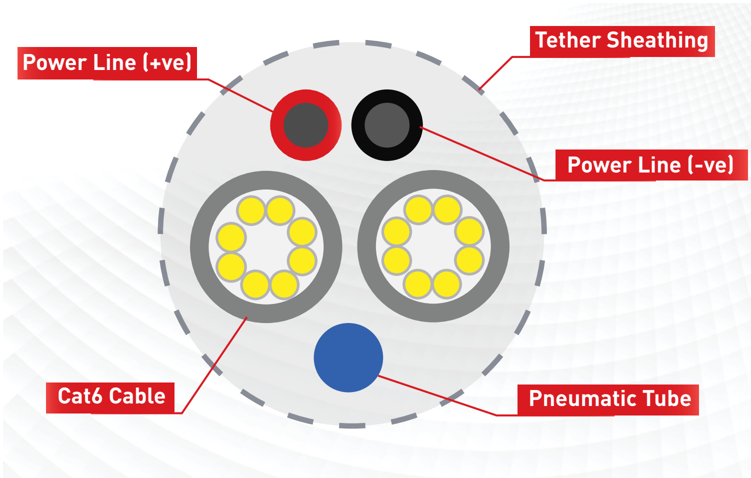

Figure 8. Cross section of ORION’s tether

One Cat6 cables is used to carry the video signals of the four cameras to the TCU, while the other is used to carry signals between the GUI and the Arduino Nano responsible for communication.Cat6 was chosen over alternatives such as coaxial, Cat5e, or Cat4 cables based on its lower crosstalk and higher signal-to-noise ratio, which altogether, minimize the distortion of the video signals during transmission over the 22 m tether.

AWG 16 was chosen for its low resistance, minimizing voltage drop over the tether's length, and carrying the ROV's current efficiently. The power cable is sized for the maximum current draw of 18.58A. The power cable has a tested resistance of 0.53 ohms and with the full load current drawn, the maximum voltage drop on the power cables equals 18.58 * 0.53 ohms = 9.8V this gives the ROV a minimum operating voltage of approximately 38V.

Imaging system

Four 3.6mm Analog - CCTV cameras were chosen for the imaging system of the ROV for their low-light capability and their wide-angle (109°) view, allowing for more objects to fit inside the frame. Another advantage of the cameras is their small size which allowed us to reduce the size of their sealed casing, which is significantly smaller from last year's, and consequently reducing their overall weight.
Unlike last year, where the ROV relied on a single gripper to perform the tasks and a single camera - besides the main view camera- was required, several mechanisms are installed on the ROV -as referred in the mechanical design section, and thus each mechanism requires its own dedicated camera, which is why four cameras were installed.

- One camera is used as the primary vision for the ROV.
- A camera used to achieve a clear view of the gripper.
- A camera used to view the grout mechanism.
- Another camera is used for viewing the lift bag to be attached to the cannon.

All cameras are connected to a four-channel Analog High Definition Digital Video Recorder (AHD DVR) which can support camera resolutions of up to 1080p. The cameras' signals are transferred to the TCU through Cat6 ethernet cable terminated by video baluns connected to the DVR for noise reduction and signal amplification.

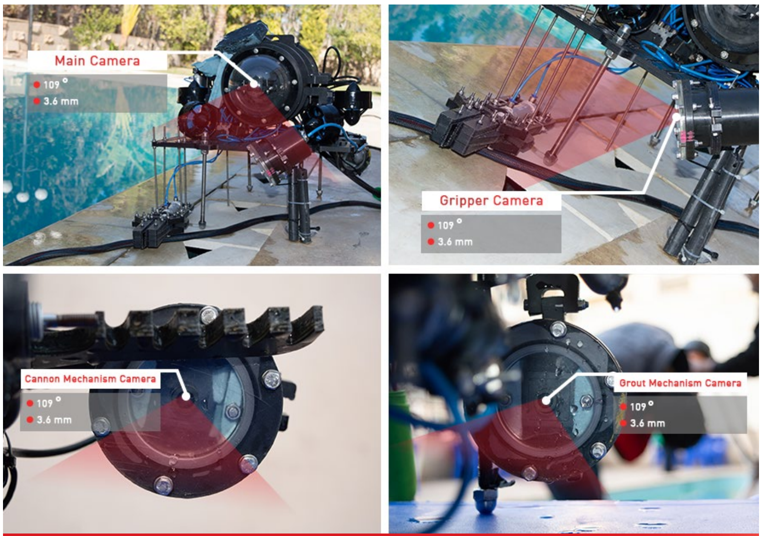

Figure 9. Cameras' FOV

The top-side laptop can receive the cameras' feed from the DVR and perform the needed image processing on them by connecting them to the DVR through an ethernet port.

Electronics Housing

After reviewing the printed circuit boards' (PCB) designs from last year, the team came to the conclusion that better space management is critical. Cylindrical-shaped power boards' designs were proposed to circumvent the issue. The new PCB arrangement focuses on modularity, serviceability, and cable management.

Using Fusion 360 for PCB visualization (Figure 10.)has enabled us to ensure that Orion's electronic components and connections have achieved optimal positioning which resulted in shorter and straightened wires to prevent muddles.

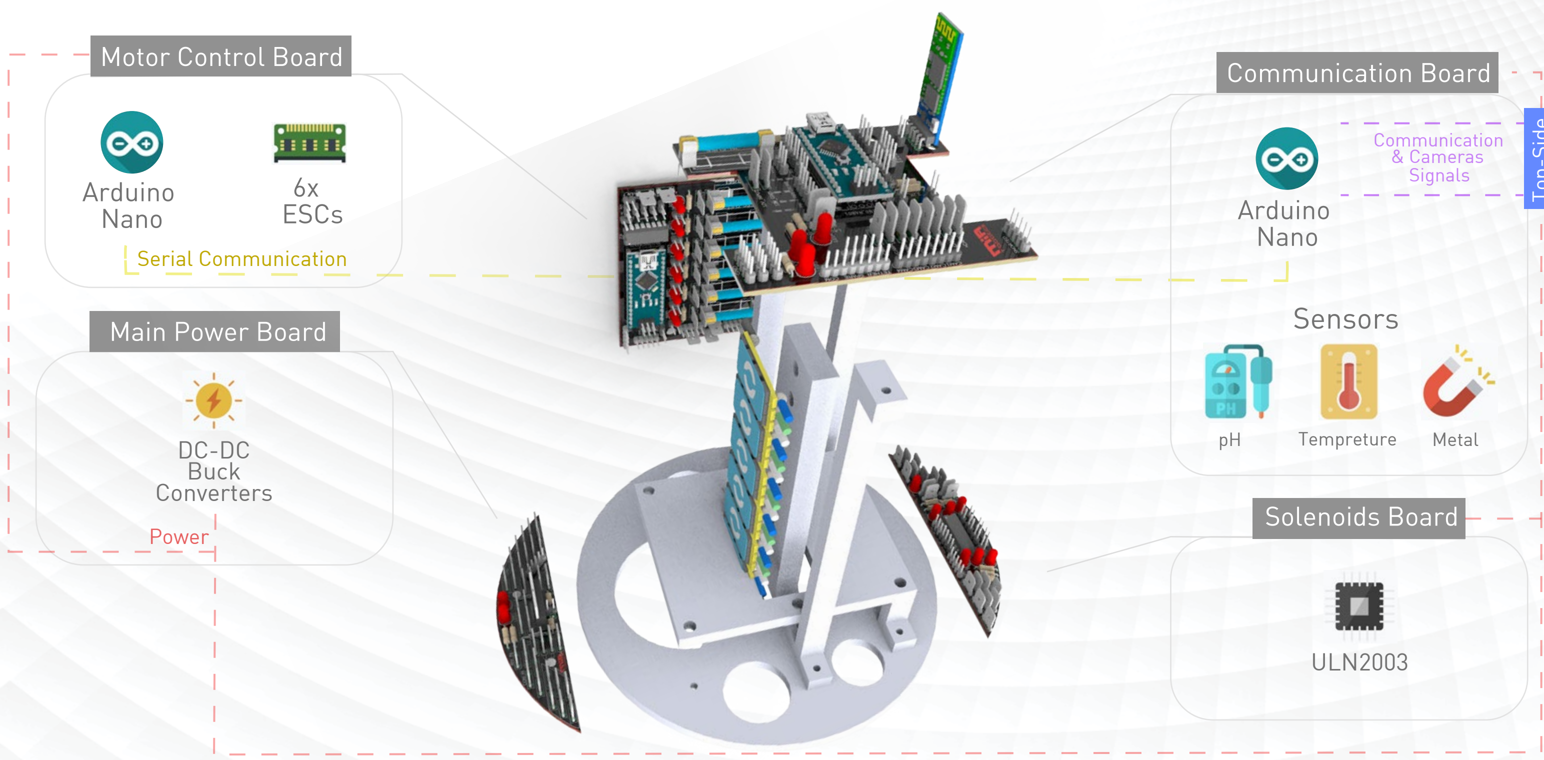

Figure 10. Exploded-View Of The Structure

Orion's electronics system consists of 4 PCBs: two semi-circular boards, an H-shaped board, and a rectangular board. All boards have LEDs on them to indicate that the power is delivered to all electrical components of the ROV and to assist the hardware team during troubleshooting.

The first semi-circular board is the main power board which is responsible for distributing the power driven by the MATE power supply to the DC-DC buck converters, and from the converters to the whole system. The second semi-circular board is equipped with a ULN2003 which is responsible for driving the various solenoids present in the ROV when receiving control signals from the main controller. Due to its small size, ULN2003 was a perfect candidate for driving the solenoids compared to using transistors, and hence it was our choice.

The rectangular board, consisting of an Arduino Nano and six Basic ESCs, is responsible for delivering power as well as driving signals for the six Basic ESCs' to control the six thrusters. Due to the high power consumption of the T200 thrusters, which results in an unstable output voltage of the converters; software and hardware constrictions are applied to guarantee that the current draw doesn't exceed 10A per thruster.

After reviewing the performance chart (Figure 11.) of the T200 thruster it was found that an input signal to the ESC within 1170 to 1830 microseconds would result in a current draw of less than 10A. Therefore, the software ensures that the input signal is always within the range of 1200 to 1800 microseconds.

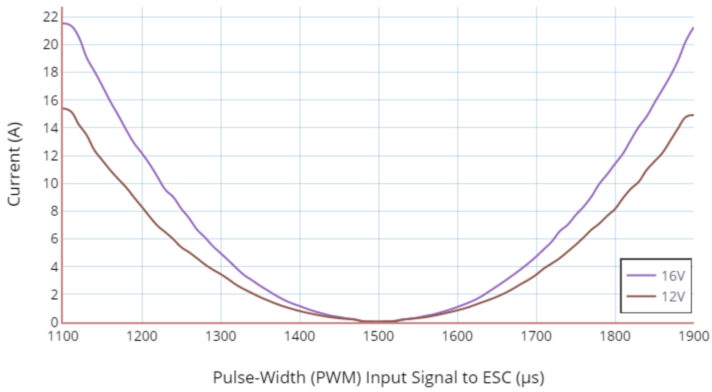

Figure 11. Performance Chart

For the hardware solution, a 15A fuse is connected to the input of every ESC to prevent damage to other sensitive devices in case of an increased current draw. The components of the board are designed in a manner that facilitates the replacement of the Arduino for firmware updates or any blown fuse.

Finally, the H-shaped board consists of an Arduino Nano responsible for sending the sensors' readings to the topside GUI. The board also drives the signals of the ROV's cameras and communication signals of the Arduino to the two Cat6 cables of the tether.

Sensors

Orion is equipped with a variety of sensors providing precise measurements and real-time telemetry. GAOHOU PH0-14 pH sensor is utilized to measure the pH value of an in-site water sample. The sensor consists of a probe accompanied by a circuit that analyses the probe's readings. These readings are then processed in the GUI providing the actual value of the pH. DROK DS18B20 temperature sensor is used to measure the water temperature with an accuracy of ±0.5 °C. Its thermo probe is a stainless steel probe head which makes it suitable for wet and harsh environments. AUTONICS PR30-15AO inductive proximity sensor is employed to differentiate between the metal cannon shells and the non-metal debris. It was chosen for its relatively high range of 15mm.

D. SOFTWARE

The software team gathered to review its strengths and weaknesses, determine the defects of last years' software, and lay down the software development timeline. A training period was allocated early this year to improve the software development and relay past experiences to new company members. We continued with last year's strategy of implementing simple, yet efficient software architecture that is divided into two layers; Top side and Bottom-side. The Top-side layer was developed using Qt Framework and coded entirely in C++, as for the Bottom-side, it was developed in C++ using Arduino Boards.

C++ language was chosen for its speed and efficiency and Arduino Nano Boards (microcontrollers) were used to take advantage of their small size in order to reduce the tube's volume, facilitate the boards' design. For the tasks including image processing, we decided to work with OpenCV library due to its comprehensive documentation and the availability of online resources for it.

Figure 12. Metal/Temperature/pH sensors

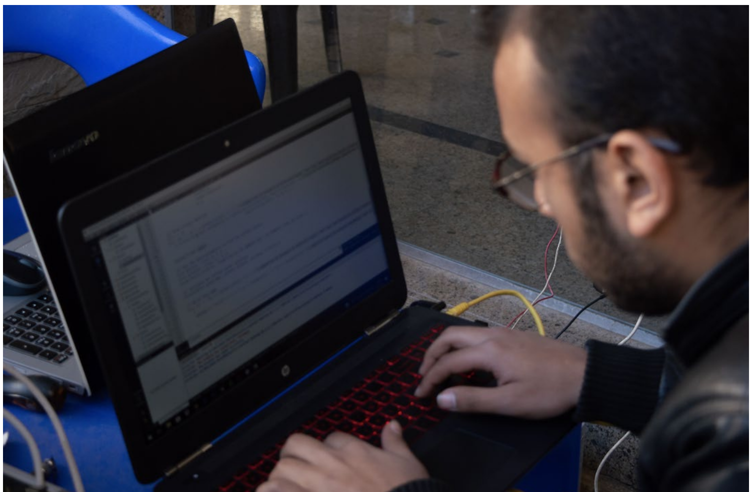

Figure 13. Software Development Phase

● Top-Side

The Top-side Control Unit (TCU) controls the ROV through a Graphical User Interface (GUI) that has been developed using Qt Framework. Being a cross-platform software development tool, Qt gave us the ability to develop and run our software on Windows, MacOS, and Linux.

Besides its aesthetic appearance, the GUI's main purpose is to act as an interface between the joystick and Orion, control the thrusters' speeds, and improve the user experience. Navigating between different widgets for each mission in the GUI makes it more organized and user friendly. For better accessibility, the GUI is designed such that it features a pilot Head-up display (HUD) that displays the ROV's telemetry and sensor readings.

The software team was able to encapsulate both the CPU intensive algorithms used for image processing and Orion's control code in the same GUI without needing to implement them in separate applications. This was done by dividing our code into multiple threads that run concurrently, which also reduced latency and made real-time processing feasible.

The emergency cases have also been handled such that if a problem occurred in a thruster causing it to become faulty, the GUI allows changing the mode of operation so that Orion can move laterally with 2 thrusters only instead of 4. This ensured that Orion can still operate and complete the missions with minimal hindrance in motion.

Due to its stability and reliability, the serial communication protocol was chosen. The

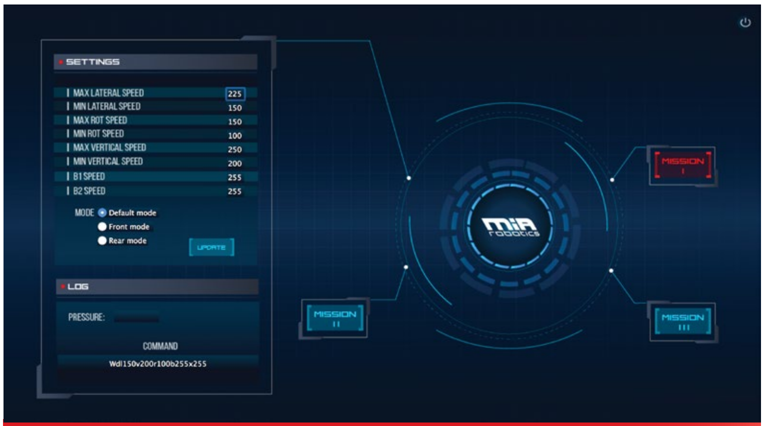

Figure 14. GUI

Universal Serial Bus (USB) to Universal Asynchronous Receiver and Transmitter module (TTL UART) is used to transfer data back and forth between the TCU and the microcontrollers. It also allows uploading Arduino codes directly without replacing the microcontrollers each time a firmware update is needed

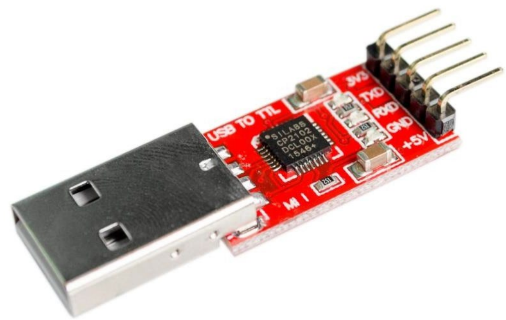

Figure 15. USB to TTL UART

● Bottom-Side

Since all the processing takes place on the Top-Side laptop, we figured that we don't need highly powerful Bottom-Side processing power so Arduino Nano Boards were chosen as Orion's main microcontrollers. The system is composed of two Arduino Nanos, one is responsible for receiving commands from the TCU and sending the ROV's telemetry to it, while the other Arduino is responsible for sending the control signals to the ESCs to drive the thrusters.

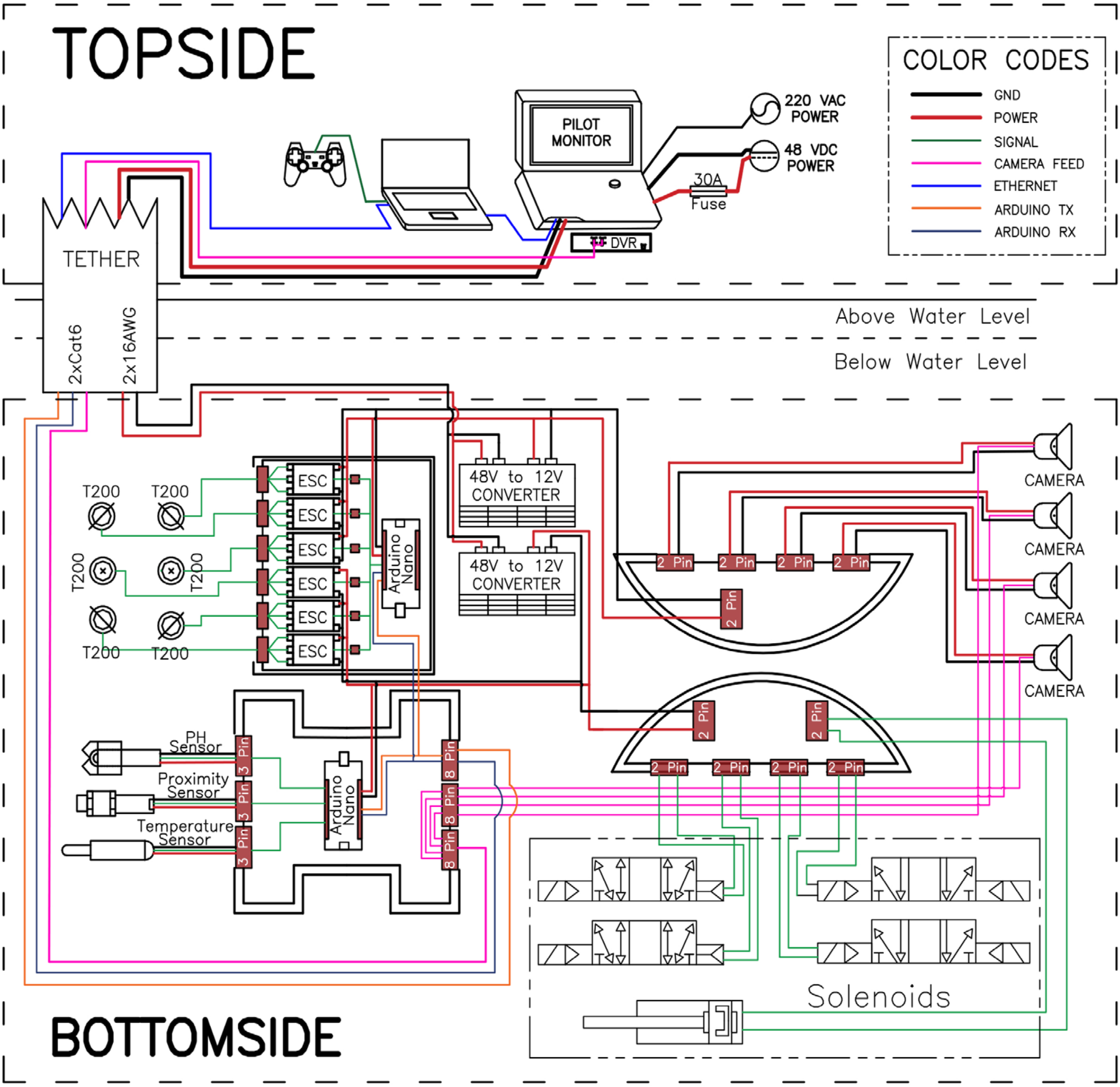

Figure 16. SID

E. FEATURES

● Autonomous Line Following and Mapping

The company has established an algorithm to perform the first mission of the competition with efficiency. One of the challenges we had was to segment the red, black and blue colors into three different matrices so that we can differentiate between the black grid lines, the red line and the crack. We tried to work with different color spaces but found that LAB color space was the best to work with as it's not prone to different lighting conditions like the HSV and RGB color spaces.

After segmenting each of these colors into different matrices, the software starts following the line, calculates the length of the crack when found and maps its location.

When the crack is encountered, the software calculates its length by taking its width as a reference according to the following formula:

$$\textit{Length of the crack} = \frac{\textit{width in cms X length in pixels}}{\textit{width in pixels}}$$

Mapping of the crack's position was very challenging for us to brainstorm and find efficient and general ideas for the task. We developed two algorithms for detecting the crack's location

Figure 17. Mapping Test Run

Algorithm 1:

The software starts by determining the direction of incrementing the rows and columns, and accordingly increment/decrement the ROV's coordinates as it encounters the grid lines. When the crack is encountered, its length is displayed on the corresponding coordinates on a blank grid map displayed in our GUI.

Algorithm 2:

This algorithm was developed to apply to all the possible maps in the competition. The idea is that we use timer that resets each time a turn is encountered to measure the time Orion takes between two consecutive turns which is then subtracted from the time Orion takes to adjust itself on the line. When the crack is inspected, the time to reach the crack is then used to get the position of the crack in the current row/column.

After many test trials, Algorithm 1 was found to be more accurate and reliable in mapping the position of the crack so we decided to use it as our main algorithm for this task.

*More information about autonomous line following, measuring the length of the crack. and mapping its position are detailed in the Image processing documentation.

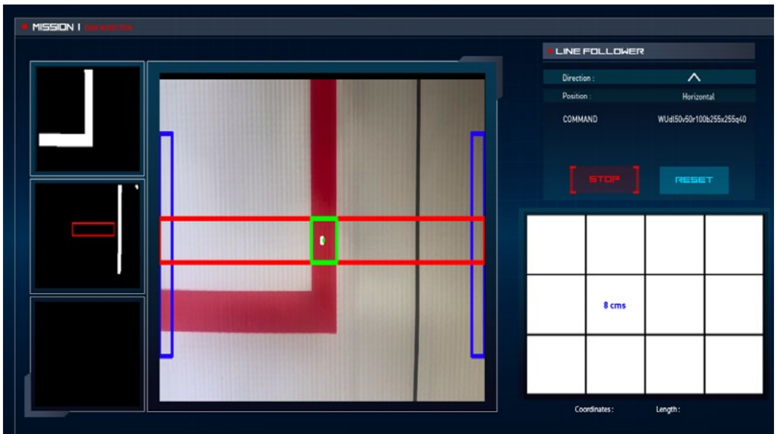

Figure 18. Mapping Widget

Identifying Benthic Species

It deemed impractical if we decided to use a dedicated camera for viewing the field below Orion to detect the benthic species. Using the feed from the camera pointing at Orion's gripper for this task was handy as it provided us with a clear view of the corrugated plastic sheet that the benthic species lie on. The procedure starts by specifying the region where the benthic species lie, after that, the perspective view of this region is corrected to be perpendicularly facing the camera. A snapshot of the corrected view is taken which is then fed into the shape detection algorithm that detects the number and type of benthic species present and displays it on the GUI. (Figure 19.)

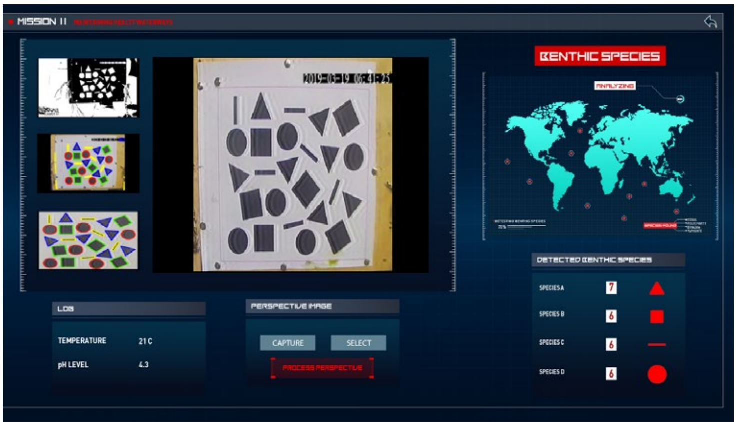

Figure 19. Shape detection widget

*More information about the identification of the benthic species are detailed in the Image processing documentation.

Cannon retrieval and dimensionsmeasurement

The target was to get a reference in the same plane of the cannon to measure its dimensions accurately. We were able to measure the radii of the cannon effectively by taking the dimensions of the brick that the cannon is placed on as reference. However,

Figure 20. Measurements Widget

measuring the length of the cannon with the same method accurately was very challenging due to the fact that the cannon and the brick don't lie on the same plane, along with the dimensions of the brick being too small relative to the cannon's length, so we had to come up with a different method to measure its length.

We came up with an idea to fix a rod of known length on the lift bag and use it as a reference to measure the cannon's length. The ratio between the rod's length and the cannon's length was acceptable and by taking the rod's length as reference, we were able to measure the cannon's length within 1 cm of its actual length. Once the cannon's dimensions are measured successfully, its actual dimensions are then fed into the calculator integrated in our GUI that calculates the cannon's volume, weight, and force needed to lift the cannon.

Micro ROV

Orion is equipped with a micro ROV that is used to inspect the inside of a drain pipe for indicators of possible dam failure. Its simple design consists of a small camera, an Arduino Nano, and one basic ESC controlling a single T200 thruster for moving the micro ROV inside the pipe with swiftness and ease. Since the inside of the pipe might be dark, headlights consisting of small LED strips are used to illuminate the inside of the pipe allowing for a clear view and easy detection of any areas of muddy water flow.

The micro ROV is powered from the main ROV, with a fuse of 7.5A attached to the point of connection to the ROV power. The same software constrictions are applied to limit the maximum power consumption of the T200 thruster to 48W. It was deemed a waste of resources had we used a dedicated joystick to control the micro-ROV, so we developed a system that allows controlling both ROVs from the same joystick by simply using a button that switches between them.

Figure 22. MICRO-ROV

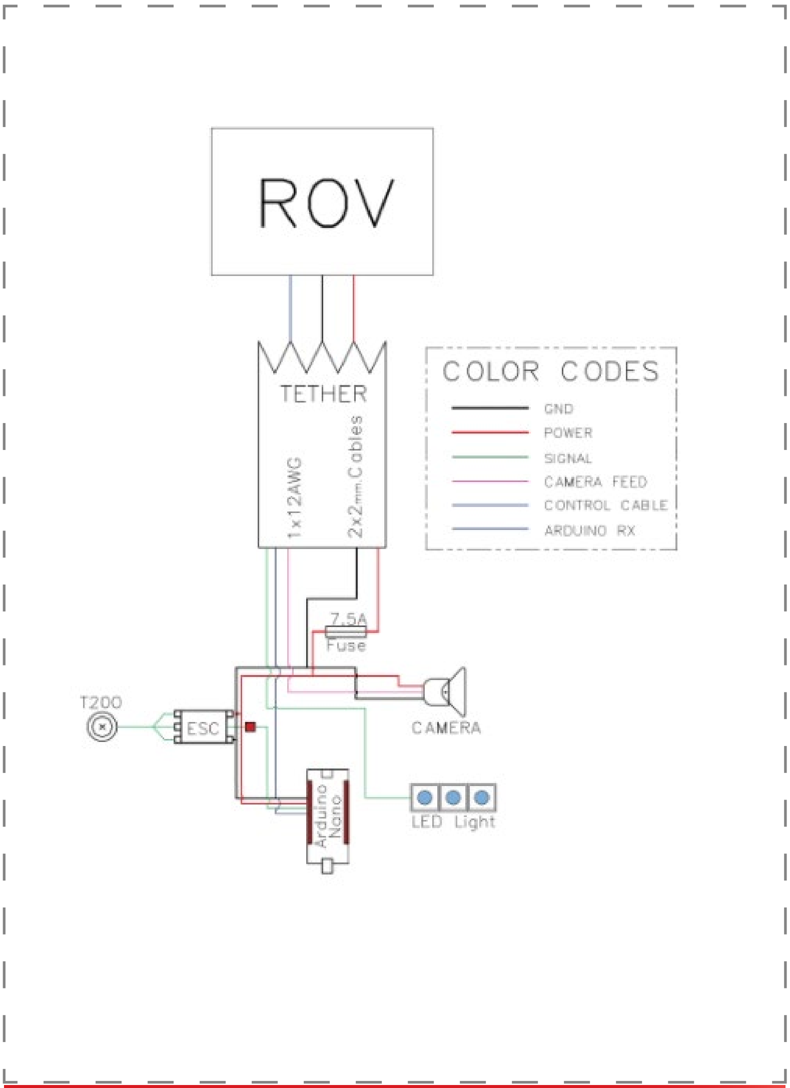

Figure 21. MICRO-ROV SID

Cannon Lift Mechanism

The lift mechanism primarily depends on a piston cylinder, the end of which is coupled with a rod, that connects to two prongs, this allows it to grapple the body of the cannon in a jaw-like manner. Afterwards, to raise the cannon to the water surface, the lift bag connected to the mechanism is inflated. Two solenoids are used to operate this mechanism: the first solenoid actuates the piston in order to grasp or release the cannon, the second one is used to inflate the lift bag.

Figure 23. Lift Bag

Cup Mechanism

Introducing further solutions towards carrying out various required tasks, this mechanism was designed mainly to hold the grouts and deploy them into the cup underneath the water. But after further development to the mechanism it was able to carry out other tasks. This approach provided us with some other free space in the ROV that we can use to secure other mechanisms performing other tasks.

The operation of the mechanism is driven by a pneumatic piston of (2.5 cm) stroke, alongside the piston exists a PVC housing that maintains the grouts in position with two links in the bottom that could be easily opened and closed using a solenoid valve. The housing and the links were manufactured of HDPE material.

The company faced many challenges within designing this mechanism. Some of which was with the fabrication of the mechanism till reaching the final design. In addition to some problems with the piston stroke and the dimensions of the links, as the bottom links could not open or close the required distance that could enable the grouts to flow into its final destination.

After further modifications and troubleshooting, we finally reached the optimum design with enough piston force. We improved the mechanism's efficiency by enabling it to do other tasks as putting the trout fry at the same cup of mechanism. We also added two links that have the shape of (L) fixed at the end of mechanism in order to hold the tire from the water up to the pool side. This approach corresponds to the canon lift mechanism which uses similar links to grip the canon. This approach has also proven to be of great advantage towards carrying out lifting the tire task with minimum effort and great efficiency, that we did not have to develop another mechanism for that specific task.

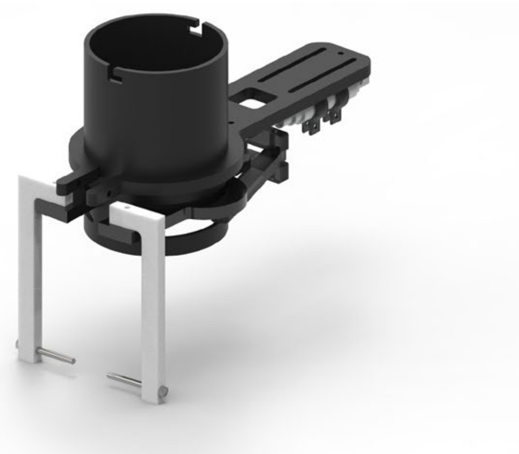

Figure 24. Cup Mechanism

Manipulator

The ROV is equipped with a multifunctional, pneumatically-actuated four-bar mechanism designed to clamp different objects underwater. Its end effectors can hold cylindrical objects that are up to 10 mm in diameter. The piston's forces vary from (199 Newtons) forward to (171 Newtons) backward to make sure that objects are locked firmly between its ends. Slots are used for pilot assistance providing various positions of the gripper. The gripper is fabricated out of 100 mm High-Density Polyethylene (HDPE) using CNC laser machine. End effectors are attached with rubber to increase the friction with objects underwater.

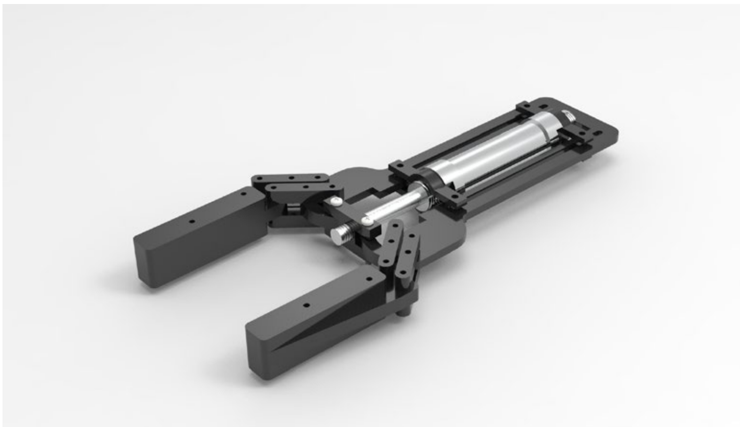

Figure 25. Manipulator

Tee Release Tool

The Tee release tool is a compact, quick and lightweight tool that will allow Orion to throw the markers in no time. The tool consists of a piston cylinder fixed on top of it a comb like HDPE part where markers are kept at uniform intervals. After the detection of metal cannon shells/non-metal debris, the piston rods takes even steps back allowing the release of the markers one after one.

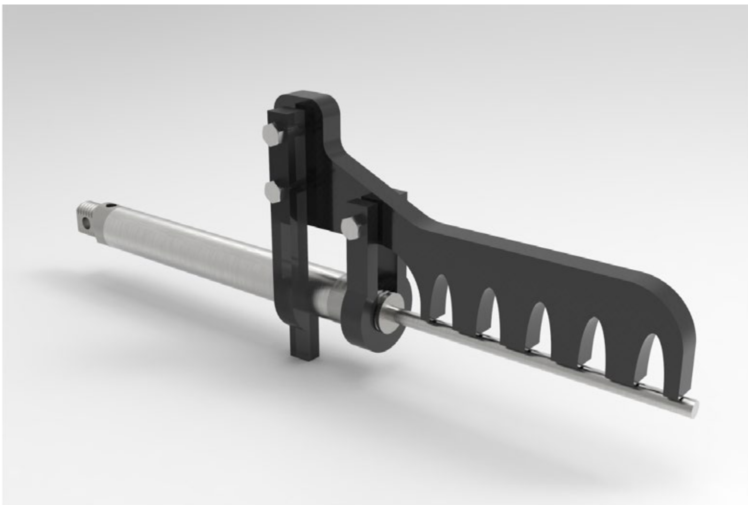

Figure 26. Tee Release Tool

3. TESTING AND TROUBLESHOOTING

We designed Orion's systems in a modular way that made troubleshooting easier. The troubleshooting process starts by initiating small test runs until locating the root problem by eliminating the other elements and isolating the faulty module. The module is then unit-tested to diagnose the error and to assign the suitable solution for it. The tests began by performing dry test on Orion's basic functionalities which was followed by placing the vehicle into a practice pool to test its underwater capabilities.

Afterwards, Orion's performance and stability assessment in completing the missions took place. Throughout the testing phase, modifications never stopped in order to increase Orion's efficiency in completing the tasks. The main advantage of long duration tests is the ability to discover hidden problems that wouldn't emerge otherwise. Stated below are the strategies followed to test every subsection of the vehicle before it was assembled.

ELECTRONICS ENCLOUSER SEALING TEST

The aim of this test is to ensure that the electronic enclosure sealing was perfect even in a very high-pressure head range compared to the maximum pressure head ROV may reach in the competition. Test starts by filling the electronics enclosure with water and increasing pressure gradually using hydrostatic pressure test unit until 1.2 bars pressure is reached as this pressure is optimal for our test as it means that our ROV could be operated in pressure head reach 12 meters of water and this was high pressure head compared to maximum pressure head in competition which was 5 meters of water.

PNEUMATIC SYSTEM TEST

Our company put great attention to ensure proper connectivity regarding pneumatic circuits through testing them several times by assigning all needed pneumatic components to enhance safety and performance of the pneumatic system used in our ROV.

GRIPPER TEST

The purpose of this test is to check if it is suitable enough to do the required missions with the minimum power losses due to friction or any other forms of power loss. So, our company prototyped the gripper to predict any malfunctions that may occur and devise solutions beforehand. As a result, the piston stroke was found to be not suitable enough to hold objects tightly, also the friction between links was relatively large. Increasing piston diameter and stroke to overlap the friction losses fixed that issue. Another problem we encountered was that the end effector surface finish was smooth and required adding a rubber layer to provide more friction for a better grip.

ELECTRICAL TEST

Our main concern was the stability of Orion's electrical system. We had to make sure that the voltage converters can supply stable power to the system even under full load. Our tests showed that the main power-hungry components were the thrusters, each drawing over 9A under full load. Because of their high power consumption, and the fact that we are using six of them, the thrusters had to be distributed such that a maximum number of three thrusters are connected on the same converter. This was achieved by connecting two of the four lateral thrusters plus one of the two vertical thrusters on one converter, while the other thrusters, as well as the communication board's power, were connected to the other converter. Since Orion can either move horizontally or vertically at a time, this ensured that no more than two thrusters can draw power from the same converter.

4. CHALLENGES

TECHNICAL

● Power Cables

Earlier this year, 18-AWG was used as the main DC power cable, but due to its high resistance of 20mΩ/m, the voltage drop across the cable was high. At full load, 16.35V was the voltage drop and the power converters would shut down due to the low input voltage to the rated minimum input voltage of 38V. To mitigate this issue, a cable with lower resistance had to be chosen. It was found that 16-AWG with its moderate resistance of 12.5mΩ/m would fit our power specifications.

● Metal Cannon Shells Detection

For detecting the metal cannon shells, a permanent magnet was used but was found to be unreliable due to its small size. And since a larger magnet will be impractical, a metal detector sensor was used in order to be more reliable. PR08-2DN inductive proximity metal detector was our first choice amongst various models for its small size, but its detection range of 2mm was too small which required direct contact with the metal for it to be detected. Finally, AUTONICS PR30-15AO was tested and it was found to be very effective, not only for its range of detection (15 mm), but also for its larger detector area which made the detection process much quicker and simpler.

● Micro-ROV

At first, the micro ROV was designed with a bilge pump as its main thruster, but it was found to be extremely slow to fulfill our needs. So, a single T200 thruster was our second choice for its considerably higher speed and efficiency compared to the bilge pump.

NON-TECHNICAL

Funding was a major issue since the company had to assume almost full responsibility for its income as self-funding accounts for 76% of the total income. To overcome this issue, the company started reaching out to local organizations for sponsorships. Limited pools and lack of testing areas also proved to be a challenge. After contacting a few sporting clubs and private pools, the company managed to find facilities that allowed testing the ROV at their pools.

Also, one of the biggest challenges was adjusting to new leadership; The CEO, CFO, CTO, and the mechanical department lead were in new roles this year, and hence had to quickly learn their duties as they were expected to lead their respective groups while on a very limited timeline. Once the timeline was laid down, everything followed in order and the company functioned smoothly.

5. LESSONS LEARNED

The electronics department knew early on the advantages of using a 3D software to visualize the end product and utilized it accordingly. Autodesk Fusion 360 helped them plan the positioning of all components starting from the power terminals to the fuses and how all the control and power circuits will be integrated into the system. For marketing purposes, the mechanical department learned to use Keyshot for providing realistic renders that are planned for use in media outreach.

Figure 27. Robotics Session

Improving management skills by assuring workload is evenly shared and maintaining good line of communication between different departments during weekly meetings was crucial. This was discovered to have an impact on ensuring appropriate progress was being made in a timely manner.

Giving back to the local community is one of the core values that has shaped M.I.A. Robotics throughout the years. This year we conducted a number of sessions in the fields of Robotics. Company employees learned how to engage with others, prepare educational content, and coordinate training sessions. The main targeted age group was children from the ages of 8 to 12. Their enthusiasm was evident and they were eager to learn more about the STEM field.

6. FUTURE IMPROVEMENTS

PID CONTROLLER

One of the scheduled key improvements is the Proportional Integral Derivative controller (PID). The growing trend of autonomous vehicles has called for more independent control from the ROV on its depth and orientation. Adding a pressure sensor and an Inertial Measurement Unit (IMU) will provide the system with real-time values of the ROV's depth, pitch, roll, and yaw.

DOUBLE-LAYER PRINTED CIRCUIT BOARDS AND SURFACE MOUNT TECHNOLOGY

PCBs dimensions are one of the principal constraints to the size of the electronics housing. Using double layer Printed Circuit Boards (PCB) and Surface Mount Devices (SMD) will considerably reduce the housing's diameter and length. This will reflect on the ROV's weight and overall dimensions.

7. SAFETY

A. COMPANY SAFETY PHILOSOPHY

At M.I.A. Robotics, we believe a safe workspace is crucial to produce a suitable environment to design, manufacture, and test. We always strive to meet MATE's safety requirements by ensuring all MIA personnel adhere to the safety protocols and warning labels. Our safety philosophy is centered around the welfare of the crew and always putting the employee's safety before the machine. In order to comply with MATE's safety regulations, a set of workplace guidelines and protocols are carried out during manufacturing and prelaunch.

B. SAFETY PROTOCOL STANDARDS

- Assigning proper PPE and avoiding actions that carry a potential for injury.
- Inspecting equipment prior to use.
- Using proper technique when using any sharp tools.
- Using vice of proper size and capacity to hold work object.
- Using a barrier around a piece of equipment being pressure tested.
- Stop work when an unsafe condition or act could occur during operation; If in doubt, Stop the job.
- Using insulated electrical tools including insulated fuse pullers, hand tools and drills.
- Before working on any electrical equipment, it must be de-energized.
- Systematic safety checks are performed before every test.

C. LAB PROTOCOLS

At the beginning of each year, senior employees mentor juniors on how to use tools and machinery and how to replace worn out parts in case of damage. All crew members are committed to following lab protocols set by senior team members. Wearing protective clothing, safety goggles, and appropriate non-slip shoes is essential during operation. In addition to this, periodic safety checks are performed prior to deploying the vehicle in the water.

Figure 28. Power Supply Kill Switches

D. SAFETY FEATURES

As required by the MATE Organization, a suitable-sized fuse is connected 30 cm from the Anderson Power-pole connectors. Strain-relief is applied to the tether on both ends to prevent strain on the connectors and ensure uninterrupted connections. Acrylic shrouds cover the thrusters' intake and exhaust without disrupting flow. kill-switches are present on the main power supply unit on the TCU. Power terminals are fused to provide overcurrent protection. Moreover, fuses are strategically placed on the power boards for quick debugging and replacement. The electronics housing, thrusters, and cameras are waterproofed to prevent short circuits or exposing personnel to any danger. Warning labels exist on the thrusters and electronics housing. The camera compartment is physically isolated from the electronics housing with the use of O-rings. The clear acrylic dome housing the camera allows for visual inspection in case of any leaks by searching for water droplets.

Figure 29. Shrouded Thruster

8. PROJECT MANAGEMENT

A. COMPANY ORGANIZATION

The company is organized into three main departments: Mechanical, Electrical, and Software. All team leads meet on a daily basis to discuss progress and propose changes to the designs according to how well they perform on the tests. Weekly company-wide meetings take place to brainstorm new ideas and set deadlines for the week after. Employees are assigned technical and non-technical roles to maximize productivity.

Prior to starting this year, a two-week training program took place in mid-August to train junior employees the basics of C/C++ programming languages, electronics, manufacturing methods, Computer Aided Design, and fluid simulation. After each training session, junior employees were tasked with assignments for performance assessment purposes. The results of these assessments determined the power points of each employee which later helped the board members assign specialties to the right candidates.

B. SCHEDULED PROJECT MANAGEMENT

With the guidance of experienced company mentors, a timeline was laid down to schedule work into main blocks. Following the detailed timeline, the company set sails by allotting the first month of work into Research and Development (R&D). (Figure 30.)Being aware with the impact of exceeding any deadlines on other departments, company employees worked hard to meet delivery dates.

C. ONLINE COLLABORATION

Online collaboration played a major role in delegating and distributing tasks, allowing company employees to work from home and increase productivity. Compared to other offline desktop-based solutions, Google Docs proved to be the better platform for writing the technical documentation. Its features like revision history and commenting allowed employees to author the file collaboratively and allowed department leads to propose changes and track progress. Google Sheets allowed the company CEO and CFO to update the cost sheet simultaneously and was used to track expenditures and consequently adjust spending.

For it is widely adopted by industry professionals, GitHub was used by the software department as the main Version Control System. It allows managing code and ensures organized parallel software development. GitHub allows reverting to previous versions which can be useful if a problem arose. Moreover, software employees were responsible for committing messages every time a code update is made to inform their colleagues about these changes.

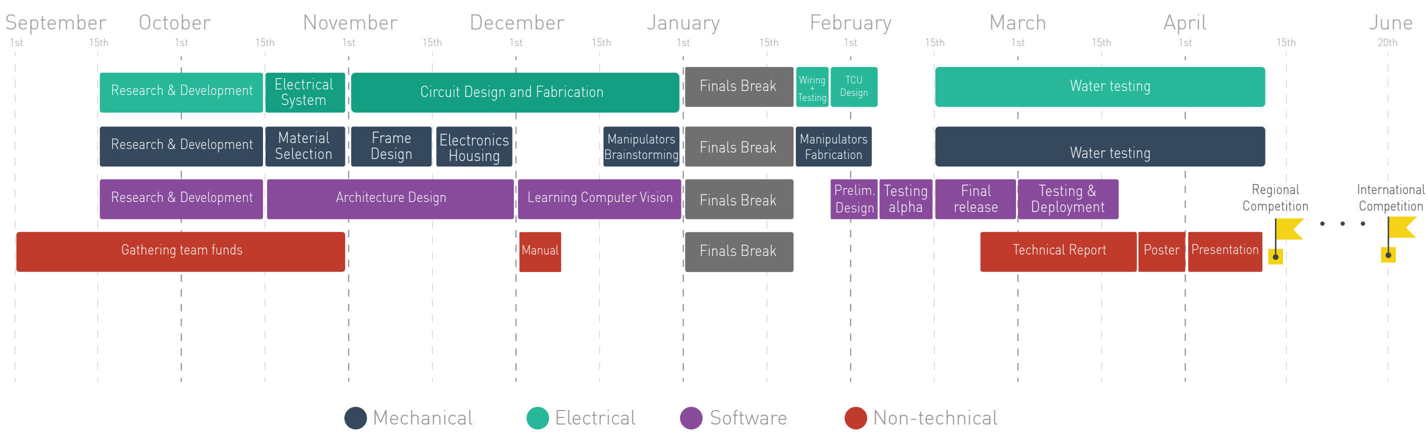

Figure 30. Company Timeline

9. REFLECTIONS

Ahmed Nour, CTO 2018-19

"Participating in this competition for three years had a great impact on my decision-making skills. It taught me to pay attention to the finest of details, consider all of the available options, and that there is always a simple solution to any problem. "

Omar Eweda, Mechanical Lead 2018-19

"I joined M.I.A. in my second year of Mechanical Engineering as a design engineer. By the end of the first year, I was reluctant to compete again. My belief was that a person does not evolve if they do the same thing again and again. But to my surprise and with an evolving industry like underwater robotics, I found new challenges. I am glad to say that competing at the MATE Competition has transformed my mindset "

Mohamed Abo Donia, CEO 2017-18

"My three years at M.I.A. robotics gave me the opportunity to learn Computer Aided Design, machining, problem solving, and leading others effectively. My time at MIA robotics has helped me not only develop technical skills, but also a mature as a person. Hours upon hours of working, staying up late, and testing our ROV in the pool have shaped my work ethic. The lessons I have learned, the experience I have shared and countless memories of working and testing will stick with me forever. Thanks to all my teammates, leaders , founders, parents and my second family: MIA Robotics."

10. ACKNOWLEDGEMENTS

- MATE Center for sponsoring this year's competition and for their generous awards.
- NTRA for sponsoring the team
- Hadath organization for organizing the local and regional competitions.
- Arab Academy for Science and Technology (AAST) for hosting the local and regional competitions.
- ADES - For sponsoring the team with travelling costs
- Alexandria Fertilizers Company - For making their workshops available for fabrication.
- Team supervisors Prof. Dr. / Hassan Warda and Dr. / Ahmed Naguib

11. REFERENCES

1. Blue Robotics www.bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster/
2. The ROV Manual: A User Guide for Remotely Operated Vehicles: Second Edition (2014), Robert D. Christ and Robert L. Wernli
3. Qt documentation: https://doc.qt.io/
4. OpenCV documentation https://docs.opencv.org/3.4.5/

12. APPENDICES

A. SAFETY CHECKLIST

Pre-power test

- Area clear/safe (no tripping hazards, items in the way).
- Verify power switches and circuit breakers on TCU are off.
- Tether flaked out on deck.
- Tether connected to TCU and secured.
- Tether connected and secured to ROV.
- Tether strain relief connected to ROV.
- Electronics housing sealed.
- Visual inspection of electronics for damaged wires, loose connection.
- Nuts tight on electronics housing.
- Thrusters free from obstructions.
- Set compressor output to 2.75 bar.
- Power source connected to TCU.

Power-Up

- TCU receiving 48 Volts nominal.

- Control computers up and running.
- Ensure deck crew members are attentive.
- Power on TCU.
- Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity).
- Verify video feeds.
- ROV lights indicate “Safe Mode” (green).
- Test accessories.

In Water

- Check for bubbles.
- Visually inspect for water leaks.
- If there are large bubbles, pull to surface immediately.
- Engage thrusters and begin operations.

Loss of Communication

- Cycle power on TCU to reboot ROV.
- If no communication, power down ROV, retrieve via tether.
- If communication restored, confirm there are no leaks, resume operations.

Pit Maintenance

- Verify thrusters are free of foreign objects and spin freely.
- Visual inspection for any damage.
- All cables are neatly secured.
- Verify tether is free of kinks.
- Visual inspection for leaks.
- Test onboard tools.
- Verify camera positions.
- Washdown thrusters with deionized water

B. POWER BUDGET

Components	Quantity	Voltage (V)	Current (A)	Power/Component (W)	Total Power (W)
Bluerobotics Thruster (T200)	6	12	10	120	720
Basic ESC	6	12	0.5	6	36
Arduino Nano	2	12	0.2	2.4	4.8
Solenoid	5	12	0.2	2.4	12
Temperature Sensor	1	5	0.01	0.05	0.05
PH Sensor	1	5	0.01	0.05	0.05
Inductive Proximity Sensor	1	12	0.01	0.12	0.12
Camera	4	12	1	12	48
Micro ROV	1	12	7.367	88.4	88.4

Total power consumption = 909.42 Watt

Current drawn from MATE Power Supply = $\frac{909.42}{48}$ = 18.95 A

Fuse value = (150%) x 18.95 = 28.42 ≃ 30 A

Micro ROV

Components	Quantity	Voltage (V)	Current (A)	Power/Component (W)	Total power (W)
Arduino Nano	1	12	0.2	2.4	2.4
Camera	1	12	1	12	12
Basic ESC	1	12	0.5	6	6
Bluerobotics Thruster (T200)	1	12	4	48	48
Headlight	1	12	1.67	20	20

Total Power Consumption = 88.4 Watt

Current Drawn from the ROV = 7.367A

Fuse Value = 7.5 A

C. PNEUMATIC SID

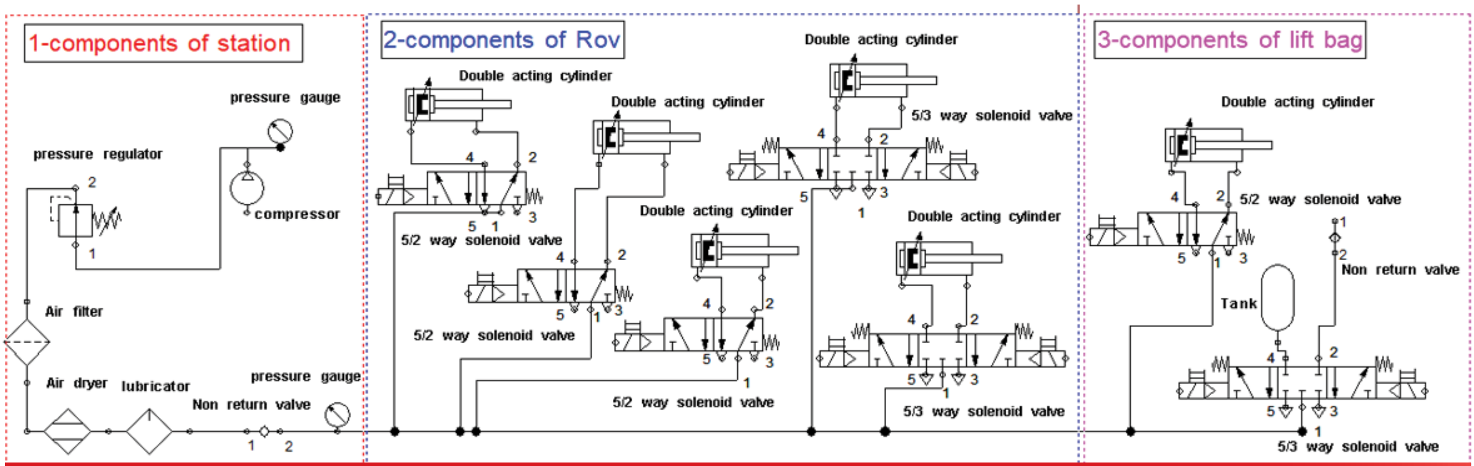

Figure 31. Pneumatic SID

D. BUDGET

Source	Income	Type			
Self-fund	$3500	Income			
Alexandria Fertilizers	$335	Machining (Lathe)			
BlueRobotics	$500	Prize			
Amazon.com	$125	Prize			
MATE	$150	Prize			
Total	$4610				
Production expenses	Budget	Type	Description	Cost	Difference
Thrusters	$1400	Production	7 T200 Thrusters including basic ESCs	$1365	$35
Fabrication	$250	Production	3D Printing, CNC, Lathe	$280.66	-$30.66
Electrical components	$140	Production	Arduino Nano, UART,	$106.277	$33.723
Vision system	$195	Production	Digital Video Recorder, Cameras, Baluns	$178.61	$16.39
Pneumatic system	$305	Production	Solenoids, fittings, tubes	$277.77	$27.23
Materials	$250	Production	Acrylic, Artelon	$230.55	$19.45
Tether	$135	Production	Sheathing, Cat6, AWG-16	$105.55	$29.45
TCU	$235	Production	Joystick, LCD, Hardcase, valves, fittings	$200	$35
Miscellaneous costs	$115	Production	Epoxy, heatshrink, strain-relief, zip-ties	$90	$25
Total	$3025		**Total**	$2834.417	$190.583
Research & Development	Budget	Expense	Description	Cost	Difference
Electronics	$22	Purchased	PCB fabrication	$27.77	-$5.77
Micro-ROV	$122	Purchased	Pneumatic system, bilge pump, wheels	$88.88	$33.12

Raspberry Pi 3	$105	Purchased	Line-following and mapping	$97.2	$7.8
Total	$249		Total	$213.85	$35.15
Operation Expenses	Budget	Expense	Description	Cost	Difference
Mission props	$155.55	Production materials	MATE mission props	$138.88	$16.67
Registration	$300	MATE entry fee	Regional & International registration	$300	0
Printings	$85	Media production	Banner, Poster, Flyers, Business Cards	$67.77	$17.23
Fluid Power quiz	$15			$15	0
Shipping	$195		International shipping, customs	$201.94	-$6.94
Total	$750.55		Total	$723.59	$26.96
Capital Expenses	Budget	Expense	Description	Cost	Difference
Vertical driller	$95	Upgrade		$88.88	$6.12
Compressor	$80	Upgrade	25-Liter compressor unit	$69.44	$10.56
Tools	$65	New	Ratchet, screwdri vers, wrenches	$77.77	-$12.77
Electrical tools	$75	New	Hot-air gun, soldering station	$61.11	$13.89
Total	$315		Total	$297.2	$17.8
Total budget and cost	Project Cost	Difference			
Income	$4610	-			
Production expenses	-$2834.417	$190.58			
Research & Development	-$213.85	$35.15			
Operation Expenses	-$723.59	$26.96			
Capital Expenses	-$297.2	$17.8			
Funds available	$540.943	-			