NIGHT OWLS

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MATE ROV COMPETITION 2022-2023

NIGHT OWLS
FAU High School
Boca Raton, Florida, USA

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Abstract

We are the FAU High Night Owls, a 10-member MATE team from Boca Raton, Florida. Our team strives to advance environmental sustainability in engineering, with emphasis on underwater robotics. Our ROV has undergone extensive upgrades to meet the requirements of this year's MATE tasks, featuring an 8 vectored-motor configuration that enables movement along all six axes with remarkable precision. The customized thruster layout ensures accuracy while performing tasks such as flying a transect (Task 2.7) or measuring the diameter of a coral head (Task 2.1). Our ROV is equipped with two high-quality cameras, one forward-facing and one downward-facing, to ensure great visibility. We have incorporated a manipulator into our system, which allows us to complete tasks such as installing a solar panel array (Task 1.1) and deploying a buoyancy engine (Task 3.1). We have optimized our craft to be lightweight, sturdy, and equipped with onboard electronics to lighten our tether and allow for faster communication times between Raspberry Pi and accessories. Our ROV's tailored code delivers exceptional processing speed and precise motor control, allowing it to perform tasks such as positioning a simulated UV light source over diseased coral areas (Task 2.3), all of which are detailed in the MATE Competition Task List.

The MATE product demonstration is designed to simulate real-world scenarios, accurately portraying the challenges that are commonly faced in marine ecosystems. Our ROV is designed to address such challenges with precision and efficiency, creating a more sustainable future for our planet.

Figure 1: Team Photo
Photo Taken by Carol O'Leary
All photos taken by Isabella Wong unless specified otherwise.

Teamwork

Project Management

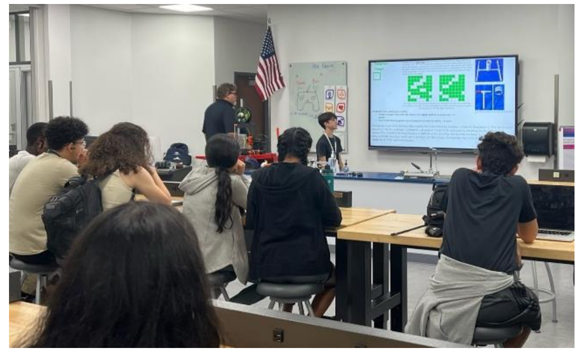


Figure 2: Company members going over task list.

The Night Owls are a group of passionate high school students who are pushing the boundaries of robotics to preserve the marine ecosystem. Building on last year's success, our team was joined together by returning members and new recruits who share the common goal of creating a more sustainable future. With a new composition of MATE members, we recognized the need for greater organization in our working processes to avoid confusion and streamline operations. For this, we implemented a system whereby each team member is assigned specific responsibilities and tasks based on their areas of expertise. Although each team member is assigned specific responsibilities, every Monday we would have a general body meeting where we discussed issues we faced in our respective fields. Discussing our issues amongst each other helped us maintain a greater understanding of the issue and collaboratively work towards a solution that aligned with the mission objective. While we do leverage our individual strengths, there is also significant overlap and collaboration between team members to combine our knowledge and skills, enabling us to perform at our best. Through this approach, we are better equipped to address the challenges posed by our work in marine robotics and deliver innovative solutions that help protect and restore the health of our oceans.

Scheduling

Our robotics team began with weekly meetings, lasting just over an hour. These weekly meetings were every Monday. Once sponsorship funding and materials for our ROV were secured, we increased our meeting frequency. Workdays typically run from 8 AM to 5 PM on weekdays, with occasional weekend sessions leading up to the competition. The frequency of these workdays was determined by the workload and deadlines. Typical operations involve continuous improvement and maintenance of the ROV, with members working together efficiently using established protocols and resources.

An archived schedule is provided in Appendix E.

Resources

The availability of various resources and our adherence to protocols has been instrumental in facilitating efficient project management for our robotics team. Our team has had access to a range of advanced tools, including a laser cutter, 3D printer, and soldering machine, which have not only expedited the assembly process of our ROV, but also resulted in the production of high-quality components. By utilizing these resources, we have been able to ensure the structural stability of our ROV, improving its ability to navigate underwater environments. Furthermore, adhering to our standard protocols has allowed our team to address any issues that arise during day-to-day operations with ease. The team works collaboratively and effectively to make progress on the ROV each day, leveraging these resources and protocols to streamline their efforts.

Safety Procedures provided in Appendix B.

ROV Assembly

Figure 3: Front of ROV.

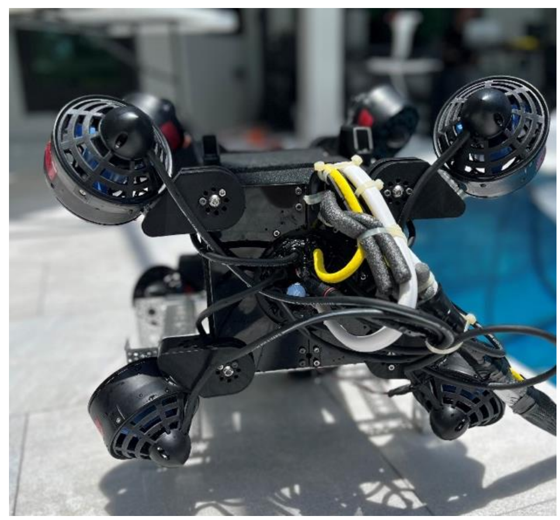


Figure 4: Back of ROV.

Design Rationale

Engineering Design Rationale

The design of the ROV was carefully decided upon by the entire team. Various design proposals were presented, and the best elements were incorporated into the final build. Based on tasks such as examining the coral head (Task 2.1) and lifting heavy objects (Task 2.6), we prioritized an eight-motor configuration. We added eight motors which were strategically angled and placed on the vertices of our frame. This configuration enables the ROV to perform multidirectional movements, including yaw, pitch, roll, and axial movements, using multiple motors simultaneously. Whilst moving in any direction, all 8 motors are contributing toward the direction, enabling faster, more precise movement. When deciding on this design, we realized that this configuration would be a challenge for our software developers, however they faced it head on.

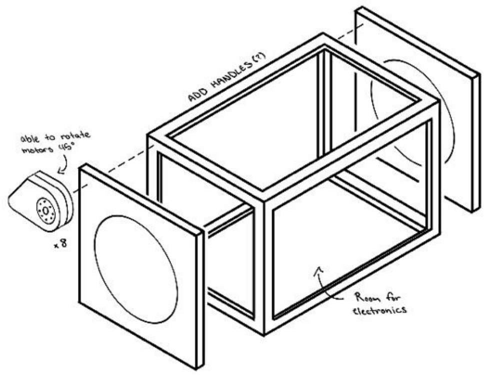


Figure 5: Initial ROV Sketch.

Another essential upgrade to our ROV design compared to previous iterations was the integration of an onboard electrical system. The decision to put our electronics inside the ROV instead of on land was highly supported by all members, as it would reduce the weight of the tether and make communication between the Raspberry Pi and the connected electronics faster. Carrying the electronics is also important for faster reaction times between the code running on the Pi and the motors. This is essential while trying to achieve efficient auto-leveling and depth lock. Wanting our ROV to be lightweight but still durable, our solution was to build a casing out of both aluminum and acrylic pieces. Our electrical tube is placed within aluminum bars to offer suitable protection, and acrylic panels were used in place of heavier materials to keep the build neat. Given the prevalence of object manipulation challenges, we chose to incorporate a front-mounted claw into our ROV design. This claw would allow us to retrieve heavy objects (Task 2.6), position a light source over a diseased coral head (Task 2.3), and deploy our buoyancy engine (Task 3.1) with ease.

Problem Solving

Our team demonstrated efficient communication and problem-solving skills, leveraging the pre-existing connections formed between members from our shared school environment. When issues were found in the ROV, our first step was to identify the root cause of the issue. We would do this by isolating individual components and testing them individually. Once that was established, all members would consult with each other to devise the most efficient and effective solution. Those possessing relevant expertise were typically at the head of such discussions. Once a solution was found, it was promptly implemented and tested until there was a successful outcome.

Figure 6: Company members collaborating on frame design. Photo by Maya Venkatesh

Figure 7: Company members collaborating on paperwork.

Throughout these trial phases, should any team member become frustrated by a particular problem, others would readily step in to reassess the situation while providing support for the individual to regain composure. This exemplifies our unwavering commitment to teamwork that is vital in our day-to-day operations. We aim to create a collaborative environment that fosters collective problem-solving and shared success.

When brainstorming ideas for our current ROV, we drew inspiration from other teams and our previous ROV. We made sure to analyze the inefficiencies and mistakes encountered with the previous ROV, which lacked proper planning and relied heavily on improvisation. Consequently, a significant amount of time was spent on construction, detracting from other equally important aspects of the project. We ended up having to disassemble and reassemble the ROV multiple times to add features we failed to consider beforehand. This would cause delays in our previous plans and leave the documentation to be done poorly. To address these shortcomings, we have taken a proactive approach this time around. By applying lessons learned and prioritizing project management, we can create a more systematic workflow that increases productivity and efficiency.

Systems Approach

By designing the electrical and communication systems in an integrated manner, we made sure that each part of the ROV would work harmoniously with one another. This approach allowed for efficient and reliable communication between the various systems of the ROV. With most electronics located onboard, motors, sensors, and servos could communicate seamlessly through the Raspberry Pi computer. The Navigator Pi-hat efficiently controls the motors so the Pi can focus on other tasks, such as high-quality camera transmission. We chose to develop the ROV and dock-side software in the Rust programming language. Our use of Rust, a modern, fast, and memory safe programming language, allows our team to be more productive by facilitating code reuse and eliminating several classes of errors and bugs. This improves the reliability and cost-effectiveness of our software. Mechanically, our focus was on developing a hydrodynamic design that also offered ease of transportation. Symmetry was a key consideration, allowing for straightforward adjustments to buoyancy by maintaining balance around the electronics tube and metal frame. Even though the ROV only has a single manipulator, it makes up for this with superb maneuverability.

Figure 8: Company members testing systems.

Vehicle Structure

Frame

We chose to build our frame using a combination of aluminum and acrylic materials. We considered using alternative materials but decided against it due to several key considerations. PVC Pipe, which we used last year, is versatile and cheap, but can be bulky and weigh down the ROV if water leaks into its chamber. While carbon fiber may offer a high strength-to-weight ratio, its higher cost and the complexity of repair made it less appealing than aluminum which offers more for less. Aluminum's ease of construction, cost, weight, and strength led to its selection. Acrylic, the other frame material used, is durable but also has transparent qualities. This allows for clear visibility of our ROV's internal components, essential for quickly identifying the state of our ROV without disassembly.

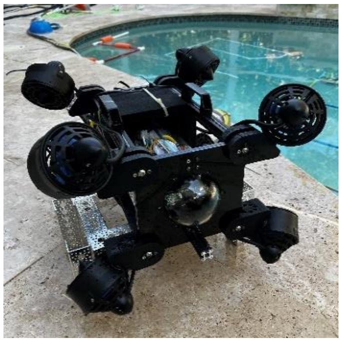


Figure 9: ROV during testing.

The aluminum and acrylic frame provides structural support and modularity without adding much weight. The aluminum bars used were upcycled from previous projects and the acrylic was laser cut with the resources provided in our workspace into a custom design that would allow us to secure our electronics tube and attach our motors at the vertices of the frame. The electronics tube can be easily removed if needed, which proved useful for accessing the central electronics during development.

Material:	Cost:	Pros:	Cons:
Carbon Fiber	High	- Light weight - Stronger than steel and aluminum	- Costly - Hard to maintain - Stiff and prone to breakage
Aluminum	Low	- Versatile - Already had in house - Moderately light - Easily Recyclable - Strong for its weight	- Steel would be stronger for cheaper. - Highly conductive - Softer than other metals
PVC Pipe	Low	- Durable - Easy to work with - Versatile - Inexpensive	- Bulky - Water may seep into holes and weigh down ROV
Acrylic	Moderate	- Shatter resistant - Durable - Light weight - transparency	- Easily scratched

Table 1: Structure Materials Comparison.

Vehicle Systems

Manipulator

The servo-actuated claw attached to our ROV has precise movement, and combined with the maneuverable ROV thrusters, can accomplish the necessary tasks. The waved internal edge of the claw is perfect for manipulation of any kind, such as securely attaching pipes or deploying our buoyancy engine.

Figure 10: Aluminum ROV frame with claw.

Thrusters

This year, our company decided to adopt an 8-vectored motor configuration, giving our ROV multidirectional thrust capabilities. To ensure optimal speed and precision, we upgraded from the motors used in our previous iteration. We bought the T200 motors from Blue Robotics as they come pre-waterproofed, eliminating any concerns associated with waterproofing them ourselves and were selected for their size and cost. Although buying eight of these motors came with a substantial price tag of $1600, the investment is well justified considering the enhanced maneuverability they deliver.

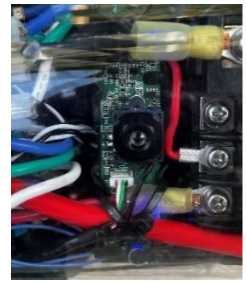
In order to meet the MATE safety standards, we custom designed prop guards using Autodesk Fusion 360, CAD software, to cover the large open spaces that allow access to the motor blades. We laser cut black acrylic for the front guards, and 3D printed the back guards which adhere to IP-20 standards.

Figure 11: Blue Robotics T200.

Tether

Our tether consists of two main wires, one wire that functions as an ethernet wire, and an 8-gauge wire that transports 12V power. Originally, we installed a 14-gauge power wire. Using our Watt Meter, we realized that we were only able to draw a maximum of 8 amps, which leaves room for improvement, as we are allowed to draw up to 25 amps. We changed out the 14-gauge wire for a much thicker 8-gauge wire. This thicker wire allows us to draw higher amperage, which makes our ROV faster and stronger. We have two backer rods in our tether which make our tether neutrally buoyant. These backer rods are more reliant than incrementally placing pool noodles, as pool noodles absorb water and become less positively buoyant after being submerged for longer periods of time. All contents of our tether are housed under a black snakeskin, which makes our tether a uniform diameter and easier to work with. It also makes our tether less susceptible to being tangled without our knowing.

Cameras



Left Image, Figure 12: Front Camera.
Right Image, Figure 13: Bottom Camera.

Our ROV supports USB webcams with on board H.264 compression support. This compression allows our team to stream several 1080p 30fps camera feeds from our ROV with minimal bandwidth usage. There are currently two cameras mounted on our ROV: a forward-facing camera and a down-facing camera. They are both taken from old webcams which are no longer in use - reducing our amount of spending. The forward-facing camera serves as the primary visual input. Mounted on a servo mechanism, the camera is able to move upwards and downwards 90°, greatly enhancing the field of view. Tilting upward allows us to see our position regarding the surface of the water while tilting downward allows us to monitor our manipulator. The downward-facing camera is positioned at the bottom of our ROV and is perfect for flying transects and positioning the ROV accurately when engaging in seafloor tasks. Having only two cameras, one of which has multiple viewing angles, prevents bandwidth while still communicating high resolution video.

Control/Electrical System

Onboard Electronics

This year, we decided to relocate the electronic components of our ROV from the landside to onboard, which would yield substantial benefits in performance and communication. This move was primarily aimed at optimizing the speed of our ROV's electronics communication. Our ROV is equipped with eight T200 thrusters, each independently managed by separate Electronic Speed Controllers (ESCs). These ESCs, along with a Raspberry Pi, Navigator Pi-hat, cameras, and a servo, are securely housed within a waterproof tube. Our ROV also uses an external depth and temperature sensor. The Navigator is equipped with a gyroscope, an accelerometer, two compasses, an internal temperature sensor, and several analog to digital converters. These sensors are primarily used to generate orientation data. This onboard arrangement allows for efficient integration and operation of the electronic systems.

Land-Based Electronics

To support the onboard electronics and power the ROV, a comprehensive system is established on the landside. The waterproof tube housing the ROV’s electronics is connected to the tether. Because most of our electronics are on the craft itself, our tether can be much lighter and is comprised of just an eight-gauge power wire, an Ethernet cable, and two long foam backer rods for buoyancy control. Because our tether is so much thinner and doesn’t carry much weight, our ROV has better maneuverability. The power supply connects to a wire equipped with a 25-amp fuse, which then passes through a watt meter. This watt meter provides real-time monitoring, displaying the current draw, voltage, and power consumption of the ROV during operation. Furthermore, the Ethernet cable is connected to a small control box (another benefit of moving our electronics to the ROV), connecting the onboard electronics and a computer. This computer serves as the control center, enabling administration of the ROV, real-time camera viewing, and precise joystick-controlled movement. To manipulate the motor movements and servo operations of the ROV, we employ a Logitech Gamepad, ensuring accurate and responsive control in all ROV operations.

ROV Software Design

The ROV code is run on a Raspberry Pi 4 with a Navigator Pi Hat. It is split into 16 "systems" running in parallel include camera streaming, telemetry, error handling and fault recovery, communication, motor control, sensor data collection and processing, and several driver assist algorithms. These systems are designed to be loosely coupled and only communicate in an event-based manner through message passing. Our ROV code has no notion of a main thread nor global ticks. If a system needs events at a regular interval, it does so by creating a thread that emits tick events that are local to a specific system. These design choices facilitate local reasoning and separation of concerns while reducing the maintenance necessary to meet requirement changes.

Figure 14: Company members dockside at regionals. Photo by Nigel McIvor

ROV Orientation

Our ROV software collects data from on board sensors using custom user space drivers written using the "rppal" Rust library. Once sensor data is mapped to the coordinate system used by our ROV, data from the gyroscope, accelerometer, and compasses is used to calculate our ROV's attitude. To do this, we use an implementation of the Madgwick Orientation Filter to process raw sensor data into a useful orientation quaternion, a type of 4d complex number that is commonly used to represent 3d rotations. The orientation data is mainly used for our driver assist features which include a real time attitude display on the topside and a leveling algorithm running on the ROV.

Driver Assist

Leveling is an important feature of our ROV as it relieves the pilot from manually controlling the roll and pitch axis - making piloting our ROV significantly more intuitive. The leveling algorithm is based exclusively on quaternion and vector math. It uses a variation of the algorithm presented in the paper "Swing-twist decomposition in Clifford algebra" to derive instantaneous roll and pitch error. This is necessary as the ROV's response to a disturbance should be independent of the yaw it currently observes. This approach also avoids the issues that occur when leveling based on Euler angles which wrap around when the ROV turns more than 180 degrees and are sequential in nature. Additionally, this approach is general over any leveling target and observed orientation, allowing the ROV to level to an inverted orientation if commanded to do so. These error measurements are then passed to two PID controllers, one for roll and one for pitch, enabling our ROV to respond to any disturbance in smooth and quick manner. Our ROV also supports depth control where the ROV will use data from the exterior pressure sensor to maintain a constant depth set by the pilot. The difference between target and observed depth is passed to a PID controller which is responsible for controlling the ROV's movement in the z-axis. Both of these driver assist features, leveling and depth control, are bound to a physical button on the pilot's controller, enabling the pilot to freely toggle these features as necessary.

Actuator Control

Our ROV supports up to sixteen PWM based motors and servos. Because both the servos and ESCs we use support the same PWM interface, we are able to reuse the same code to handle both types of actuators. Our software calculates the raw PWM commands from pulse widths measured in microseconds according to the formulas presented in the datasheet for the PCA9685, the PWM controller on our Pi Hat. These commands are then written into registers on the Navigator's PWM controller chip at regular intervals. The main difference between how servos and thrusters are implemented is how the pulse widths are calculated. Our servos are position controlled: the angle of the servo is proportional to the duration of the pulse. This means that we simply need to linearly remap our servo commands into the PWM pulse widths expected by the servos. On the other hand, the force produced by our thrusters is related to the duration of the pulse. Due to our ROV's unique motor configuration with six degrees of freedom and non-linear relationship between PWM pulse width and force, the PWM pulses for each thruster must be derived from our motor mixing implementation.

Motor Mixing

The first step in our motor mixing algorithm is to use vector math to determine how strongly each motor contributes to the requested movement. The result of the vector math alone cannot be used directly to derive motor speeds for three main reasons: our thrusters produce considerably less thrust while moving backwards compared to forwards, we need our thrusters' combined current draw to remaining below our fuse rating, and thrust is non-linearly related with PWM pulse widths. To solve the first of these issues, we observed that the reverse thrust of our motors was about 80% of their forward's thrust. Modeling the difference between forwards and backwards thrust as a linear relationship allowed us to compensate for this by simply scaling the target speed of motors going backwards by 125%, the reciprocal of 80%. The second and third issues are solved together

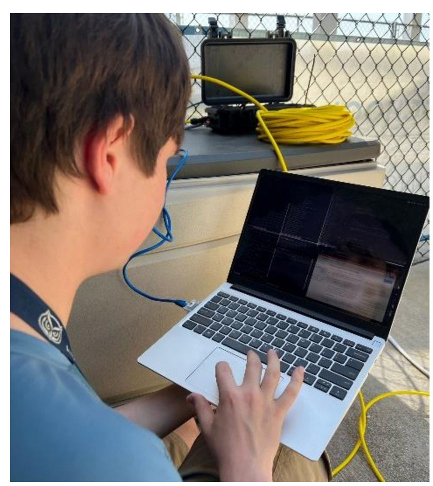


Figure 15: Company member testing ROV motors

by using a trick and publicly available data on our T200 motors. Although the result of our vector math is technically the thrust relationships between each motor, we can instead interpret the result as amperage relationships as amperage draw and thrust are roughly proportional. This shift in perspective turns the amperage constraint into a trivial problem as we simply need to scale down the amperage targets by the ratio between amperage constraint and the sum of the unconstrained amperage targets. Additionally, this design choice means that there is only a single solution for any movement command, eliminating the need for a multivariable solver and keeping the algorithm performant (it needs to run hundreds of times per second). Once we determine the target amperage draw for each motor, we simply search publicly available motor data to find the PWM pulse width necessary. One particularly helpful feature of this algorithm is that it accounts for the fact that when some motors are stopped, the others can increase their speed to compensate. This is an important feature for our motor configuration as half of our thrusters must stop in order for our ROV to move diagonally, allowing the remaining thrusters to move at double speed without exceeding the fuse rating.

Topside Software

Our ROV is piloted using our custom topside software written using a Rust game engine called Bevy. To draw our UI, we use a Rust library egui which provides an immediate mode graphics framework that is compatible with Bevy. The choice to use an immediate mode graphics library simplifies the development and maintenance of our UI system and ensures that the data displayed on screen is always in sync with the internal state. Our topside control software includes attitude display that depicts a 3D model of the ROV that is orientated according to the sensor data streamed from the ROV. This display allows the pilot to better understand the position of the ROV and what camera feeds are depicting. The control software has direct integration with gstreamer and OpenCV to receive, decode, process, and display camera feeds to the pilot. Our OpenCV integration allows our team to apply image processing techniques to complete tasks autonomously. The UI allows the pilot to edit OpenCV pipelines and display their intermediate computations as camera feeds. Performance is also a central aspect of our video processing code. Our gstreamer pipeline is optimized for low latency and our video processing and display code recycles all buffers to eliminate unnecessary memory allocation. The pilot controls the ROV using a standard game pad commonly used for video games. Our control software also includes a notification display that alerts the pilot of critical events, such as one of our leak sensors being triggered or when the ROV is connected or disconnected.

Propulsion

Our ROV uses eight T200 blue robotics motors that allow the craft to efficiently and swiftly move through the water. This was ideal due to the essence of our mission, to successfully complete tasks in a timely manner. Based on our findings, T200s are the most efficient in terms of power consumption and cost on the market. Each motor cost $200 dollars, and we purchased 8, which totaled around

$1600. Each motor is pre-built and waterproofed, eliminating many issues that could occur due to taking improper steps to waterproof them, which was a key element in our decision.

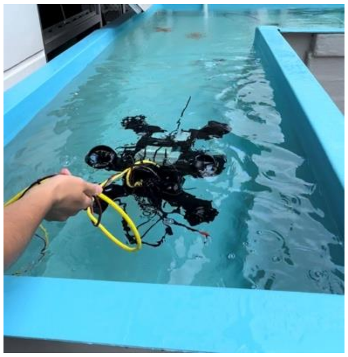


Figure 16: ROV motor configuration being tested.

The motors are positioned in an 8 Vectored-Thrusters Layout, each angled at 45 degrees. This is in order to allow our ROV to move in all directions, turn, and most importantly allow it to strafe, which is the ability to move from side to side without having to turn. It is a useful feature that we decided to incorporate into our ROV's setup in order to keep our focus on a target, even while moving in another direction. Being able to strafe allows us to make subtle adjustments while trying to perform tasks that require high precision and patience, giving us an advantage by allowing us to complete tasks faster. This is especially useful for task 2.1, which requires our ROV to measure the diameter of a coral head.

By precisely calculating the adjustments required for each motor, we seamlessly coordinate multiple motors to navigate the ROV along a stable flight path. This is necessary to map the controls to our eight motors. The wide array of possible thrust combinations enables our ROV to execute pitch, yaw, and roll maneuvers with exceptional agility. This enhanced maneuvering capability compensates for the presence of a single manipulator and significantly augments its lifting power, ensuring optimal performance in a variety of tasks such as lifting a heavy container (Task 2.6).

Buoyancy and Ballast

Figure 17: Company members testing ROV buoyancy.

Our ROV has a tube on board that holds all of the team's electronics, however this tube is full of air. This contributes to the craft's buoyancy, but not enough for it to be neutrally buoyant. To combat the ROVs negative buoyancy, we added Last-A-Foam, which would take off some of its weight in the water. The goal was for our ROV to be slightly positively buoyant, so that when the craft has something in its claw, the ROV will have an easier time repositioning or bringing the object back to the surface. We couldn't randomly place our Foam, or else our ROV could be disbalanced. More Foam would need to be added to the rear of our ROV since the tether was making it heavier. The principle of buoyancy states that "when an object is in a fluid, the buoyant force on the object is going to be equal to the weight of the fluid displaced by the object." The weight of the ROV in the water is 550 grams without any Sea Foam, therefore, we need 1245.42 cubic millimeters of Seafoam to get our ROV to the desired buoyancy. We used leftover products from previous projects, decreasing our necessary spending.

Payload and Tools

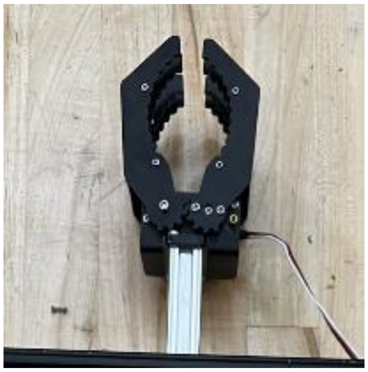


Figure 18: Claw on Servo.

The ROV included two webcams, both placed in the electronics tube. One of the cameras is placed at the bottom of the tube, in order to look at the pool floor for tasks such as flying a transect. The other camera is placed at the front of the tube, in a dome shaped piece of acrylic. The dome is to allow space for our servo driven camera movement, which we can use to look straight ahead, up, and down. Having two cameras, one of them being able to move 90°, allows for good visibility of the pool and all the tasks, while still having a neat electronics tube, not crammed with wires.

Our ROV has a gripper on a servo so that the pilots can open and close the claw. The front camera can view the gripper, allowing the pilots to be able to view what the claw is near or holding. Our team can use the gripper to effectively manipulate different objects in the pool to be able to complete the given MATE missions. Since the ROV has eight different motors, it is super maneuverable in the pool, making it easier to complete all the different challenges in the pool with only one claw.

The gyroscope on the navigator measures how fast the ROV is rotating in each axis and helps with calculating the orientation of the ROV. Our accelerometer helps determine the pitch and roll of the ROV by measuring the influence of Earth's gravity. The magnetometer derives yaw, using Earth's magnetic field like a compass. This is useful when tasks in the water and the pilots need to know which direction the ROV is facing. We use our depth sensor to keep the vertical position of the ROV ready. There is a temperature sensor in the electronics tube which is useful to make sure the ROV does not overheat. All of the sensor data collected from the navigator helps keep the ROV level in the water and control its orientation, making sure we complete all the MATE tasks efficiently.

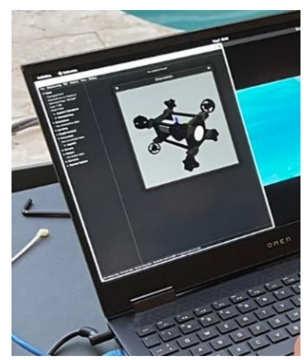


Figure 19: ROV Navigator.

Build vs. Buy

Our ROV was mostly built in house and utilizes many different parts, both new and old, to successfully function. For example, the frame of the ROV, made from aluminum bars, was cut to the sizes we needed and then threaded down the middle. Cutting and threading the parts of the frame in house allowed us to make sure the size of the frame was appropriate for our design and that the threads for the frame were compatible with the types of screws we were using. All the acrylic and 3D printed parts that connected the frame, motors, and electronics tube were also designed and made at our school. By designing and building these parts of our ROV instead of outsourcing them, we can make sure that all components were the exact size we needed. There were, however, parts of the ROV in which it would be better to buy instead of building ourselves. This would include our T200 motors, which came waterproofed, eliminating any issues that could occur from attempting to seal them ourselves. The motors guards and holders are made from PLA 3D print filament and acrylic, made with the machinery provided to us in our workspace. Since our team members can CAD, it was more reasonable to print and cut these items ourselves to ensure a perfect fit and only need to pay for our used materials, lowering expenses in the long run.

New vs. Used

Deciding whether to reuse old materials can be vital to the functionality of an ROV. In our case, we had many perfectly usable parts from other projects that could be incorporated into our design. The aluminum pieces that make up the frame, our cameras, and our acrylic electrical tube were all upcycled and reused. This would allow us to cut costs and make space for newer materials in the future. We used as many past parts as we could, but there were certain things we knew were worth adding into our budget, or simply didn't have on hand. This includes the motors, ESCs, and claw which were bought to make this year's MATE ROV. These were all necessary expenses that would contribute to our ROVs ability to complete all the MATE tasks.

Safety

The safety of our MATE underwater robotics team is maintained through operational, personnel, and equipment safety measures. Our safety protocols aim to prevent accidents and enable effective team communication, while emergency preparedness ensures swift and appropriate responses. Personnel safety is ensured by using personal protective equipment, comprehensive training, and supervision. Equipment safety is maintained through regular maintenance, equipment familiarization, and quality assurance checks. These safety measures collectively foster a secure working environment, safeguard team members, protect spectators, and preserve the integrity of the equipment. Our ROV is also equipped with many safety features to ensure general safety. Our custom-made prop guards are up to IP-20 Standards and are wrapped in brightly colored tape to signify the moving parts. Attached to the rear of our ROV is a strain relief to ensure no damage is done to our wires in case the tether is accidentally pulled on. On land, there is a kill switch that can immediately power down our ROV if a problem is detected, and we always wear proper PPE when operating.

Safety Procedures for ROV Operation: **(BOLD = double check)**
1. Conduct a thorough risk assessment of the ROV and its operating environment to identify potential hazards and develop appropriate safety measures. 2. Ensure that operators and personnel involved in ROV preparation receive comprehensive training on safe operating procedures, emergency protocols, and equipment handling. Only trained individuals are authorized to operate the ROV. 3. Implemented suitable safeguards and protective measures to prevent accidents and injuries. This **includes an emergency stop button** to always have full control of our ROV. 4. Provide and enforce the use of appropriate PPE, such as safety glasses and gloves when necessary, to protect operators and personnel from potential hazards associated with the ROV's operation. **5. Established clear emergency procedures and communication protocols in the event of an incident.** 6. **Conduct routine maintenance and inspections of the ROV** to identify and address any mechanical or electrical issues that could compromise safety. 7. Always maintain a clean and organized work area, free from unnecessary obstructions or potential trip hazards. 8. Have qualified supervisors present during ROV operation to provide guidance, monitor safety compliance, and intervene if unsafe practices are observed.

By following these safety procedures, the risks associated with ROV operation can be minimized, ensuring a safe working environment for operators and greatly reducing the potential for accidents or injuries.

SID provided in Appendix A
Further Safety Procedures for machinery and tools provided in Appendix B

Critical Analysis

Trouble Shooting and Testing

When we were first designing our ROV, we tested all laser cut pieces with cardboard before using acrylic pieces. This was done to make sure the piece we would be using fit perfectly and that there were no wrong alignments or changes we needed to make before cutting it on the more expensive material. If any holes or part of the design did not line up, we were able to troubleshoot by measuring sizes again and finding out what was measured incorrectly the first time. Printing on the cardboard first allowed us to test design iterations and troubleshoot alignment issues without having to waste funds until the final cut was ready to be made.

When evaluating issues with electronics the main tool we used to troubleshoot was a multimeter. By using a multimeter, we were able to identify any power issues and any ethernet issues when testing the wiring of the ROV. If a certain part of the ROV was not receiving any or enough power, we were able to use the multimeter to determine how many volts were present in certain areas and were also able to find places where power wasn't reaching by seeing if any volts were present in the wiring. The multimeter also proved to be effective while testing ethernet cables where the continuity setting showed whether the wires were connected properly. By doing a continuity check from the waterproof tube to the power box on land we were able to confirm that there was signal being sent down properly through the tether.

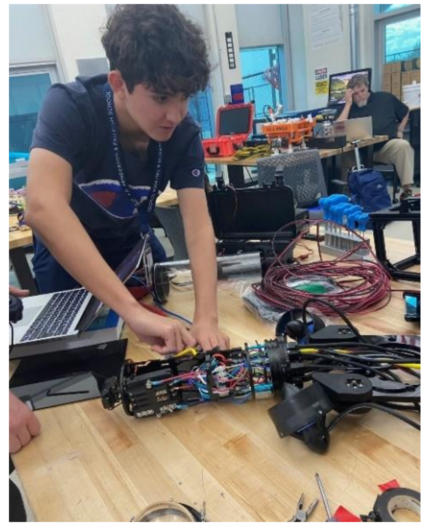


Figure 20: Company members testing

Making sure our ROV was ready to be placed in the water was a very important testing step. When preparing to deploy our ROV, we always test our control and electrical systems on land. This would be to make sure all thrusters, cameras, and our gamepad were fully functioning. We also confirm that there are no leaks present in our tube, or else we risk killing our electronics. Before putting the ROV in the water, we always use a Mityvac vacuum pump to make sure our tube PSI isn't dropping.

Accounting

Travel Budget

This year, we knew we wanted to make significant changes to our ROV, and this would require a larger budget. To make sure we didn't spend carelessly, we carefully planned all expenses and documented our spending in google sheets. Our estimated spending amount was around $17,000 dollars, which would include all components that went into building the ROV, our control system, and travel expenses.

Figure 21: Company members setting up at regionals.
Photo by Carol O'Leary

ROV Spending

Upon completion of the ROV construction, a thorough assessment of our expenditure was conducted and totaled $3,705.80. Slightly less than half of this budget is consumed by the eight T200 motors and motor controllers. We knew that having an eight-motor configuration would be pricey, so we attempted to upcycle as many parts as possible. Most of the pieces that we did not purchase came from old robots built for different competitions, such as T Slotted Bars from old RDL (Robot Drone League) robots and the Raspberry Pi 4 from an FRC (FIRST Robotics Competition) robot. Although we were not able to get many of the parts from our ROV donated, we were luckily able to raise most of the money required to attend MATE Internationals this year.

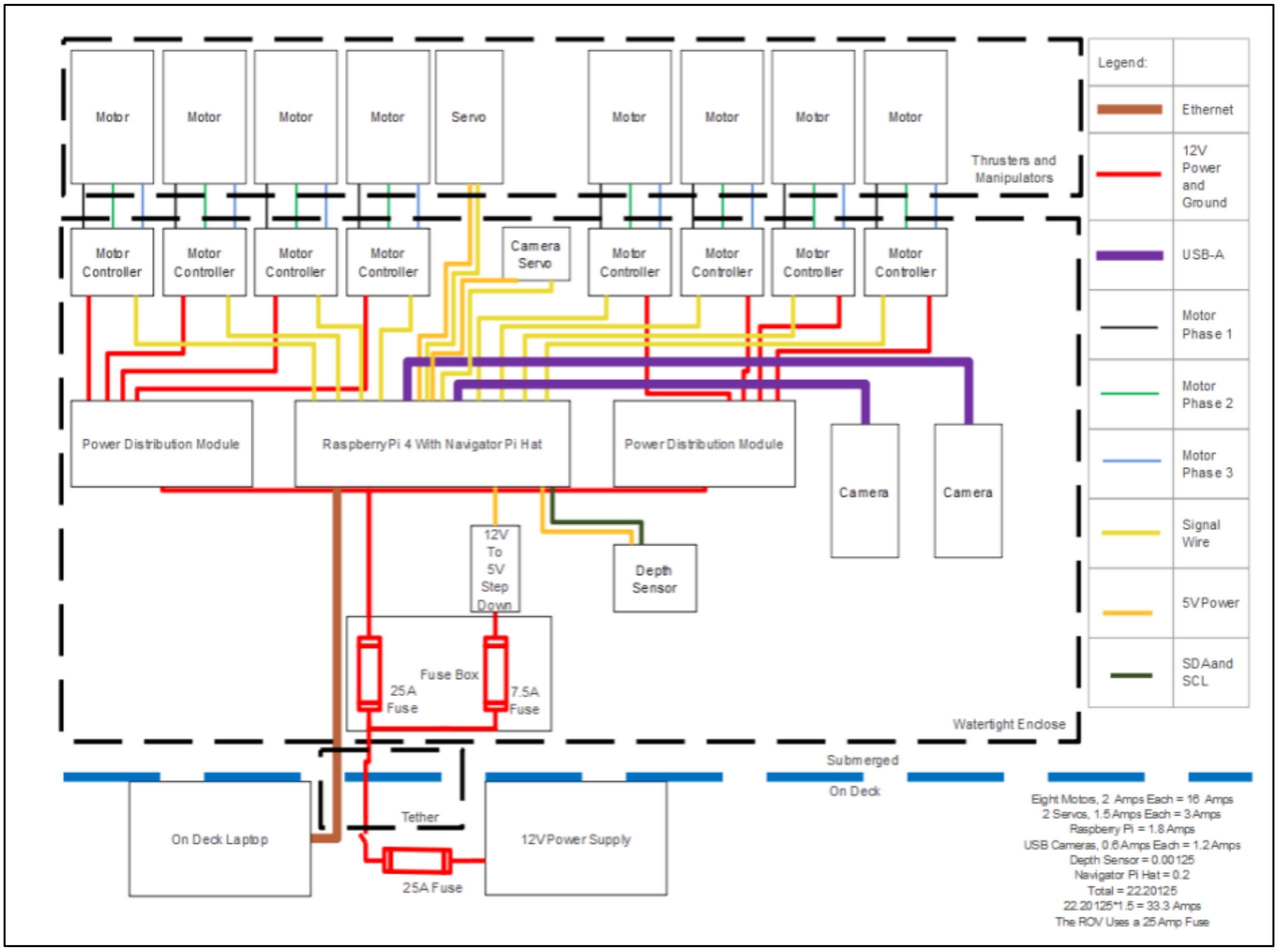
Spending amounts further detailed in Appendix C & D

Acknowledgments

Our company would like to acknowledge all contributors that helped us make it to internationals this year. Firstly, we would like to thank our mentors, Mr. Nance and Mr. Phipps, whose guidance and commitment helped shape our team. Also, a huge thanks to our sponsors, FPL, Motorola, and the FAU Office of Undergraduate Research and Inquiry (OURI), whose donations have helped cover ROV expenses, allowing us to be here. Furthermore, we extend our gratitude to The Cane Institute of Advanced Technologies for graciously providing us with access to their facilities. We would like to thank The Cane Institute of Advanced Technologies for letting us use their space. Last but certainly not least, we would like to thank Mate II for hosting these events and allowing us to compete in this amazing competition. Their commitment to fostering collaboration, knowledge sharing, and excellence in the field of robotics has been a true inspiration.

Appendices

Appendix A: SID



Appendix B: Safety Procedures

Safety Tools	*Safety Procedure*
3D Printer	- *Ensure that the printer is in a wall ventilated area and placed on a stable surface and away from flammable materials.* - *Regularly inspect printer for any signs of damage, and promptly address any issues.* - *Always monitor the printing process closely and avoid leaving the printer unattended for long periods.*
Glowforge Laser Cutter	- *Inspect laser cutter for any signs of damage or malfunction before use and address any issues promptly.* - *Ensure proper ventilation in the workspace to help minimize the concentration of potentially harmful fumes.* - *Maintain a clean and clutter-free workspace, keeping flammable materials away from the laser cutter.* - *Leave lid closed during and 15 minutes after operation.*
Power tools	- *Members are familiar with specific instructions and guidelines provided by the manufacturer for each tool used.* - *Maintain a clean and organized workspace to prevent tripping or other accidents.* - *When using drills or other rotating power tools, ensure that the workpiece is securely clamped or held in place to prevent unexpected movements.* - *Never remove or tamper with any safety features or guards on the tools, as they are designed to protect us.*
Soldering iron	- *Always handle the soldering iron with caution, keeping it away from flammable materials and ensuring it is placed on a stable surface.* - *Inspect the soldering iron for any damage or loose connections and address any issues promptly.* - *make sure the work area is well-ventilated to prevent the accumulation of fumes produced during the soldering process.* - *never touch the hot tip of the soldering iron, and allow it to cool down completely before safely storing.*

In case of emergency, fire extinguishers are always nearby, and all company members know how to operate them effectively. Machinery is never left unattended to reduce the risk of injury and accidents. Proper PPE is always equipped when operating, which includes using safety glasses, gloves, hearing protection, and safety vests.

Appendix C: Travel Budget

	Total Estimated Costs	Source
Competition Entry Fees	$250.00	Donated
Hotel ($220/room/night x 7 rooms x 3 nights) Actual =	$4,620.00	Donated
Flight to Denver - United ($209.48/person x 13 people)	$2,723.24	Purchased By Students
Flight from Denver - AA ($221.30/person x 13 people)	$2,876.90	Purchased By Students
Car Rental (one 12-passenger van)	$477.13	Donated
Car Rental (one mini van)	$272.38	Donated
Baggage (AA $200 for oversize fee, UA $200 for oversize)	$400.00	Donated by Mike McGivern
Gas $3.75 x 12 gallons @ 25mpg x 2 vehicles	$90.00	Donated by Mike Mcgivern
Total Adult Meals (2 chaperones x $144)	$288.00	Donated by Mike McGivern
Airport Parking ($25/day x 2 vehicles x 4 days)	$200.00	Donated by Mike McGivern
Apparel (Team t-shirt, polo, and jacket)	$1,500.00	Donated
Total	13,697.65	

Appendix D: ROV Budget

	Part:	Quantity:	Cost Per Unit:	Combined Cost:	Source:
Structure					
	Sheet Of Black Achrylic	4	4.375	17.5	Reused
	3D Printer Motor Holders	8	1.11	8.88	Reused
	3D Printed Motor Shrouds	8	0.23	1.84	Reused
	Waterproof Servo Case	1	16.99	16.99	Purchased
	T-Slotted Rail	4	8.99	35.96	Reused
	Hardware	1	40	40	Reused
	SeaFoam	1	19	19	Reused
Motion					
	T200 Motor	8	200	1600	Purchased
	Waterproof Servo	1	16.5	16.5	Purchased
	Waterproof Connectors	1	2.99	2.99	Reused
Watertight Enclosure					
	Tampons	8	0.21	1.68	Reused
	O-Rings For Penetrators	14	0.21	2.94	Purchased
	Marine Grade Epoxy	1	7.28	7.28	Purchased
	Silicone Grease	1	6.99	6.99	Purchased
	Clear Tube	1	216	216	Reused
	O-Ring Flanges	2	43	86	Purchased
	Penetrator End Cap	1	32	32	Reused
	Penetrators	3	5	15	Reused
	Pressure Relief Valve	1	9	9	Purchased
	O-Rings For Tube	4	0.86	3.44	Purchased
	O-Rings For End Caps	2	0.83	1.66	Purchased
	Clear Dome End Cap	1	40	40	Purchased
	Leak Sensor	2	3	6	Purchased
On Board Electronics					
	Basic ESC Motor Controlle	8	36	288	Purchased
	Logitech USB Camera	2	60.69	121.38	Reused
	Rasperry Pi 4	1	39.99	39.99	Reused
	Navigator Pi Hat	1	500	500	Purchased
	Depth Sensor	1	75	75	Purchased
	Power Distribution Module	1	11.99	11.99	Reused
Tether					
	Fathom ROV Tether	1	220	220	Purchased
	Power Wire Tether	1	109.99	109.99	Purchased
	Snake Skin For Tether	1	24.99	24.99	Purchased
	Backer Rods	6	4.99	29.94	Reused
	Tether Strain Relief	1	8	8	Reused
On-Deck Assembly					
	Watt Meter	1	14.91	14.91	Donated By Motorola
	Pelican Case	1	47.95	47.95	Reused
	Gamepad	1	17.52	17.52	Reused
	Anderson Connectors	1	8.49	8.49	Reused
Total:				**3705.8**	

Appendix E: Schedule Archive

Time Frame:	Goals:
August 29th	- Introduce new members to MATE. - Go over presentations of previous competitions and task lists. - Go over the safety features of machinery and tools.
September 12th, 19th	- Establish two teams that will compete in the Regional tournament. - Old members will explain previous ROV's functionality. - Vote on team positions (CEO, COO, etc.)
October 3rd	- No In-Person Meeting. - Release official team member position results. - Upperclassmen discussion (Topic: New ROV and Funding)
October 10th, 17th	- General Work Day. - Decide on team name (Night Owls) - Finalize ROV plans and start applying for grants. - Help underclassmen with their ROV if needed.
November 7th, 14th, 28th	- MATE 2023 Task List is released. - Team discussion (Topic: New ROV features to complete missions) - General Workdays.
December 5th, 12th, 19th	- General Workdays. - Frame, Electrical Tube, and Manipulator should all be finished before winter break. - Place orders for any parts needed.
January 16th	- Grant money was received and used to cover previous expenses. - Most parts have been received. - Start building buoyancy engine
January 23rd, 30th	- Test print CAD designs for ROV frame on cardboard (laser cut). - Test print CAD designs for motor holders with low infill (3D print). - ROV frame and motor holders need slight adjustments. Implement changes and test again. - All parts functional, ROV frame is complete.
February 6th – 10th February 13th – 17th	- All week-long meetings start. - Electronics testing begins. - All received parts are functional EXCEPT cameras. - Improvise: Took apart two old webcams and used them on ROV. - Code is actively being created to control all motors.
February 20th – 24th February 27th – March 3rd	- Electronics and code are mostly complete. - Need to waterproof electronics tube. - Bought: O-rings to fit tube | Used: Pressure tester. - Made sure electronics fit inside the tube. - Front camera is put on a servo.
March 6th – 10th March 13th – 17th	- Motor Configuration tested and working. - Added handles to frame for ease of transportation. - Made ROV stand so motors don't hit the ground. - Fully configured ROV tested out of water. - Once back from spring break, will test in water.
March 28th – 31st	- Test ROV out of water. - Establish a start-up protocol for team. - Test ROV in water. - Motor configuration had an issue with going up instead of forward, issue was resolved within the same day.
April 3rd – 6th	- Work on tether and ROV buoyancy. - Re-greased o-rings because ROV wasn't holding pressure. - Tether operators created an official protocol.
April 10th-28th	- Underwater practice days. - Weekend practices were hosted at a team member's residence. - Any minor issue resolved immediately. - Practice startup and tether protocol.
April 29th	- Regionals - Scored 2nd Place
May 8th-19th	- Underwater practice at a team member’s residence until June 11th.

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