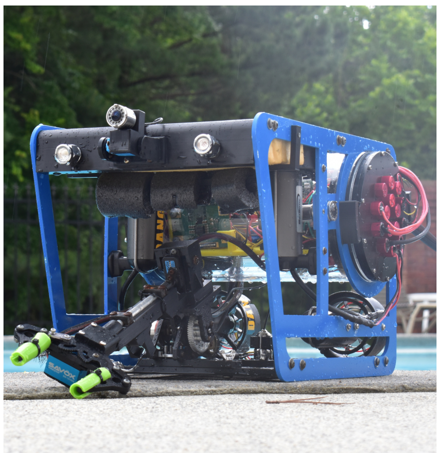
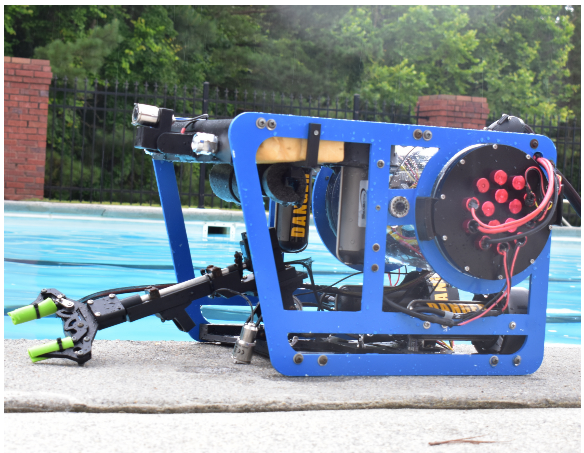
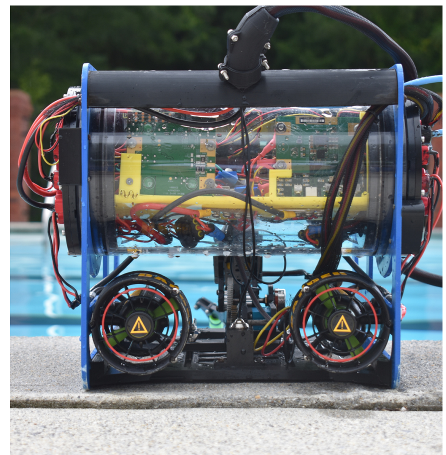
404 Engineering

TECHNICAL DOCUMENTATION


2021 MATE World Championship
Excite, Educate, Empower:
Students engineering solutions to global problems

East Tennessee State University
Johnson City, TN
August 2021

MEET OUR EXPLORER TEAM

Glen Lewis - CEO, Pilot, Lead Electrical Engineer

Michael Lees - Director, Props Mgr., Lead Software Engineer

Ben Buzzelli - CFO, Tether Mgt., Electrical Engineer

Spencer Hood - Safety Officer, Co-Pilot, Mechanical Engineer

Mentors: **Mark and Melissa Lewis**

Kennesaw State University
Dallas, Georgia, USA

ABSTRACT

404 Engineering designed and manufactured, *Error*, a remotely operated vehicle (ROV) capable of completing all requests given by the MATE Center. *Error* can survey a submerged subway car, flying a transect line, monitoring species health and wellbeing, as well as cleaning debris from waterways. Designed with a lightweight and durable frame, *Error*, is easily transportable and capable of withstanding harsh conditions. *Error* was also designed to be as simple as possible to perform maintenance on, making it the perfect choice for long usage scenarios in which maintenance and repair may need to be performed on-site.

404 Engineering as a team is made up of 4 members that worked tirelessly to ensure that *Error* is ready to take on any task. Whether it be the manipulator, the frame, or the software that makes it run, every part of *Error* was meticulously tailored to the needs of the MATE Center to ensure healthy waterways for years to come.

One of the main focuses for the company this year was ensuring transportability was easy so that no job was off-limits due to transport limitations. Thus, *Error* is one of the lightest ROVs the company has ever made, allowing it to complete tasks quickly and without trouble, without compromising on durability and longevity. *Error* is also one of the smallest ROVs the team has ever made, allowing it to maneuver smoothly underwater and fit into tight spaces that would have previously been unimaginable.

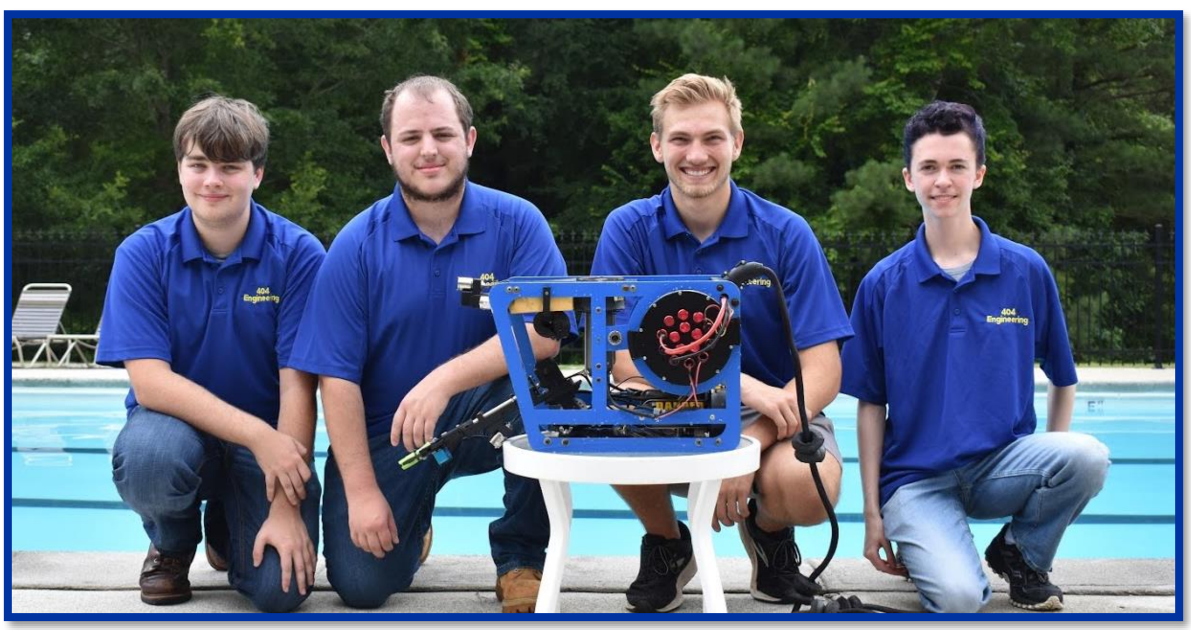


Figure 1: 404 Engineering Team Members pictured with *Error*
(left to right) Glen Lewis, Michael Lees, Ben Buzzelli, and Spencer Hood.
Photo Credit: Melissa Lewis

TABLE OF CONTENTS

DESIGN RATIONALE

Engineering Design Rationale

404 Engineering used a very strict design rationale when developing *Error*. All mechanical parts were required to be designed in 3D CAD software and then discussed with the rest of the team during a meeting. This discussion weighed the cost and effectiveness of the idea compared to other ideas, as well as gave critiques on the design to produce a product that was efficient and cost-effective.

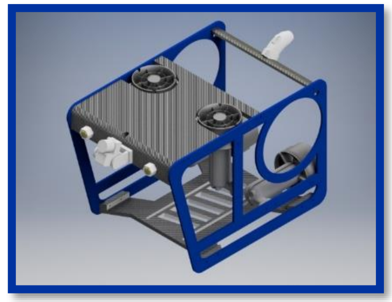


Figure 2: 3D CAD Conceptual design
Image pulled from Autodesk® Inventor®

Throughout the build, the tasks given to us by the MATE Organization were at the forefront of the design. We designed the build to be maneuverable so that it could create a photomosaic of the artificial reef created from a subway car, outplant coral colonies, and complete maintenance on a Seabin. Thrusters were shrouded and placed in such a way as to protect them from the ghost net retrieval. The manipulator was designed to withstand the weight of the eel traps while still being accurate enough to carefully collect a sponge sample. The design of *Error* is simple enough for repair to be a breeze, but still sophisticated enough to complete autonomous flights of a transect line and perform visual imaging. Overall, the entire ROV was designed to meet the specifications of the MATE Organization, while at the same time being capable of future tasks to ensure healthy waterways. *Erro*r was tested thoroughly and thoughtfully throughout the build, leading to a ROV that is better than anything we have previously produced.

Control/Electrical System

Surface Control Box

With surface control systems becoming more complicated, 404 Engineering decided to construct the surface control box centered around simplicity and functionality. The new surface control box (SCB) is where all the surface electronics are stored to protect them from the outside environment. The SCB consists of a 12-volt bus bar that receives power from the ROV and powers our 4 cameras and video splitter. In addition, we have custom fabricated a special camera switch specifically made for the autonomous

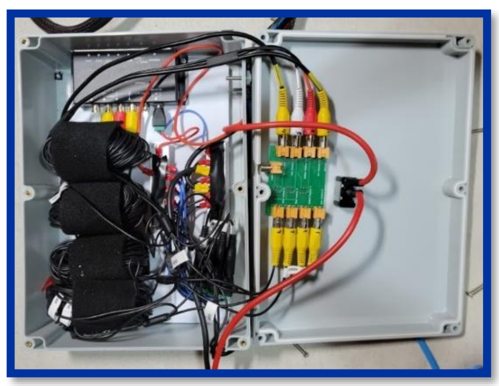


Figure 3: Inside the surface control box.
Photo Credit: Melissa Lewis

portion of the missions. This switch allows for one of the camera's inputs to be diverted from the camera splitter to the laptop for a quick and easy transition of camera inputs. The SCB also contains our communication ethernet cable, main power cables, and camera wires. All excess wire is stored neatly inside the SCB to maintain cleanliness and safety while transporting our ROV.

Accompanying our SCB, are two control joysticks, a monitor, and a laptop. One joystick is operated by the pilot to control the main directional functions of the ROV, consisting of up/down and left/right movement as well as camera tilt. The second joystick is used by the co-pilot and controls all functions of the manipulator; up/down, open/close, and rotation. This separation of roles allows for the streamlined operation of the ROV. The single monitor is used to view all 4 of our camera inputs simultaneously with the help of our camera splitter for quick visualization of the underwater surroundings. The laptop is used mainly for the autonomous operation of the ROV during the transect section of the missions, as well as delivering commands to the Arduino onboard the ROV.

Figure 4: Control Joystick
Photo Credit: Melissa Lewis

Onboard Electronics

The onboard electronics of 404 Engineering was designed to be as efficient and robust as possible, while also maintaining a simple diagnostic and repair process. The system is divided into three main sections, allowing for problems to be isolated and for any upgrades to be easily developed into the current design. Each section contains its own Vicor 48V to 12V switching regulator, capable of outputting 12V at 9A at up to 90% efficiency.

Figure 5: Onboard Electronics using a Blue Robotics Tube
Photo Credit: Melissa Lewis

Section 1: Main Signal Processing

The first section of the onboard electronics system, the Main Signal Processing (MSP), is focused on the microcontroller that is responsible for carrying out all onboard signaling on the ROV, the Atmega2560. This microcontroller runs at 16MHz and communicates with the surface laptop via a USB to Ethernet conversion on either end, allowing for fast data transfer speeds at lengths further than the base USB 2.0 protocol allows for. The microcontroller takes the signals it receives and

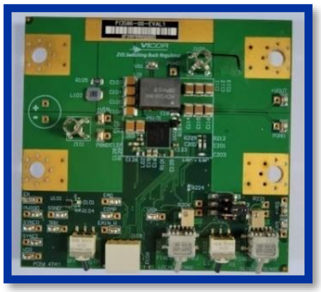


Figure 6: Vicor 48V to 12V switching regulator.
Photo Credit: Melissa Lewis

converts them into varying digital and Pulse Width Modulation (PWM) signals. Those signals are then outputted through the various I/O pins to a custom PCB, the Voltage/Signal Distributor (VSD). The VSD routes the digital signals that it receives to output connections where they can be easily connected to their respective components, including servos, lights, and Electronic Speed Controllers (ESCs). The VSD is also responsible for taking in 12V from the MSP 48V regulator, and then transforming this down to 5V using linear voltage regulators and 7.4V using switching regulators. The 5V coming from the VSD powers the Atmega2560 and the camera tilt servo, while the 7.4V powers the servos on the manipulator.

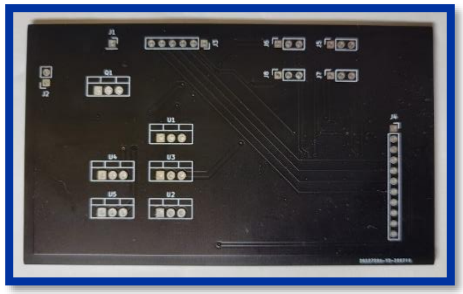


Figure 7: Voltage/Signal Distributor (VSD).
Photo Credit: Melissa Lewis

Sections 2 and 3: Left/Right Motor Control

Sections two and three of the onboard electronics system each consist of a 48V Regulator and a Sabertooth 2x12 ESCs capable of controlling two brushed DC motors at 12A each. Each section controls one side of the ROV, including both the horizontal and vertical thruster on its respective side. The Sabertooth ESC takes in a PWM signal running at 50Hz with an on-time ranging from 1000 to 2000 μs. This signal is then used to control the polarity and voltage delivered to the ROV's thrusters. The voltage to the Sabertooth is given by each section's respective 48V to 12V regulator, allowing for maximum available

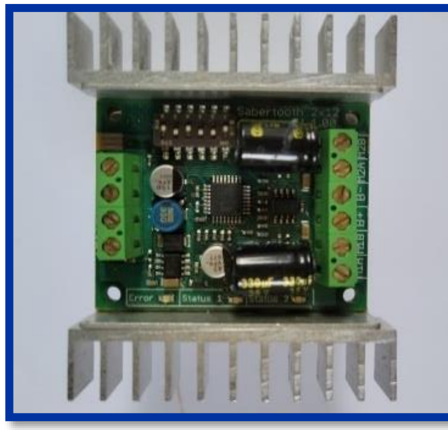
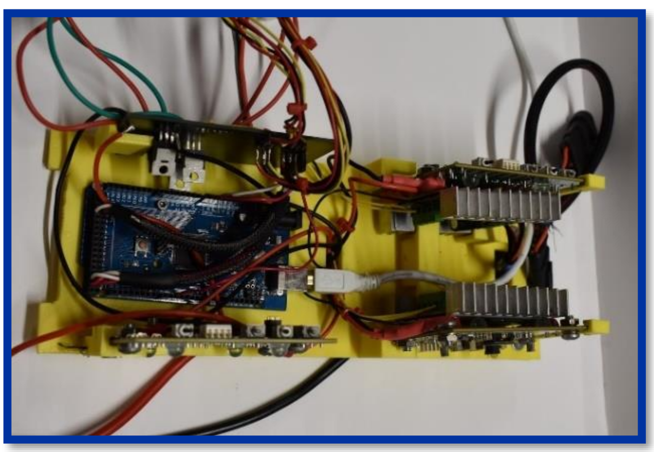
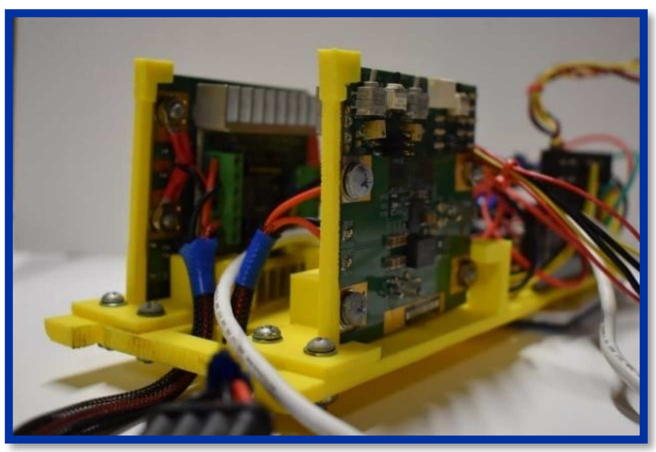


Figure 8: Sabertooth 2x12ESC
Photo Credit: Melissa Lewis





Figures 9 and 10: Control system components installed inside the onboard electronics housing shelf.
Photo Credit: Melissa Lewis

amperage delivered to the motors while still constraining the size of the electronics.

The ROV uses a Blue Robotics 6-inch series enclosure to protect the electronics contained inside from water, and anything outside the housing from the electricity contained inside. The enclosure measures 16.5cm in diameter and 30.5cm in length. The opening to the cylindrical housing is approximately 13cm and all electrical components had to be small enough to fit within this size. All of the electrical components protected by the housing are mounted to a custom 3D printed shelving unit and are connected to the ROV's components via detachable connectors. This allows for the electrical components to be maintained and repaired easily without having to disassemble the entire onboard enclosure.

Tether

Error's tether consists of one CAT 5e Ethernet cable, two 10 American Wire Gauge (AWG) wires, one 16 AWG wire, and the four camera cables; all sheathed within half-inch tech flex. The two 10 AWG wires and the 16 AWG wire are silicone insulated, allowing for the tether to be more flexible. The silicone cables are heavier and require adding buoyancy to help keep the tether neutrally buoyant. The ethernet cable is used to communicate between the laptop and *Error*, the camera cables provide video feeds to the pilots, and the other wires are used to distribute power to and from the ROV. The tether is about 18m in length, allowing for *Error* to reach deep waters and far away tasks. Overall, the flexibility and length of *Error*'s tether allow for heightened maneuverability easy transportation of the ROV.

Figure 11: Tether
Photo Credit: Melissa Lewis

Software

Basic Controls:

The programming for 404 Engineering's *Error* comes in two forms: the onboard programming utilizing the Arduino C++ variant and the surface program which utilizes the Python programming language. The surface control scheme consists of two Logitech extreme 3D pro joysticks connected to the computer via the USB interface. The python program reads this input as a data array, which is then converted to a motor and servo data array using various mathematical equations. This converted data array is then sent to the ROV via the serial communication protocol utilizing a byte array. The byte array allows us to achieve roughly 200 μs round trip communication. The data is read by the

Arduino's on-board programming written in the Arduino wrapper for C++ and is converted to electronic signals for the servos and motor controllers.

Transect Autonomous Program:

Error was designed with an autonomous program capable of moving itself over a distance of three meters while taking pictures every meter. These pictures are then stitched together to form a collage of the coral reef below. 404 Engineering decided to utilize a deep learning algorithm to ensure *Error* followed a straight path and pictures were taken at the proper intervals. Our deep learning model was trained via a unity simulation created with various real-world attributes such as drift and gravity. This model took only twenty hours to complete training.

The algorithm designed for *Error* detects the outer edge lines of the coral reef while testing the middle lines for the end of the coral reef. We created this algorithm using a reinforcement learning model, which utilizes teaching the algorithm utilizing a reward system. If the algorithm makes a correct move it is rewarded, however, if it makes a wrong move it is reprimanded. As in every reinforcement learning algorithm, the first few generations of training are of a lower quality than the final generations. However, after approximately 20 hours of training the reinforcement algorithm and fine-tuning, the model resulted in an algorithm that can perform beautifully.

After the model was successfully moving through the water, we configured the program to take a picture every three squares, allowing the algorithm to properly create the three images needed for the image stitching. After completing the flyover of the coral reef, the three images of the coral reef are then sent to a remote server hosted on a cloud computing service.

The server then takes the three images and returns the final stitched image. The complete photo mosaic is created using the order in which the images are taken. After the image is stitched together, an image recognition algorithm is applied to analyze the individual parts

Figure 12: Image recognition screen.
Photo Credit: Michael Lees

of the coral reef. The individual parts are analyzed using a shape recognition algorithm to determine what the individual components of the coral reef are. After each of the coral-reef pieces are determined, the correct shape is drawn on top of the original image after being analyzed, the original image is then removed leaving the new layer which is then shown on the laptop screen after receiving the final image via the secure file transfer protocol.

Subway Autonomous Stitching Program:

To complete the photomosaic of the Subway car, the pilots of *Error* position the ROV in front of each side. When positioned the pilots take a picture which is then stored within a folder for later use. After each side of the subway car has been photographed, the images are then sent to a remote server. The server is responsible for completing the photomosaic and sending the completed file back to the pilots. The server takes each image and searches for the largest contours or shapes, for which it crops the images down to the size of their largest shapes. After completing this for each image, the shapes are then positioned within a coordinate grid determined by the order of the images taken. The photomosaic image is then sent to the control laptop where it can be reviewed.

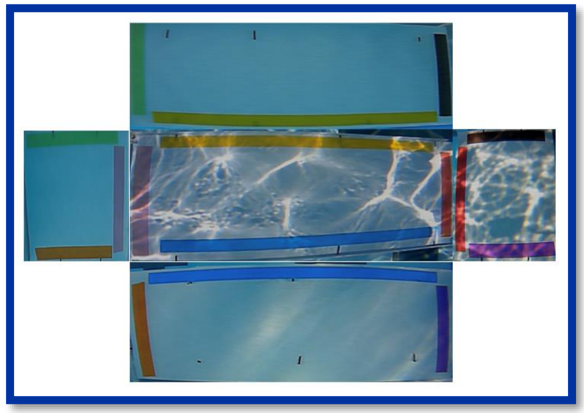


Figure 13: Image recognition screen.
Photo Credit: Michael Lees

Image Recognition Program:

Error has been configured to determine the health of a coral colony positioned within a coral reef. The pilots receive a file containing an image of the coral colony from one year before the mission start. The pilots are able to take a picture of the coral colony which is then saved onto the control laptop. The image recognition program then uses an overlay method of comparison, which is when the reference image is overlaid over the new image taken. The program performs a compare-contrast algorithm to determine the differences.

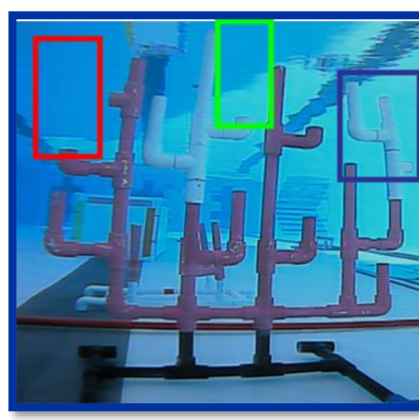


Figure 14: Image recognition screen.
Photo Credit: Michael Lees

Frame

The company's goal for this build was a more refined design that was lightweight and smaller than previous builds. To accomplish this, we chose to make the main structure of the frame out of 3/16-inch PVC sheets. We utilized our college's waterjet CNC to get the sides of our frame manufactured. There are holes cut out for the onboard electronics to be properly seated on the ROV. The thrusters are mounted inside the ROV to meet the size requirements and provide forward and backward motion. The top and bottom plates of the ROV are 3D printed to provide a custom solution that best fits the design. For wire management, the top plate was designed with a channel to keep wires maintained and protected. The top plate was designed around two thrusters for easy water flow and vertical motion. In previous years it was discovered that a retractable arm was extremely useful for transport and the company decided to incorporate it in this year's baseplate. To do this, slots built into the base plate that mounts to the manipulator using quarter-inch bolts with wing nuts.

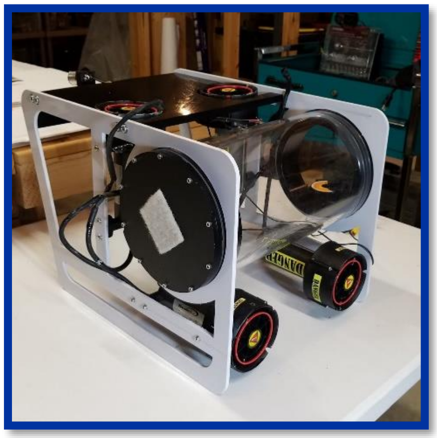
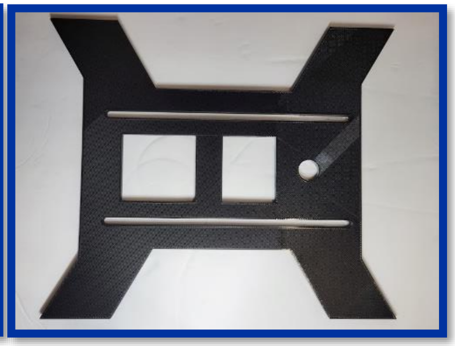


Figure 15: Test fit with frame.
Photo Credit: Melissa Lewis



Figures 16, 17, 18 left to right: Side frame piece cut from PVC. Scale frame prototype. 3D printed bottom base plate.
Photo Credit: Melissa Lewis

Thrusters

Our ROV consists of four Seabotix BTD150 motors that were used on previous builds. Each thruster is positioned inside the frame, two are positioned vertically for upward and downward motion and two are attached to the frame at the back of the ROV for forward and backward motion.

Figure 19: BTD150 Seabotix thruster
Photo Credit: Melissa Lewis

The four BTD150 Seabotix thrusters have a depth range of 150 meters. The continual thrust is 2.2 kg at only 4.25 amps. The propellers on the thrusters consist of 76mm blades. The dimension for each thruster is 17.3cm x 9.4cm x 8.9cm, with each weighing 350 g in water. The thrusters use an anti-corroding steel and allow water to flow freely throughout its compact design. The ROV draws 17 amps of electrical power when all thrusters are in use.

Figure 20: Forward/back thrusters mounted on ROV baseplate.
Photo Credit: Melissa Lewis

Buoyancy and Ballast

The buoyancy for *Error* was made using a polyurethane two-part mixture and was cut using a CNC to fit under the top plate of the ROV. Much of the buoyancy comes from the Blue Robotics electronics enclosure, so much that ballast was added in the form of two 1.14kg weights underneath the enclosure to level out the ROV for optimal maneuverability. The amount of polyurethane used was estimated by using the Archimedes principle, which uses the density of the water, acceleration due to gravity, and the volume of the ROV to estimate the amount of buoyant force present. This calculated force is then compared to the force necessary to lift the ROV and the amount of polyurethane needed is then calculated. By using this method, we were able to get a very close estimate of the amount of buoyancy necessary before arriving at the pool for testing. Any deficit that was found was made up using open cell pool noodles added under the top plate of the ROV.

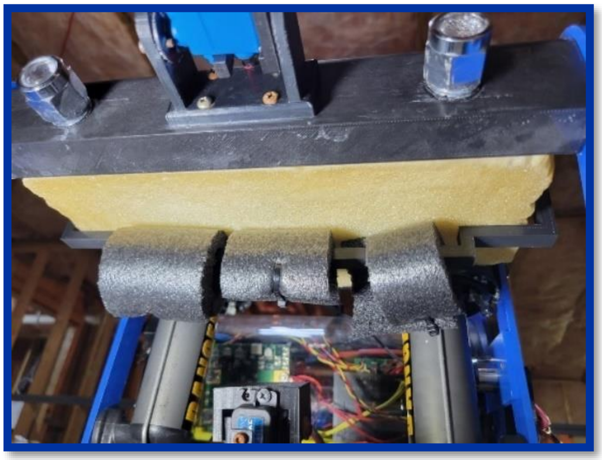


Figure 21: Buoyancy mounted underneath top plate.
Photo Credit: Melissa Lewis

Payload and Tools

Manipulator:

Figure 22: Custom designed manipulator.
Photo Credit: Melissa Lewis

Error has been configured with a two-axis manipulator measuring 24 cm in length and consists of 3 servos, a tilt mechanism, and a claw. The manipulator utilizes three waterproof Savox SW-1210SG servos to allow the manipulator to rotate in two axes. The first axis of movement for the manipulator is the tilt which allows the pilots to move the manipulator roughly 100 degrees. The second axis allows the manipulator to twist 140 degrees, allowing the pilots to position the claw in various positions so the ROV can remove the pin from the ghost net and retrieve coral pieces from the ocean floor.

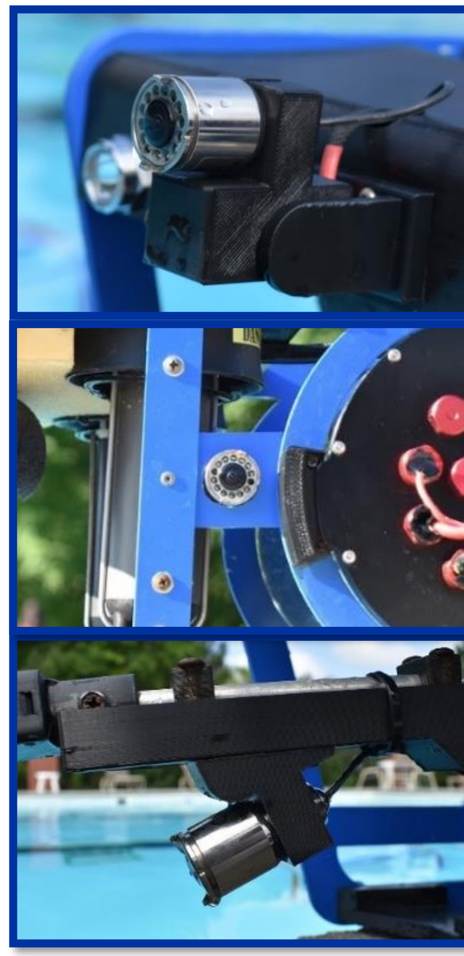
During testing and troubleshooting the tilt mechanism went through various revisions. 404 Engineering attempted to create the mechanism utilizing a 3D printer. Each revision allowed the company to better understand how each part of the tilt mechanism functions and make the necessary adjustments to improve the overall function of the manipulator. This increased the effectiveness of the ROV allowing for expedited task completion times, saving on the cost of running the ROV in the future.

The company decided to purchase and modify the SPT-400 tilt kit from servo city as the costs associated with the research and development of these revisions were growing close to the cost of the tilt kit. This reduced the downtime for the assembly of the manipulator and allowed the company to focus on other tasks of the ROV. The twist portion was 3D printed and used an aluminum rod allowing for a custom design while being cost-effective and lightweight. The claw for the manipulator allows for the pilots to provide the ample grip strength required for retrieving the ghost net pin, coral fragments, and the eel trap. Instead of working with a custom 3D printed design for the claw, 404 Engineering decided to use a claw kit from Servo City USA that had been used in past builds to simplify the complexity of the design and time to manufacture. The entire manipulator weighs roughly five pounds.

Cameras

Error uses four cameras placed in strategic locations to complete tasks efficiently. *Error* uses fish finder cameras as they are easy to mount and waterproof. Each camera is placed where it can be used for a different purpose: the main camera is placed on a custom designed tilt mechanism, the manipulator camera is placed on the bottom of the manipulator, the side camera is placed near the center of the side plate of the frame, and the bottom camera is placed near the rear of the bottom of the base plate. All the cameras' cables connect to the surface through the tether. Once on the surface, they are routed through a custom camera switch that allows pilots to choose where the camera signals are going. The switch can allow cameras to go to the laptop where it is used for visual recognition or to the video splitter where multiple cameras are put into a single video feed and sent to the monitor.

The main camera of *Error* is mounted on a custom-designed tilt mechanism to increase ROV efficiency. By having the camera capable of tilting, the pilot gains both spatial awareness and depth perception by being able to tilt the viewing angle. The tilt mechanism is created by using a Hitec HS-5086WP micro waterproof servo that is mounted to a 3D printed housing. The concept behind the main camera tilting mechanism consists of the servo horn being mounted to a plate and the other side of the servo being mounted to a rod using the 3D printed housing. By mounting the servo like this, it allows for the servo to tilt the camera the full 150°. The new tilting design saves cost, weight, and space compared to previous designs by using 3D printed parts, as well as using a micro servo rather than a full-sized servo.



Figures 23,24,25 Cameras
Top: Front main camera on custom tilting mount.
Middle: Side View camera
Bottom: Camera installed on manipulator
Photo Credit: Melissa Lewis

The other cameras are placed where they can effectively be used to complete other tasks given by the MATE Organization. The camera on the bottom of the manipulator allows for better depth perception when picking up important objects. This camera also gives a viewing angle to properly install the Seabin power connector as well as out planting the coral fragments. The side camera allows for a better understanding of the ROV's surroundings, as well as a viewing angle that allows for *Error* to save time when completing the subway photomosaic by not having to rotate for most of the faces of the car. The bottom camera is also used for viewing the surrounding area, as well as allowing for the transect line to be flown autonomously by sending the video feed to the laptop.

Quadrat

Error comes with a quadrat that is used to easily estimate the number of mussels present in a mussel bed. The Quadrat is square and made from PVC sheeting with inner dimensions of 50cm. The Quadrat is placed on top of a mussel bed. Knowing the number of mussels present inside of the quadrat and the total area of the mussel bed, an estimate of the number of mussels present inside the entire mussel bed can be made. This is done by taking a ratio of the number of mussels inside the quadrate vs the area of the quadrat and comparing this to the number of mussels inside the entire bed vs the area of the whole mussel bed. After getting this number, an estimate can be made of the filtration rate of the mussel bed. This number can help determine the health of the bed and the ecosystem it is in, and a further decision can be made about whether this vital part of the ecosystem needs human intervention and assistance.

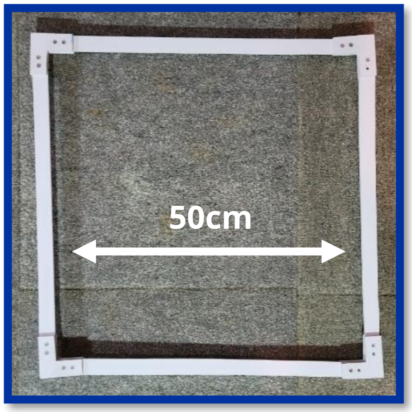


Figure 26: Quadrat
Photo Credit: Melissa Lewis

Seabin Power Connector

404 Engineering was tasked with designing a custom Seabin Power connector to perform regular maintenance on a Seabin deployed in the water. This power connector uses an inductive coil to transfer power to the Seabin, where the light will illuminate once properly powered. 404 Engineering met all specifications provided for designing the power connector and created it in a way that it was easy to install with *Error*. The power connector has an 18-meter-long cable that is sheathed using tech flex allowing for the connector's cable to stay out of the way of the ROV while it performs other tasks and allows for safe packing of the connector as no sharp cable ties are present.

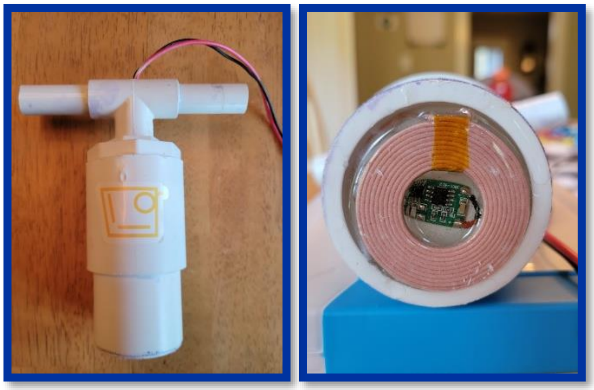


Figure 27 and 28: Seabin power connector and inductive coil.
Photo Credit: Melissa Lewis

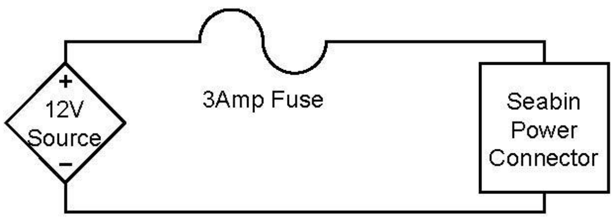


Figure29: Seabin power connector SID

Plastic Pollution Retrieval Device (PPRD)

Error comes equipped with a Plastic Pollution Retrieval Device, allowing for trash to be removed from the surface of the water with just one attachment. The PPRD is attached to *Error* by connecting it to the manipulator, allowing for a strong and stable connection that also lets the pilots control how much of the device protrudes above the water. A net was chosen to collect the pollution because it was cost-effective and did not require any electrical components that would draw power, such as a bilge pump alternative. The PPRD is easily attached to *Error*, and after retrieving the pollution from the surface of the water, it can be easily removed to allow *Error* to continue to complete other tasks without hindrance.

Figure 30: Netting portion of PPRD
Photo Credit: Melissa Lewis

CRITICAL ANALYSIS

Testing and Troubleshooting

Throughout the build, many parts needed to be tested, and sometimes parts would need maintenance and repair. Each year the thrusters are tested to ensure proper thrust output using a spring scale that allows us to measure the force of thrust given by the thrusters at different voltage levels. PCBs are also tested using a Digital Multimeter (DMM) and a variable power supply to ensure all traces and circuits were working as intended.

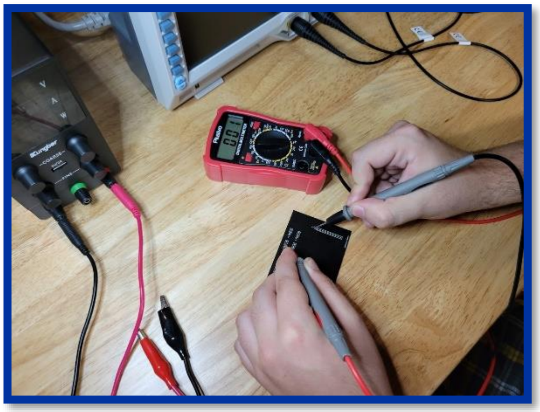


Figure 31: Testing signal continuity through new PCB.
Photo Credit: Michael Lees

When problems occurred on the ROV, we followed a strict method of diagnosing the issue. First, the problem was determined to be either Mechanical, Electrical, or Software related. If the issue were mechanical, the part would be disassembled, and the root problem would be redesigned to prevent further issues. If the issue were determined to be electrical, a DMM would be used to determine that all wires are carrying the proper voltages and signals. The issue could then be determined to be a bad part by following the voltages that would then be replaced or could be

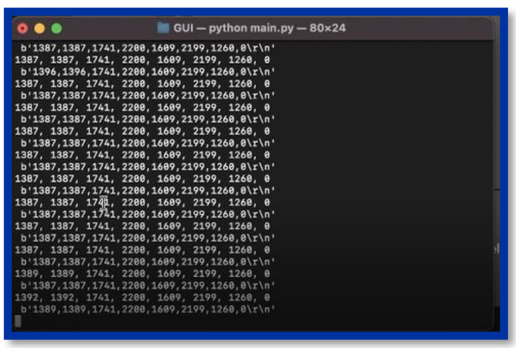


Figure 32: Debugging output from computer terminal.
Photo Credit: Michael Lees

determined to be a break in a wire. If the issue is determined to be a software related, the software is looked at for any debugging errors. The output for these kinds of problems is printed to the computer terminal where both the pilots can see the errors.

During the build three voltage regulators malfunctioned, causing them to need to be replaced with either exact replacements or higher amperage equivalents to prevent future malfunctions. Three servos malfunctioned during the testing phases of the ROV, two of those servos had to be replaced, and one was able to be repaired by fixing a gear mesh issue. By being able to repair the servo, the company was able to save on the expenses of purchasing a new one.

PROJECT MANAGEMENT

404 Engineering is a company consisting of four members who have been designing and building ROVs for over 8 years. We met twice a week and always began with a detailed description of what had been accomplished in each member's own time, as well as what needed to be done moving forward. Each member was responsible for specific tasks throughout the week, allowing for a four-man team to do the job of what had previously taken ten or more people in the same amount of time. This increased efficiency allowed for more time to practice with the ROV and for more issues to be noticed before they became a large problem.

SAFETY

Safety is imperative in everything that is built by 404 Engineering. Whether it be working conditions or the ROV itself, safety is always maintained and evaluated. For instance, danger stickers placed on all moving parts like the manipulator and thrusters to prevent injury via placing an object in their path. To ensure the thrusters were safe and not harm any underwater wildlife we added our own custom printed shrouds, these shrouds also prevent thin objects such as the ghost net from getting caught in the thrusters and causing issues. We did a thorough check of our ROV to confirm there were no sharp edges that could harm anyone handling the ROV and confirmed all designs used rounded corners rather than sharp ones whenever possible. All solder joints that are present underwater have heat shrink and a liquid sealant to ensure they do not conduct electricity to the surrounding waters, causing electrical hazards and possible malfunctions of the ROV.

Figure 33:
Using proper PPE when operating machinery
Photo Credit: Melissa Lewis

To make our work environment safe we used a well-vented space with fans. All dangerous equipment is placed away from our main work area to ensure people are safe from flying objects or any accidents that might occur when operating the equipment. All our members had to demonstrate proper training on any tools before they were able to use the tools on their own, and many tools required partner supervision in case of an accident occurring. Large equipment was always shut off after use and sharp objects or blades were always covered to prevent accidental injury. Proper clothing like close-toed shoes was always worn and eye protection was used when handling equipment and tools. A respirator was used whenever operating the CNC or working with chemicals to prevent respiratory hazards.

At the pool, we made sure all our members knew how to swim in case of emergency. Before the ROV was powered on we checked to make sure no water was present inside the onboard electronics housing. All connections are checked to ensure they are connected properly and away from water to prevent an electrical hazard. When placing the ROV in the water and taking it out deck commands are used, such as ROV in, hands clear, and ROV out. While the ROV is in use the tether stays neatly coiled to prevent tripping hazards and ensure tether management is simple so the ROV can maneuver through the water with ease.

ROV Checks	Completed (√)
a. All Payloads are secure	
b. Dangerous parts are shrouded to prevent injury	
c. No sharp edges are present on the ROV	
d. The Onboard Electrical Housing is properly sealed	
Pre-Launch Checks	
a. Tether is neatly coiled to prevent tripping hazards	
b. Ensure Onboard Electrical Housing is sealed	
c. Fuse is properly sized	
d. Fuse is within 30cm of power connection	
e. Danger labels are properly placed	
f. Anderson power plugs are used as the main electrical attachment point	
g. Surface Control Box is sealed	
Operating Checks	
a. Ensure no water has leaked into Onboard Housing	
b. Ensure no threads get caught in the thrusters	
4. Removal Checks	
a. Ensure Motors are off	
b. Ensure Arm is in a safe position	
c. Ensure both tether and retrieval members are prepared	
d. Ensure the ROV suffered no damage after removal from the water	

Table 1: Safety Checklist

ACCOUNTING

Budget

As a first-year Explorer team, with previous experience from recently being a Ranger team, we are used to forming a proper budget and sticking to the budget throughout the building process. By comparing our expenses from previous years, we were able to construct a solid budget consisting of $2,500 for purchased components. We successfully were able to stay under budget as we only spent a total of $2,231 this year. We were able to make a small budget this year as a large majority of components were reused and saved us a large sum of money. This year we reused a total of $3,591, with our BTD-150 motors saving us the most. An additional segment in our budget was added this year to purchase manufacturing and miscellaneous equipment. The team was given a budget of approximately $3,400 and we came in just under that at the end of the season. These funds are not included in our build budget as the money was provided to us by North Paulding Robotics in a exchange for their team's use of the equipment throughout the season.

Our income this year consisted of member dues as well as fundraisers. To keep track of all costs throughout this extended season, we maintained a folder containing all our invoices and receipts so we could constantly keep track of how much we have spent and to ensure we do not go over budget.

Build vs buy, new vs re-used

This year our team decided to manufacture several parts of our ROV that would be cost-effective for our team. Some of these items include the manipulator, top and bottom brackets, and the frame. Deciding to build these items saved us a large sum of money as we did not have to pay for a 3rd party manufacturer to construct each part. Additionally, building these parts enabled us to test our research and design capabilities and allowed each team member to become more familiar with a variety of CAD design software.

When deciding to buy an item rather than build it, our team would decide if building the part would be more cost-effective compared to purchasing the part. Such items that were purchased included servos, motors, PCB manufacturing, and several electronic components.

404 Engineering Budget:

Reporting Period:	Aug 2019 - June 2021
CFO/Budget Manager:	Ben Buzzelli

Reused Components			
Name	Budgeted	Spent	Deficit
BTD-150 Thrusters	n/a	$3,000.00	n/a
Waterproof Electronics Housing	n/a	$451.00	n/a
Tilt Kit	n/a	$30.00	n/a
Claw Kit	n/a	$30.00	n/a
Video Splitter	n/a	$50.00	n/a
Lights	n/a	$30.00	n/a
Total -Reused	n/a	$3,591.00	n/a

Purchased Components			
Name	Budgeted	Cost	Deficit
Frame	$175.00	$150.00	$25.00
Sabertooth ESCs	$175.00	$150.00	$25.00
48V to 12V Regulators	$200.00	$250.00	($50.00)
Voltage Regulators	$50.00	$25.00	$25.00
Misc Electrical Components	$50.00	$30.00	$20.00
Filament	$200.00	$125.00	$75.00
Electrical Wiring	$75.00	$46.00	$29.00
Savox Servos	$540.00	$690.00	($150.00)
Hitech micro servo	$50.00	$43.00	$7.00
Buoyancy	$60.00	$50.00	$10.00
Tether	$120.00	$114.00	$6.00
Surface Electronics Housing	$55.00	$29.00	$26.00
Cameras	$250.00	$200.00	$50.00
PCB Manufacturing	$60.00	$50.00	$10.00
Fuses	$30.00	$27.00	$3.00
Anderson Powerpole Connectors	$110.00	$104.00	$6.00
Misc Hardware	$300.00	$230.00	$70.00
Total -Purchased	$2,500.00	$2,313.00	$187.00

Purchased Equipment		
Name	Money Given	Cost
CNC Mill		$2,000.00
Batteries		$370.00
48V Power Supply		$432.00
Band Saw		$180.00
Drill Press		$170.00
Bandsaw Blades		$60.00
Bag Sealer		$25.00
Total Cost	$3,400.00	$3,237.00

Income		
Membership Dues		$1,000.00
Fundraising Efforts		$1,250.00
Sponsorships		$250.00
Total Income		$2,500.00

Totals - Overall		
Reused		$3,591.00
Purchased		$2,313.00
Equipment		$3,237.00

Table 2: Budget

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bioPURE
East Tennessee State University
Jody Patterson and the Gray's Reef National Marine Sanctuary

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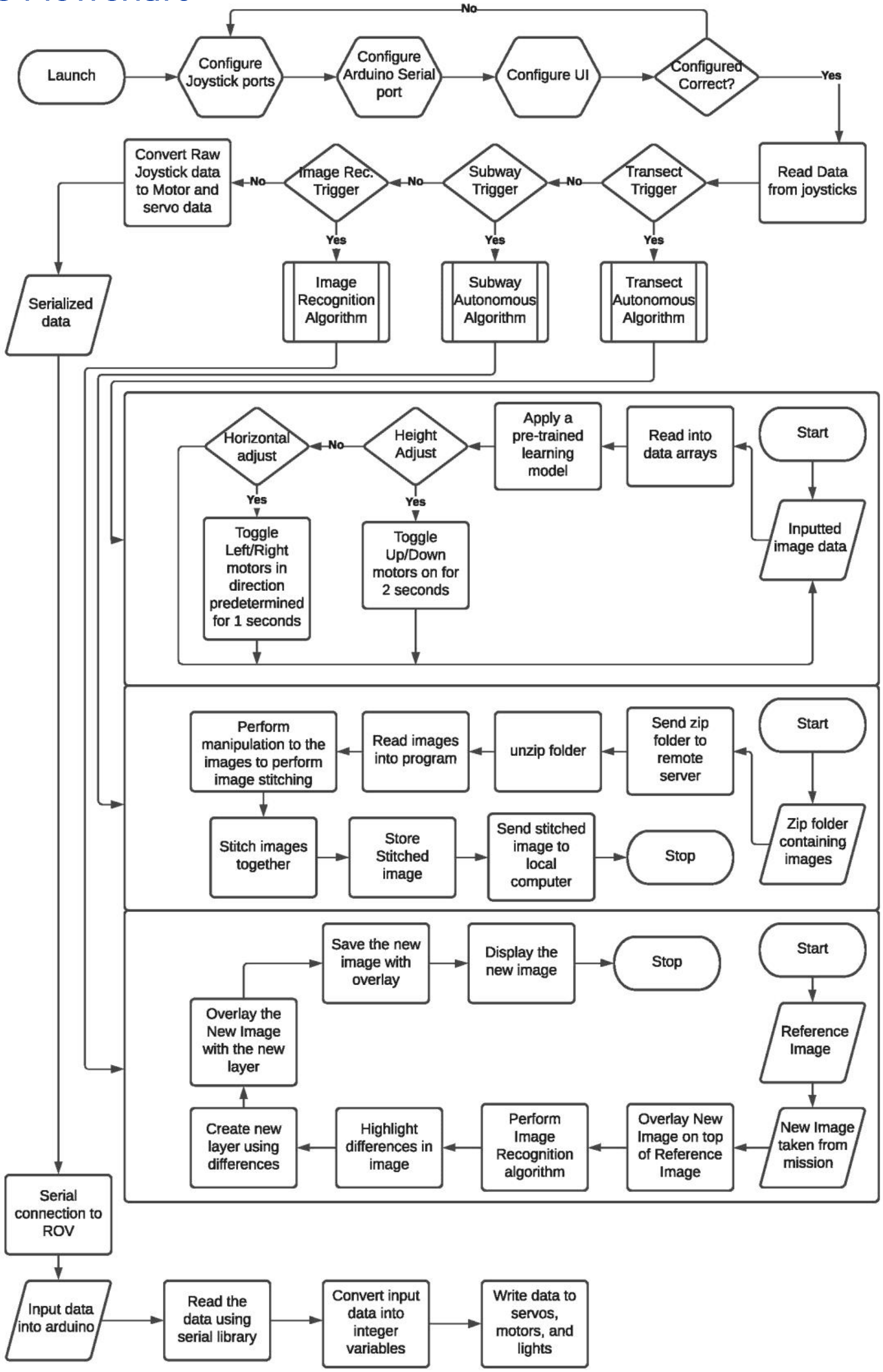
EY
Floor and Décor
Think GA Homes
Governor's Town Club and Senator's Ridge Subdivision for the use of their pools.
Our mentors Mark and Melissa Lewis, Roland and Nicola Lees, and our parents.

Appendix

Software Flowchart



Main Electrical SID