Brother Rice Robotics

"Battling for a Bluer Tomorrow"

10001, S. Pulaski Ave, Chicago, IL, USA

NEMO 2.0

Photo Credit: N Scott

Crew Members

Sam Lapenas	'24	CEO	Dan Hernandez	'24	Fabricator
Andy Andrade	'24	CEO	Jack Makuch*	'26	Fabricator
JD Gamboa*	'24	Lead Electric	Jack Tadevich	'24	Fabricator
Nic Dodsworth*	'24	Lead Code	Oscar Roa	'25	Fabricator
Max Griffin*	'26	Lead CAD	John Kruder	'25	Fabricator
Bobby Gilligan	'24	Lead Mech	Nate Sears*	'26	Fabricator
Elijah Lemay	'24	Lead QC	Dom McCann*	'27	Fabricator
Alex Kmak*	'25	Lead Marketing	James Lapenas*	'24	Fabricator
Dominic Lanuti*	'26	Asst. Electric	Derek Van Dyke		Club Mentor
Vince Walker*	'26	Asst. Mech			
Nick Smolek	'24	Fabricator			

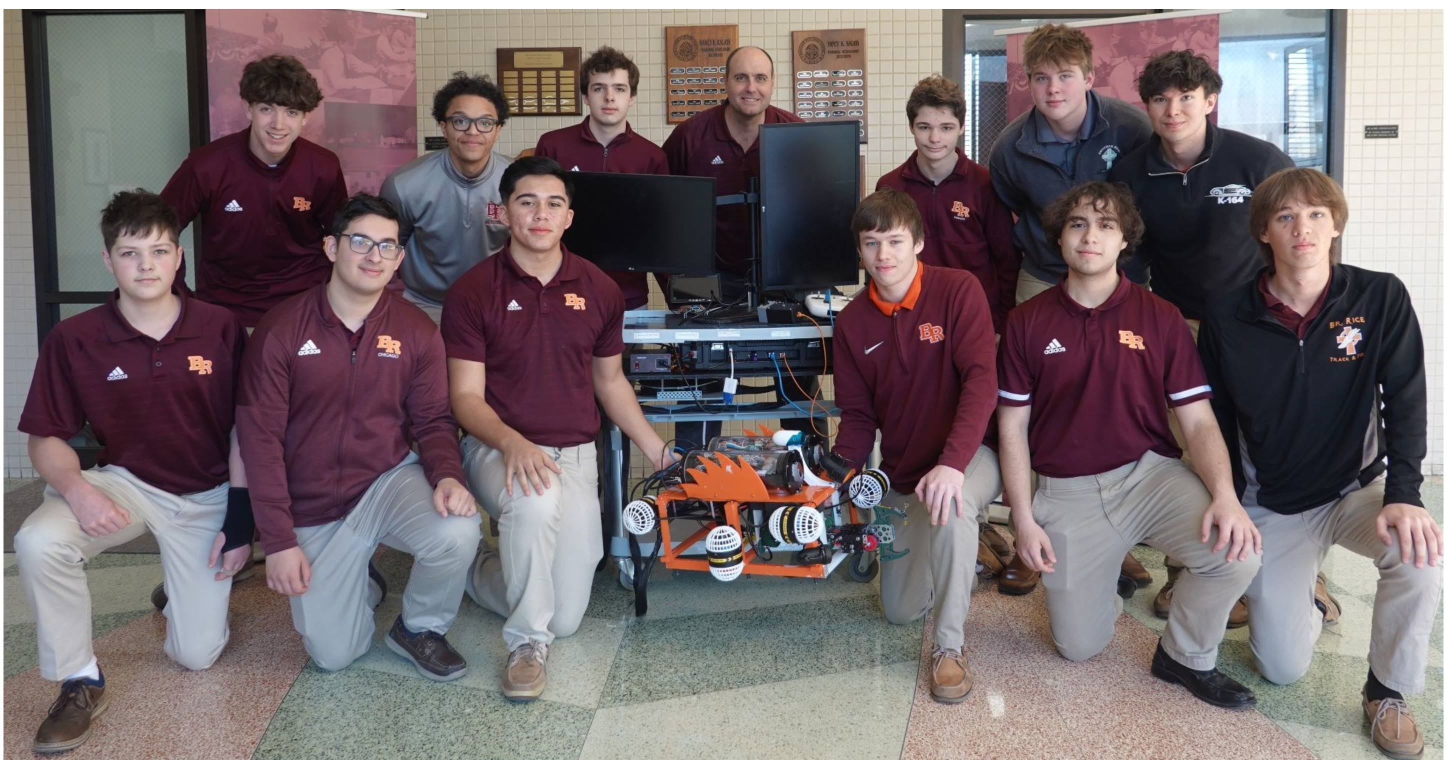
* Denotes New Crew Member

Table of Contents

Abstract

Brother Rice Robotics is driven by the urgent need to understand our global ocean, protect it from the ravages of human induced climate change and pollution and restore it back to the “ocean we need” in order to sustain the vibrant diversity of aquatic and terrestrial life that planet earth is known for. We believe robotics is the most effective vehicle to improve global ocean health. We have been in operation in Chicago, IL since 2014, designing the technologies needed by the Global Ocean Community to do their vital work. We are especially proud to be developing technologies to assist the GOC in meeting the United Nations 10 sustainability goals for their “Decade of Ocean Science for Sustainable Development”[1] initiative.

NEMO stands for; Nautically Engineered Marine Operator. Our NEMO 1.0 ROV was a success in 2023. Our goals for NEMO 2.0 were threefold 1.) continue successful NEMO 1.0 traits 2.) improve NEMO 1.0’s weaknesses and 3.) meet the demands of the GOC in 2024. We used engineering design methodology to design and perfect NEMO 2.0. A new wide angle camera and depth sensor aid in navigation and photogrammetry. A temperature sensor allows for calibration of Smart Repeater Nodes, and the claw can now rotate 90deg to turn the coral probiotic valve and remove buoy pins. Named in honor of the great submersible explorer Victor Vescovo[2], our vertical profiling float, the VESCO 1.0 (Vertical Environmental Survey Collecting Omnibus), is also new for 2024. The tools and capabilities of NEMO 2.0 and VESCO 1.0 will allow them to succeed at MATE ‘24 and to be used by the GOC to perform vital observational and restorative marine tasks around the world.



Company Photo

Back Row (Left to Right): Vince, JD, John, Derek, Dominic, Bobby, Elijah

Front Row (Left to Right): Nate, Dan, Andy, Sam, Nick, James

Photo Credit: N Scott

Project Management

Company Profile

Brother Rice Robotics is an employee driven company dedicated to delivering the highest quality products to our customers. BR Robotics is passionate about developing advances in robotics to help better understand and conserve the planet, specifically in the area of global ocean health. We have been partnering with the GOC for some time to help better understand and conserve the global ocean and meet the UN's 10 Ocean Decade goals[1]. We currently employ 19 team members who range in company experience between 1 and 4 years and have a good mix of returning (experienced) and new (inexperienced) team members. The team uses the following considerations (Figure A) to democratically assign team member roles (Figure B), within our three tiered club structure for each season.

Role Assignment Considerations

1. Previous roles
2. Previous performance
3. Skills and knowledge possessed
4. Organization and attention to detail
5. Team commitment level and number of outside commitments

Fig. A: Credit: JD Gamboa

Description of Team Roles

Level 3: Chief Executive Officer (CEO) — This role can be assigned singly or to a pair of individuals. The CEO(s) is responsible to lead the club and provide strategic and decisional over sight to all areas of the project

Level 2: Lead — This role takes charge of a specific branch of engineering, Electrical, Software (coding), Mechanical, CAD, Quality Control (QC) and Marketing. Leads assist in every area of the project in which their discipline is utilized. Lead's often have assistants who are apprenticing for the Lead role in the future.

Level 1: Fabricator — This role is very general and those with this designation help out in any area of the project as needed and as determined by the team Leads. These members are gathering the skills and knowledge needed to one day ascend to level 2 or 3 leadership positions.

Fig. B: Credit: JD Gamboa

Planning and Scheduling

Each season BR Robotics engages in two lengthy planning sessions that in two separate phases. Phase 1 analyzes the performance of the previous year's ROV. Specific areas of improvement are determined and brainstorming for those specific advances is initiated. These advances are considered "global" as they are needed no matter what the needs of the GOC may happen to be. A schedule was then put together to finish these improvements prior to the MATE 2024 release. Phase 2 began in December when MATE released the Ranger Competition Manual[3] which outlined the needs of the GOC in 2024. The team then conducted an additional planning session to determine what new tools and capabilities will need to be developed. A summary of this work can be seen in Figure C. Team leads then took responsibility for the planning and execution from that point forward.

Global Improvments			
Capabilty	**Specific Improvement**	**Assigned to**	**Taget Date**
Greater speed	Upgrade to T-200 L and R thrusters	Kmak	End Oct
Navigation veiw	Purchase and install 3rd camera and monitor	Max	End Oct
Organize WTE	Purchase and install new 4" WTE	Nico	End Oct
Easy & safe transport	Cart System	Sam	End Dec
Organize TCB wiring	Clean up wiring pathways	JD	End Nov
Visual Recognition	Fish theme, functional eyes and fins	Vince	End Nov
Safety Signage	Install warning labels on NEMO	Elijah	End April

2024 GOC Improvements			
Capability	**Specific Improvement**	**MATE Task/s**	**Taget Date**
Versitile claw	Improve claw to rotate 90deg	1,2,3	End Mar
Lower required balast	Reduce the volume of WTE's with "innertube"	1,2,3	End Mar
Water temp verification	Install temp seonsor on NEMO	3	End Mar
Mate Floats	Vertical Profiling Float	4	End April
Float sensor and transmit	Pressure, salinty, temp and wireless transmit	4	End April

Fig. C: Credit: JD Gamboa

Project Management

Collaboration and Flexibility

The success of Brother Rice Robotics has been built largely on a culture of collaboration and flexibility. The systems approach that we employ required that we collaborated on nearly every part of both the NEMO 2.0 and VESCO 1.0. Each device is an intricate combination of hardware, mechanisms, software and electrical power. Leads and the fabricators that work for them were constantly consulting, working alongside and sharing information with members of other disciplines. We also pride ourselves on being highly adaptable and flexible. Most of our team members are not exclusive members of Brother Rice Robotics and are members of one (and usually more than one) other club or sport. This meant that team members would often miss meetings or entire blocks of time to meet those other outside obligations. Team Leads and fabricators often had to be very flexible and juggle multiple tasks and parts of the project at a time. Clear and frequent communication in person, via paper notes and over email and text were key to staying on schedule. Team members also regularly utilized their lunch hours and study halls in order to keep NEMO and VESCO on schedule while still meeting all their other outside commitments afterschool.

Design Rationale

Engineering Design Process

Brother Rice Robotics uses a very simple and nimble design methodology called Agile Design[4] (Fig. D). Agile Design includes all the classic steps of a traditional 6/7 step Engineering design process as well as being iterative or cyclical in nature. BR Robotics prizes the short, simplicity of the terminology and its focus on analyzing and using data so team members have the information to decide on a solid “next step” in the ACT phase. Agile Engineering has been instrumental to BR Robotics’ success over the years. For good examples of our use of Agile Design and the tradeoffs that were studied please see Frame and Buoyancy in figures F and N.

- Define the problem
- Define success
- Research & Design Matrix
- Incorporate prior lessons
- Plan for/design the solution

- Build the solution
- Test the solution
- Gather data related to the success criteria from PLAN

- Implement and finalize or...
- Adjustment & retest or...
- Go back to the PLAN phase if design is far from success

- Analyze testing data
- Rate the solution based on success criteria
- Highlight and note any issues

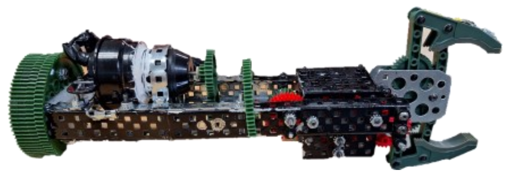
Agile Engineering Design
Fig. D: Credit: Nicola Piccinini

Design Rationale

Innovation

Innovation is defined as the process of bringing about new ideas, methods, products, services, or solutions that have a significant positive impact and value. It involves transforming creative concepts into tangible outcomes that improve efficiency and effectiveness, lower costs, and address unmet needs[5]. BR Robotics is committed to continuously dreaming up and executing new and creative solutions to meet the needs of our clients, especially the GOC. Below are just a few of our recent innovations!

- Multifunction Claw (grasp, push, pull, hook, twist, magnet) (pg. 16)
- "Diagonal Directional" motor configuration (pg. 13)
- Cart system (pg. 8)
- Buoyancy Reduction Vessels (pg. 14)
- Using Stock Bilge Pumps as Servos (pg. 16)
- Domed thruster shrouding (pg. 9)

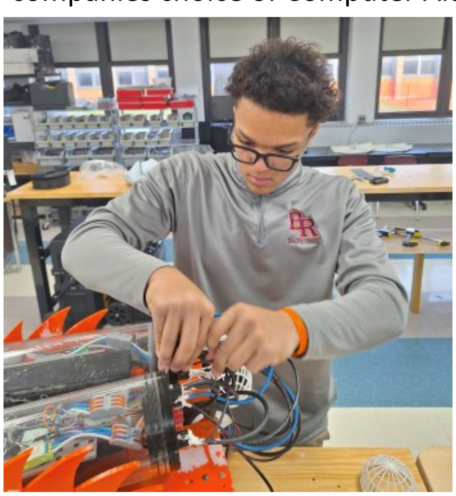


Multifunction Claw Manipulator
Credit: N Scott

Buoyancy Reduction Vessel
Credit: N Scott

Problem Solving

Each day at Brother Rice is an exercise in problem solving, which is a key skill that our team members must possess. Significant tenacity and grit is required to meet challenges, and arrive at working solutions that are innovative and meet or exceed the desires of our clients. Most problem solving work occurs in the PLAN phase of our agile design process. The most difficult problem our team had to solve this season were the Buoyancy Reduction Vessels (BRV's). The initial problem arose when we added a second Water Tight Enclosure (WTE). This made the ROV too buoyant and required the addition of more than 1kg of ballast which slowed the ROV and reduced its agility. Our team was able to remove the ballast by creatively reducing the volume of the WTE by cutting a hole in the endcap and engineering an "inner tube" (BRV) that would fill with water and reduce the volume of the WTEs. The BRV was engineered to the exact volume needed using our companies choice of Computer Aided Design (CAD) software, Onshape[6]. We were frustratingly unable to get the BRVs to seal to the endcaps and after three month's of failed attempts to seal the BRVs, the team decided to solve the problem by using a flexible water bottle, pvc pipe, pvc cement, and gaskets. These items were chosen because they were already industry standard and approved as water tight materials. This finally solved the problem and allowed the BRV's to seal properly.



JD working on WTE/BRV
Credit: N Scott

BR Robotics Problem Solving Procedure:
1. Clearly define and understand the problem
2. Define success criteria
3. Brainstorm as many solutions as possible
4. Research existing or similar solutions
5. Value and assess ALL ideas without prejudice
6. Use success criteria and matrix to move an idea forward
7. Save all unused ideas for possible future use

Systems Approach

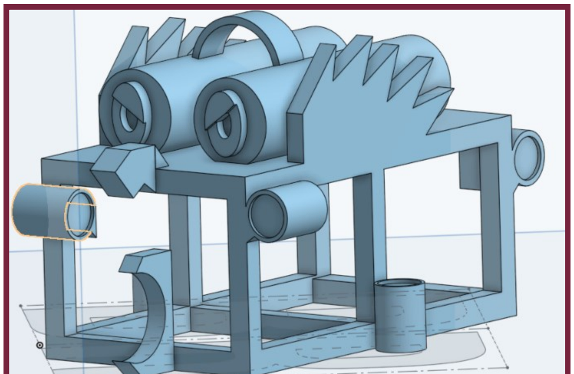
Living organisms are composed of many separate yet highly interconnected systems. Brother Rice Robotics followed this same approach when developing our "organism," the NEMO 2.0. Understanding that no system can function in isolation and that every system depends on at least one other system in order to function, we still felt it was the best choice to break NEMO 2.0's development down into individual systems. Team members were then assigned to manage and develop each system. Due to the high level of interconnectedness between systems, team members from different systems were constantly working, communicating, and collaborating with team members from other systems. This approach dramatically sped up our build time, as all systems were in development simultaneously. Our attention to detail and collaboration efforts have allowed all of NEMO 2.0's systems to function together seamlessly. Organization of our systems can be seen in Figure E.

#	System	Oversight by:
1	Coding	Nico
2	VESCO 1.0	Bobby/Nico
3	Bouyancy	JD
4	Propulsion	Andy
5	Frame	Kruder
6	Tether	Kmak
7	TCB	Sam
8	Claw	Sam
9	Cameras	Max
10	WTE	JD
11	Cart	Elijah
12	Safety	Vince

ROV Systems Organization
Figure E: Credit: Sam Lapenas

Frame

Significant time and numerous discussion sessions were spent on deciding the material and shape of the NEMO 2.0's frame. A summary of the material considerations can be seen in figure F below. Ultimately we chose to re-use the frame from NEMO 1.0 as it was still in great condition, worked well in '23, and would still allow us to meet the needs of the GOC in '24 without any added cost. The Frame of NEMO 2.0 is composed primarily of HDPE making the ROV lightweight and maneuverable whilst still having a sturdy structure capable of being cut, drilled and fastened with ease. The frame was shaped into a rectangular cube design that conserves material, has ample interior volume for components and tools, and is fastened together using screws and bolts; additional vex gears, components, and custom 3D printed parts were required to complete the frame. With this abundance of interior space, the frame can suit the needs of the GOC by allowing the easy addition of a wide variety of tools and payloads. The frame also features numerous cosmetic design aspects such as fish eyes, fins, and a clownfish color scheme to help branding and make our ROV standout.



NEMO 2.0 CAD Concept

Credit: N. Scott

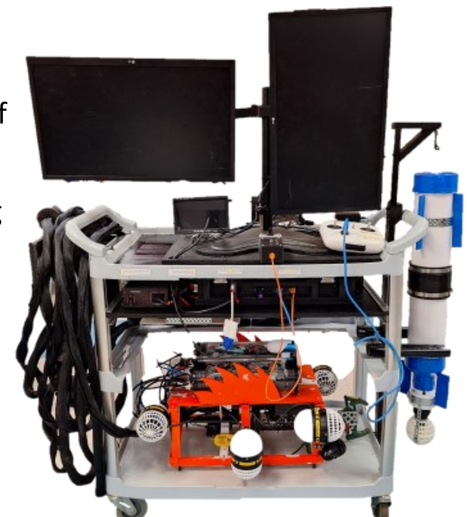
Frame Material Analysis Matrix

Fig. F: Credit: S. Lapenas

Material	Cost	Modifiable w/ handtools	Density	Strength	Production time	Ease of attachement	Final Score	Ranking
PLA	3	2	3 (1.24g/cm)	1	1	2	12	3rd
HDPE	4	4	4 (0.97g/cm)	3	3	3	22	1st
PVC	2	3	2 (1.45g/cm)	2	4	1 (too round)	4	4th
VEX Metal	1	1	1 (7.85g/cm)	4	2	4	13	2nd
4 = Best, 1 = Worst								

Miscellaneous Vehicle Systems: Cart

The cart is an all-in-one transport system and workstation; it was designed with mobility, stability, reliability, and serviceability in mind. The upper section of the cart holds our three monitors that are centered, balanced, and secured to the cart. These monitor mounts also are adjustable if needed for transportation purposes. Apart from the monitors the upper part of the cart also holds the two controllers for the propulsion and claw systems. The middle section of the cart is where the Topside Control Box (TCB) and 12v power supply are housed in a pull out drawer. When the drawer is in, the TCB is protected from the elements. When the drawer is removed, the inside of the TCB can be accessed for adjustments or maintenance to any electrical components. The drawer also can be completely removed for major repairs if needed. The bottom section of the cart houses the NEMO 2.0. This spacious housing was custom fit to NEMO 2.0, protecting it from bumps and drops and the wide side opening allows easy removal and placement of NEMO 2.0 on and off the cart. On the left hand side is the mount for the tether. This mount allows the tether to be secure, safe, and untangled, as well as able to be unspooled quickly. On the right hand side is the mount for the VESCO 1.0 Float.



All-In-One Cart System
Photo Credit: N. Scott

The cart is versatile in not just carrying all of our needed components, but also in being a mobile workstation. The cart can be rolled easily by just one person, reducing the risk of musculoskeletal injuries to the crew. The cart has two large handles that allow four crew members to team lift the cart up or down stairs or across uneven terrain. When setting up shop, the cart's custom wheel chocks are activated to ensure the cart remains stationary. Every plug connector for power, signal and camera feed can be removed. These plugs can also be left in place to greatly speed up setup time, reduce the change of a "plug-in-error", and reduce wear and tear on the plugs and wires themselves. Finally, the cart comes equipped with a 120v AC power strip that eliminates the risk of a power surge and allows the large monitors and the 120v AC to 12v DC power supply to be plugged in. This power strip is the only connector that needs to be plugged in to activate all of NEMO 2.0's systems. The team spent considerable time early in the NEMO 2.0 build, discussing and determining the tradeoffs of a cart system vs. transporting each component individually. A summary of this work can be seen in figure G below.

Transportation System	Chance of operator injury		# of operators needed for transport		Set up time		Chance of damage to equipment		Allow for large monitors		Any other item required for setup?		Final Score	Ranking
Induvidual Carry	Higher	1	Four	1	Longer	1	Higher	1	NO	1	Table	1	6	2nd
Cart System	Low	2	One	2	Shorter	2	Lower	2	Yes	2	Nothing	2	12	1st

1 = Worst 2 = Best

All-In-One Cart System Tradeoffs and Decision Matrix
Figure G: Credit: Alex Kmak

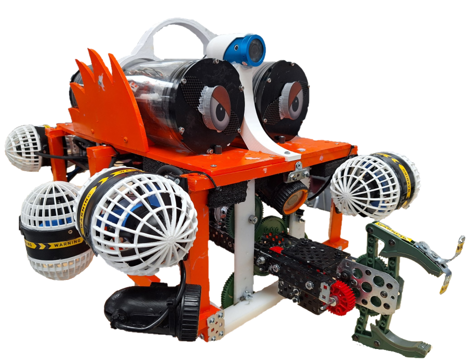
Miscellaneous Vehicle Systems: Safety

Safety is top priority at Brother Rice Robotics. Our team follows numerous safety protocols during the build process and has also carefully selected and incorporated many safety features directly into the NEMO in order to keep operators, crew and marine life safe during use. Our notable safety features are highlighted in figure H. Additionally we have developed a Job Safety Analysis (JSA) and an operational safety checklist to be used by the pilots and crew during ROV operation. This checklist is included on page 25 in Appendix A.

Safety Feature	Description
Thruster Guards	Custom domed design, 3D printed and conforms to IP-20 standards to ensure safety of human and marine life
Warning Labels	Custom, brightly colored warning labels denote spinning blades and pinch points
25 Amp Fuse	Located between the powersupply and the TCB, this fuse prevents amperage overload which could be dangerous to the pilots/crew and could damage sensitive electrical components
Tether Sheath	The tether sheath keeps all the tether wires tightly bundled and prevents tripping and entanglement
Tether Strain Relief	Strain relief has been built into both the ROV and TCB end of the tether to ensure that electrical components do not experience any undue stress/strain
Cart System	The cart system ensures that operators do not undergo significant muscular strain during ROV transport
Cart Wheel Chocks	The custom wheel chocks lock the All-in-One cart in place during ROV operation
ROV Lift Handle	The lift handle allows NEMO 2.0 to be placed in the water and removed from the water with only one hand, allowing the crew member doing this task to stay balanced during this delicate manuever
High Visability Color Scheme	The orange color choice ensures that NEMO 2.0 is highly visible to other teams/operators during joint missions
Claw circuit	The claw circuit defaults to an "open" non-powered state, allowing "pinched" objects to be quickly removed

NEMO 2.0 Notable Safety Features
Figure H: Credit: O Roa

Miscellaneous Vehicle Systems: Functional Theming



NEMO 2.0 Color Palate
Credit: N Scott

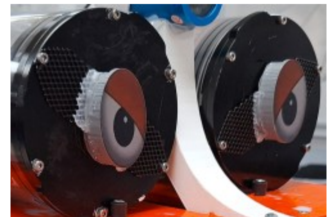
NEMO 2.0Inspiration
Credit: Aquarium of the Pacitic[7]

Everything on NEMO 2.0 has been carefully selected and crafted to be highly functional, and to serve a significant purpose. The theming and color scheme of NEMO 2.0 are no exception. While these features may seem completely aesthetic or cosmetic each serves a functional role. Our main theme features a Clownfish color scheme, dorsal fins and eyes. Aesthetically the orange, white and black coloration of NEMO 2.0 invokes the famous marine clownfish. Additionally orange is also our main school color. Functionally the orange frame is very noticeable, making surface or underwater recovery of the ROV easier in the event of a major malfunction. Orange also makes our ROV highly visible to other companies during team operations, reducing the risk of collisions and ROV damage. The white on the thruster guards was intentionally chosen as it is highly noticeable against the orange frame, making this dangerous part of the ROV very visible. Having black as our third color was a cost saving choice, as a majority of purchased ROV components come in some shade of black, eliminating the need and cost of painting those components, aesthetically the dorsal fins again invoke the clownfish.

Thruster Guards
Credit: N Scott

Functional Fins
Credit: N Scott

Functionally the dorsal fins are actually a part of the lift handle for the ROV. Our 3D print capabilities only allow us a maximum component width of 11 inches. The lift handle needed to be 14 inches wide. The fins solve this issue by allowing the handle to be printed at a shorter width. The fins are secured to the frame on either side of the water tight enclosures and are then secured to the lift handle. Finally the eyes of NEMO 2.0. Aesthetically they complete our clownfish look. Functionally they act as covers to our buoyancy reduction tubes that reduce drag and improve hydrodynamic flow around the ROV. They also act as covers to keep debris and marine life from entering the BRV's while still allowing them to fill with water and perform their intended function. Brother Rice Robotics desires that the NEMO 2.0 is the most recognizable and capable ROV on the market. We feel our theming efforts, and the functionality they provide, ensures that we have met that goal!



Eye Covers
Credit: N Scott

Control and Electrical System: Topside Control Box (TCB)

The TCB is where all the ROV magic happens! All power, signal, and camera feed enters and exits through the TCB. Multiple voltage converters are utilized to transform the 12v DC current that enters the box into the 11v, 9v, and 5v loops we need to power each component on NEMO 2.0.

Topside Control Box
Credit: N Scott

An Arduino UNO stores and runs the propulsion code. Great care was taken to ensure that all wires and wiring pathways were neatly organized and executed. Wiring pathways are neatly arranged and all wires are securely connected through solder joints, screw connectors, and snap connectors. All screw and snap connecters are securely attached to the control box. Our TCB has been mounted on a drawer in the cart that seals it from the elements. This drawer slides out to allow every part of the box to be checked and adjusted as needed. Additionally, the drawer is also completely removable in the event major repairs are needed. This accessibility is key should any issues arise during MATE

Alex Adjusts the TCB
Credit: N Scott

Control and Electrical Systems: Tether

The Tether system plays a crucial role in the functionality of the NEMO 2.0, providing the necessary hard wired connection for underwater operations. Our first task was determining the appropriate length for the tether. To achieve this, we measured the dimensions of the MATE Demonstration Field, which spanned 6 meters in length, 10 meters in width, and 4 meters in depth. Utilizing the Pythagorean Theorem we went about calculating the maximum length of tether needed. That length is the distance between the two farthest corners, which are the top left and the bottom right corners respectively (fig. I). First, we obtained the hypotenuse of the

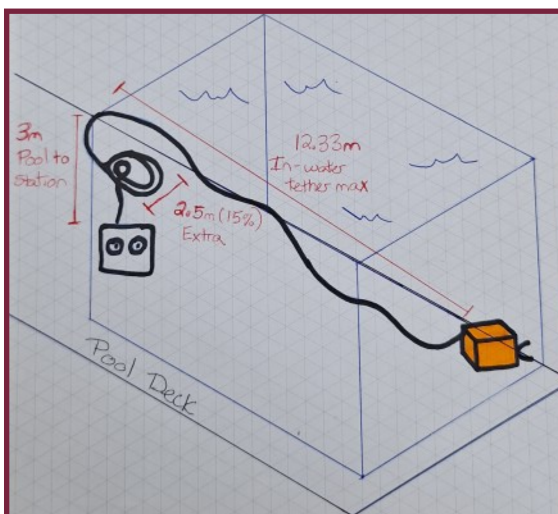


Diagram of Tether Length For NEMO 2.0
Figure I: Credit: JD Gamboa

surface length between opposite demonstration corners (11.7m). We then used that 11.7m distance as a new leg of another right triangle that went down 4m to the bottom of the pool and came up with a maximum in water tether length of 12.33m. Next we added the 3m distance between poolside and control station for a total of 15.33m and lastly to account for anything unexpected we added an additional 2.5m (15%) for a total tether length of 17.83m (58ft). A diagram of our tether length methodology can be seen in figure I on the previous page. We are confident that these calculations ensure that NEMO 2.0 has ample tether for any task without inefficiency or wasted funds.

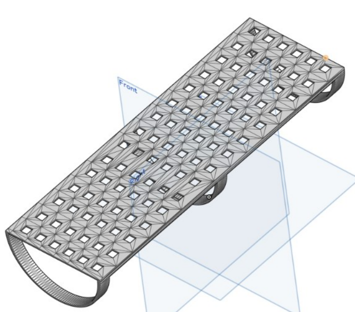
The tether is composed of multiple wires, each tailored to transmit specific power and signal feeds to and from the ROV. A specialty, highly flexible 12-gauge MTD wire delivers power to the ROV, while an 8-strand Ethernet cable handles signal transmission to and from the thrusters. Additionally, 20-gauge wires manage the camera power and camera feed and 4 18-gauge wires power the two claw motors. To protect these essential wires and prevent tangling or damage, they are encased in a woven Velcro tether wire enclosure. The choice of Velcro was deliberate, as its quick disassembly and reassembly allows for future modifications or repairs while still being robust enough to protect the tether wires in both marine and terrestrial environments. This upgrade enhances the tether's versatility and ensures seamless operation of the ROV during underwater missions. The tether also is equipped with strain relief at either end to reduce the likelihood of damage.

NEMO 2.0 Tether
Credit: N Scott

Control and Electrical Systems: Watertight Enclosure

Last year's NEMO 1.0 had only a single Blue Robotics 100mm dia. by 38cm long WTE. We were unable to neatly contain all our ESC wiring in this single enclosure so the team made the decision to purchase a second WTE from Blue Robotics. These enclosures are expertly designed and rigorously tested and a of higher quality and reliability than anything we could construct or innovate on our own, despite their $400.00 price tag. A reliable watertight seal is vital, as a poor seal would result in mission and device failure. These enclosures house all the incoming power and signal wires for the 6 thrusters, the electronic speed controllers (ESCs) for each motor, and the return (ground) lines before sending them back up the tether to the TCB . By completing all the power and signal connections and splits for power and signal within these water-tight enclosures we greatly reduce the amount of waterproofing that is needed and greatly reduce the risk of motor/signal failure and short-circuiting. The WTEs are centered on the top of the ROV where they allow easy access for maintenance and upgrades as well as allowing for easy visual inspection for broken electronics, disconnected wires and leaks during troubleshooting. We designed a custom 3D printed electronics shelf to hold and organize all the WTE wiring.

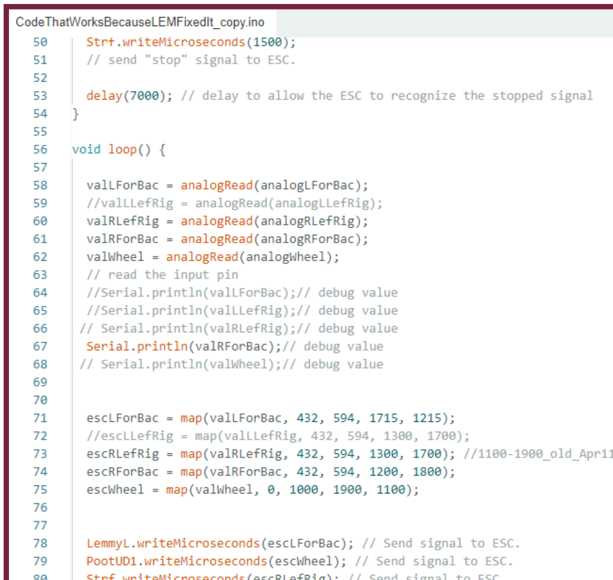
NEMO 2.0 Dual WTEs
Credit: N Scott



CAD of Electronics Shelf
Credit: A Novak

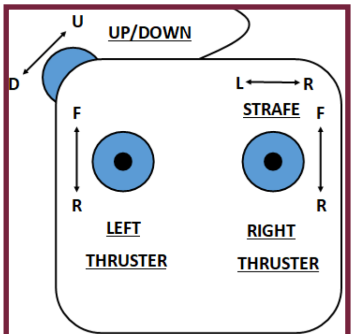
Control and Electrical Systems: Coding

Our code is written in C++ on the Arduino Uno coding platform[8] and is downloaded, stored and executed on an Arduino Uno. We like the simplicity and cost effectiveness of Arduino, as NEMO 2.0 is not currently undertaking any tasks that would require the use of more sophisticated hardware or software. The actual coding of NEMO 2.0 is elegantly simple, a sample of which can be seen in figure J. Brother Rice Robotics sees this simplicity as a significant advantage, as it leads to very few software issues and makes troubleshooting a potential software issue much easier and faster than it would be if the code were more complex. NEMO 2.0's code execution begins at our repurposed DJI drone controller with four potentiometers which constantly send a degree value to the Arduino (Fig. K). When in the neutral position the potentiometers send a value of 512, as the stick/wheel is pushed "up" from neutral the value increases to its max of 1023. As the stick/wheel is pushed down from neutral the value decreases to its minimum of 0. We instructed the Arduino to read this incoming value and then to MAP it to the signal frequency, in microseconds, that the Electronic Speed Controllers (ECS) want to read in order to control the thrusters. The frequencies the speed controllers need is between 1100ms and 1900ms. They use this to increase or decrease thruster voltage and direction. A MAP function essentially aligns the min and max of two separate scales, in order to set them proportional to each other, so that we reach the max and min of the thruster power as we reach the max and min of the potentiometer range. A model of this MAP can be seen in figure L. After receiving the potentiometer signal the Arduino follows the MAP, calculates the frequency of the signal it needs to send and then sends it out through the assigned output port, down the tether wiring to the desired thruster. 1500ms is the center of the thruster range, and 512 is the center of the potentiometer degree range. We programmed a dead band of +/- 80 around this point to keep the controls from being too "touchy". This means that values from 1562ms to 1900ms spin the thruster forward and values of 1438-1100ms spin the thruster backwards.

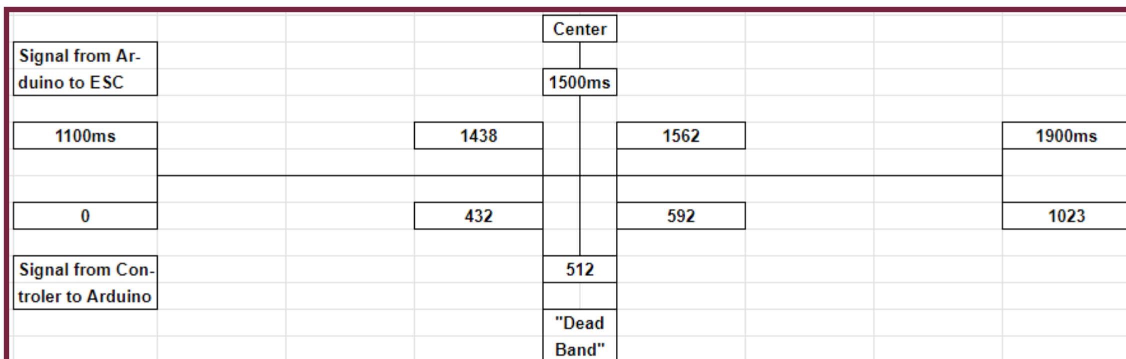

CodeThatWorksBecauseLEMFixedIt_copy.ino

```
  Strf.writeMicroseconds(1500);
  // send "stop" signal to ESC.

  delay(7000); // delay to allow the ESC to recognize the stopped signal
}

void loop() {

  valLForBac = analogRead(analogLForBac);
  //valLLefRig = analogRead(analogLLefRig);
  valRLefRig = analogRead(analogRLefRig);
  valRForBac = analogRead(analogRForBac);
  valWheel = analogRead(analogWheel);
  // read the input pin
  //Serial.println(valLForBac);// debug value
  //Serial.println(valLLefRig);// debug value
 // Serial.println(valRLefRig);// debug value
  Serial.println(valRForBac);// debug value
 // Serial.println(valWheel);// debug value


  escLForBac = map(valLForBac, 432, 594, 1715, 1215);
  //escLLefRig = map(valLLefRig, 432, 594, 1300, 1700);
  escRLefRig = map(valRLefRig, 432, 594, 1300, 1700); //1100-1900_old_Apr11
  escRForBac = map(valRForBac, 432, 594, 1200, 1800);
  escWheel = map(valWheel, 0, 1000, 1900, 1100);


  LemmyL.writeMicroseconds(escLForBac); // Send signal to ESC.
  PootUD1.writeMicroseconds(escWheel); // Send signal to ESC.
  Strf.writeMicroseconds(escRLefRig); // Send signal to ESC.
```

Section of NEMO 2.0 Coding
Figure J: Credit: N Dodsworth



Controller Layout
Figure K: Credit: N Dodsworth

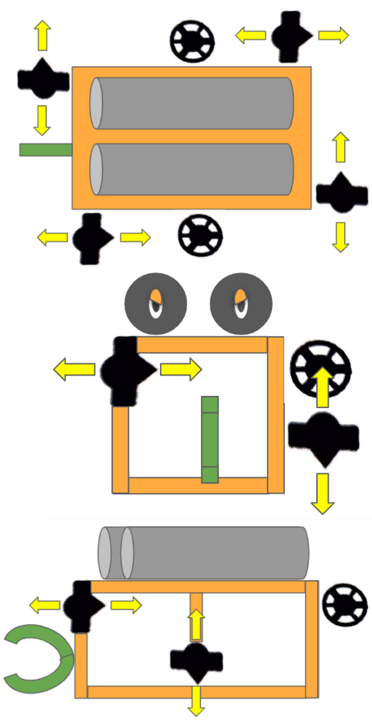


NEMO 2.0 Coding Potentiometer to Thruster Signal MAP
Figure L: Credit: N Dodsworth

Propulsion

Thruster Installation
Credit: N Scott

NEMO's propulsion system consists of six Blue Robotics thrusters. The two forward and back and two up and down motors are all T-200 Motors while the two strafe motors use the older T100 model. Understanding that T-200 thrusters provide more thrust and are more reliable, we still only saw a benefit to upgrading the fwd/back and up/down thrusters. We choose to reuse the older T-100 thrusters for our strafe control as this motion needed to be slower anyhow, and allowed us to cut costs on NEMO 2.0 without sacrificing performance. The tether sends 12v power down the 12 gauge braided MTD wire specifically chosen to have the amp capacity to power all 6 thrusters. One power and one return line runs down the tether and is split off to each thruster inside the Water Tight Enclosures (WTE). Signal from the controller runs through an Ethernet cable and is also split off to each thruster in the WTEs. NEMO 2.0 uses "tank" style steering as opposed to the more common vectored thrust configuration. Our "tank style" steering uses two thrusters for forward/back control, two thrusters for up/down control and 2 thrusters for strafe control. The up/down thrusters work as a pair as do the strafe thrusters. The forward/back thrusters are controlled independently allowing the ROV to "spin turn" left and right. Due to the placement of the two WTEs we cannot place our up/down thrusters inside the frame of the ROV. That then meant that the up/down and forward/back thrusters all needed to occupy the same mounting location. This would not work, and a new creative thruster layout was developed. Our solution was a unique "diagonal" thruster placement that puts the up/down thrusters centered on the sides, places the strafe thrusters on two opposite corners and the forward/back thrusters on the other two opposite corners. Figure M gives a more detailed view of our thruster orientation. This ensures that the flow of water through each thruster is not inhibited and that each thruster is in a balanced pair. Though unconventional, we continue to use and prize the "tank style" control, and its equally unconventional thruster placement, as we feel it is the most intuitive control system on the market and has the shortest learning curve for new pilots, which is a major selling point for NEMO 2.0.

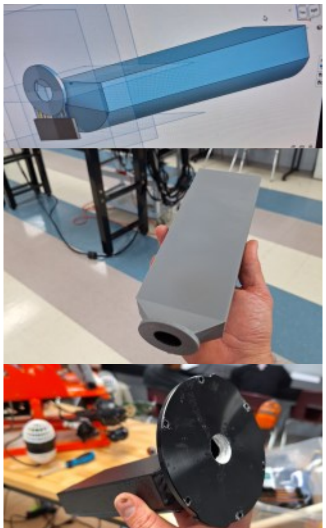


Diagonal Thruster Orientation
Figure M: M Griffin

Buoyancy and Ballast

Neutral buoyancy may be one of, if not the most important traits of any ROV. Performing delicate tasks underwater requires that an ROV neither sink nor float and that it stays at the exact depth the operator puts it at. To achieve neutral buoyancy we needed NEMO 2.0 to have the same density as the water around it. If its density is less than water it will float and if its density is greater than water it will sink. Either issue must be avoided at all costs and would require the operator to make constant depth adjustments and greatly reduces their ability to perform complex and precise tasks underwater, rendering the ROV inefficient, difficult to control and undesirable to the GOC. The addition of the second Water Tight Enclosure (WTE) to NEMO 2.0

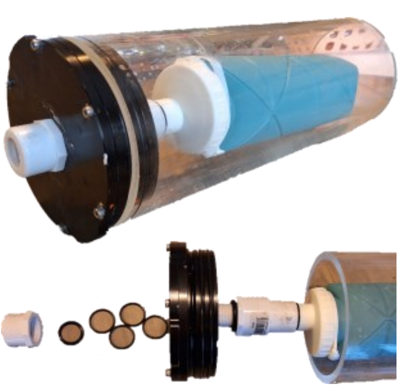
rendered it extremely positively buoyant (“floaty” as the team called it!). Just over a kilogram of ballast was needed to achieve neutral buoyancy. This ballast increased the mass of 2.0, making it sluggish and unresponsive underwater. After deliberating many possible solutions the team decided to innovate a first of its kind Buoyancy Reduction Vessel (BRV) for each WTE. Knowing 1ml of water is equal to $1cm^3$ of volume we used CAD to create two “pop bottle like”, half moon vessels that each had an internal volume of 500ml (1000ml total). Each BRV was custom designed to fit on the inside, bottom half of each WTE. The top half of each WTE would still house the thruster ECS’s as previously planned. A hole was precision bored into each WTE front endcap to align perfectly to the opening in the BRV and then each BRV was secured to its endcap with waterproof epoxy. One of the primary hurdles we encountered was getting the BRV’s to seal to the WTE endcaps. The BRVs simply would not seal completely and we were constantly dealing with leaks in our WTEs dramatically slowing our progress. We tried what felt like a billion solutions, until we finally decided to scrap the custom BRV tubes and the waterproof epoxy. After significant brainstorming and deliberation, (our decision matrix and votes can be seen in figure N), we decided to use solution #3 and use plumbing/ beverage industry, “waterproof rated” materials to make each BRV. In doing so we lost the precision sizing we had prized with our custom designed vessels. We purchased a 500ml flexible water bottle, used rubber gaskets and hose clamps to connect it to a short piece of 1/2in pvc, and used pvc cement to adhere a threaded end on the pipe. The threaded end fit through the bored hole in the endcap and we used a pvc cap and 6 gaskets to compression seal the BRV to the endcap. Finally we drilled a hole in the pvc endcap to allow water to enter the BRV. We repeated this process in the other WTE. Due to not being able to custom build each BRV the tubes hold roughly a combined 1300ml of water, which is greater than the 1000ml we desired. This meant that the ROV was negatively buoyant (“sinky”). We fixed this through trial and error testing by adding foam to the front of the frame until neutral buoyancy was achieved. The development of the BRVs is one of BR Robotics’ proudest innovations!



Failed BRV Design
Photo Credit: N Scott

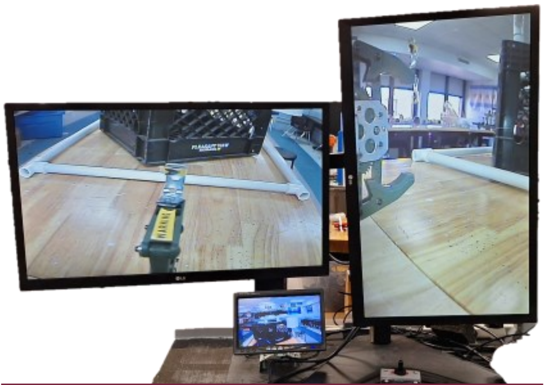
Solution	Description	Pro's	Con's/Issues	Votes
1	Purchase new endcaps and add 1kg of ballast	Garanteed not to leak, quick fix, get on to other tasks	Cost 100.00, ROV will be slow and will handle poorly	None
2	Cut the acrylic tube of each WTE to shorten it and reduce the volume of each by 500cm3	Fast fix and costs nothing, will allow all balast to be removed as planned	The newly purchased WTE has a highly machined end that we may not be able to recreate	2
3	Use "stock" bottle and plumbing parts/methods to make each BRV	Low probability of leaking, will allow most ballast to be removed	Minor additional cost, will not be able to remove the exact amount of ballast, but could likely get "close"	6

Tradeoffs and Decision Matrix for Bouyancy Issue
Figure N: Credit: JD Gamboa

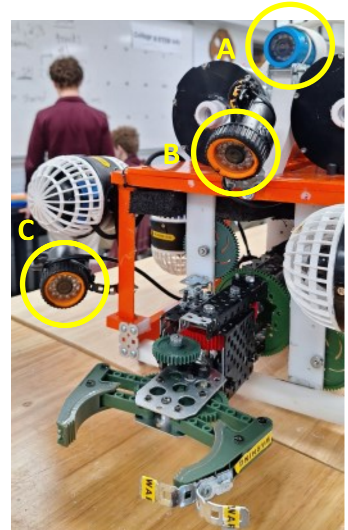


Custom BRV Enclosures
Photo Credit: N Scott

Payload and Tools: Cameras



NEMO 2.0 Camera Monitor Setup
Photo Credit: N Scott



Camera Positions Figure O:
A—Nav Cam
B—Claw Cam Top
C—Claw Cam Side
Credit: A Andrade

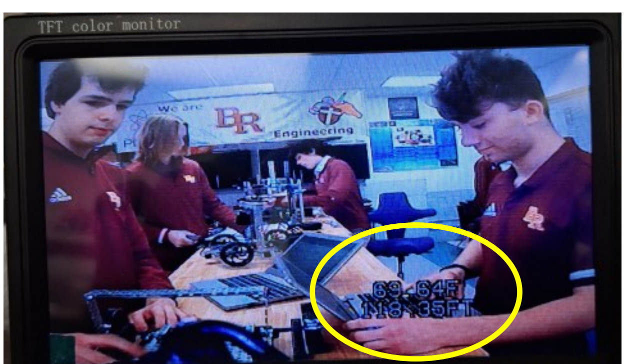
NEMO 2.0 has three underwater rated cameras mounted to its frame. Two of the cameras are installed to provide two different close up views of the claw manipulator, giving information about the X, Y and Z axis and allowing for the completion of delicate and precise tasks. Both claw cameras possess LED lights for increased visibility in the manipulator area. The third camera is the "navigation camera" and is mounted on top of the frame between the watertight enclosures. This positioning gives the operator a wide angle view in order to easily navigate through the environment. When the ROV surfaces is has the ability to act as a periscope allowing the operator to see crew members and easily navigate back to the entry and exit point. Additionally, the top camera is equipped with infrared capabilities, a thermometer, and a depth sensor, the latter two assisting temperature calibrations in Task 2 and photogrammetry in Task 3. Due to their importance and the significant difficulty in custom constructing a waterproof camera the team chose to reuse the two cameras from NEMO 1.0 and purchase the "navigation camera" for NEMO 2.0. The navigation camera includes its own 23cm (9") monitor that allows the operator to navigate the ROV into position and then switch to the larger claw monitors for precision tasks. The claw cameras are connected to two large 61cm (24") monitors that allow for greater precision in object manipulation. All three camera placements on the NEMO 2.0 can be seen in figure O.

LED Claw Camera
Photo Credit: N Scott

Infra-red Nav Camera
Photo Credit: N Scott

Payload and Tools: Depth and Temperature Sensors

NEMO 2.0 is able to measure depth as well as the temperature of the surrounding water through two sensors located in the blue navigation camera. During our search for a third camera the team came across this camera that already had these two sensors built in and purchasing it was a "no-brainer". Finding components that serve more than one function is a great way to increase functionality and reduce costs. The data from these sensors is sent to the navigation monitor and is displayed on the screen for the pilots and crew to use. These sensors will be used to ensure calibration of the Multi-function Node and will also be used for photogrammetry to allow the crew to gauge the height of the seamount so an accurate 3D model can be created in CAD.

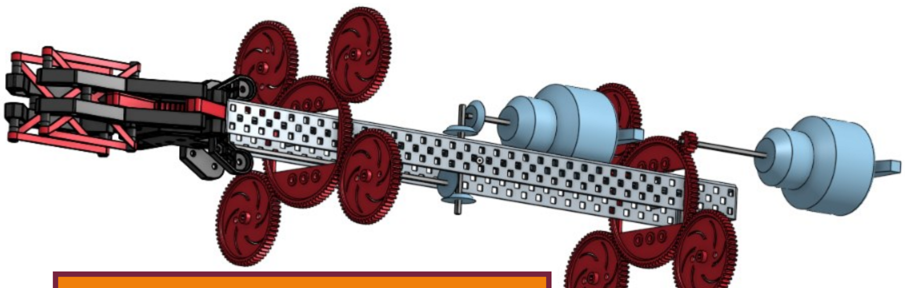


Depth & Temp Readout From NAV Camera
Photo Credit: N Scott

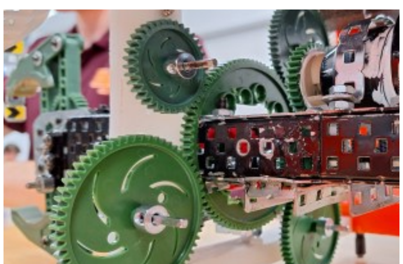
Payload and Tools: Claw

Claw Manipulator & Egg-tooth Hook
Credit: N Scott

The claw manipulator on NEMO 2.0 is one of the most innovative and versatile tools in the industry. The claw is capable of grasping, carrying and twisting objects up to 10cm in diameter. It also comes equipped with a two-way “egg tooth” hook, mounted on the top jaw of the claw, that can be used hook and pull objects. Finally the claw can be closed and used to push objects around underwater. The claw uses a high strength gear train and bevel gears connected to a 500 GPH bilge pump motor to control opening and closing of the claw gripper. An additional 500 GPH bilge pump motor rotates the claw assembly 90 degrees allowing us to twist and grab objects in numerous positions. As stated, the claw is extremely versatile and allows us to complete tasks such as moving coral, pulling pins, plugging in the MFN, and transporting acoustic recording equipment. The claw gripper motor runs on a 3:1 gear reduction to slow the rpm of the bilge pump motor to an acceptable level. We intentionally chose a very fast claw closure speed to allow our gripper to hit its mark even when the ROV is drifting slightly. ROV’s are rarely ever completely stationary and a claw that “strikes” quickly is a significant advantage. Rotating the claw assembly required more torque than the bilge pump motor could provide so we geared down this motor by a ratio of 52:1. This allowed the motor to create enough torque to actuate claw rotation and also slowed down the motion enough to allow for precision movements. The ability to rotate the entire claw is one of our greatest innovations and triumphs this season. A final claw innovation helped us save significant costs. Most conventional grippers would be powered by waterproof servo motors that cost upwards of $150 each. We chose to use boat bilge pump motors instead. These cheap ($20), but reliable motors come pre-sealed and can be easily controlled by a simple 3-way switch without any additional coding or potentiometers. A matrix of our deliberation, tradeoffs and final decision can be seen in figure P.



Claw Initial CAD Concept
Credit: M Griffin



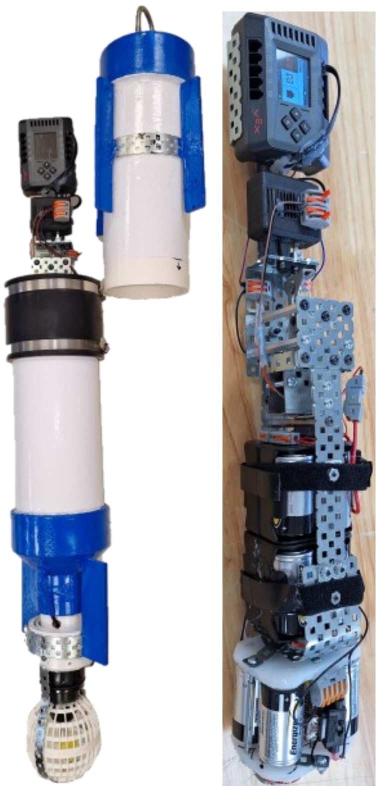
Close-up of Front Claw Cradle
Photo Credit: N Scott

Close-up of Rotation Motor
Photo Credit: N Scott

Tradeoffs & Decision Matrix for Claw Motors
Figure P:
Credit. JD Gamboa

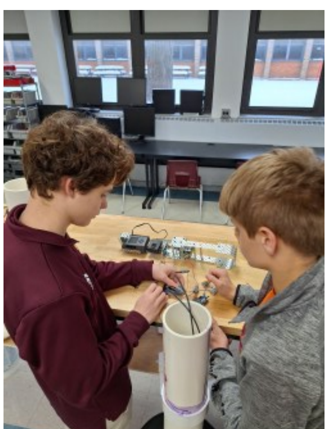
Component	Cost	Ease of integration	Precision	Actuation Speed	Safety	Final Score	Ranking
Waterproof servo	1 ($150.00)	1 (must be coded through arduino and requires an additional potentiometer	2 (can precisely hold in any position)	1	1 (always powered, so it will need a "kill switch" programmed/installed)	6	2nd
500gph bilge pump motor	2 ($20.00)	2 (only needs power and a 3 state bi-directional switch)	1 (cannot hold, when swtich is in nuetral claw is non-energized	2	2 (when switch is nuetral motor is not powered, a pinched limb can then be easily removed)	9	1st
1 = Worst 2 = Best							

Payload and Tools: VESCO — Vertical Environmental Survey Collecting Omnibus



VESCO 1.0
Credit: N Scott

VESCO 1.0 is the newest creation from BR Robotics, and is our first foray into the survey float arena! VESCO stands for, Vertical (Profiling), Environmental, Survey, Collecting, Omnibus. It is an omnibus because it can house any sensor the client desires. The float housing is constructed from 4” PVC pipe and endcaps that are connected and sealed with PVC primer and cement. This is the plumbing industry standard and will withstand the immense pressures it will be subjected to. The float housing is split into 2 halves and is joined by a rubber boot that employs hose clamps to form a watertight seal. The case on VESCO can be opened with an 8mm wrench or ratchet. The guts of VESCO are attached to an internal frame that was custom fitted to the inside shape of the float housing. This internal frame can be easily removed from the housing to allow maintenance to be performed and activation of the cortex. VESCO employs 6 small vertical fins to guide it in a straight path to the bottom and to keep the float from spinning during descent, which is a side effect of using a propeller to power the descent. VESCO is powered by a 500 GPH bilge pump motor attached to a 2 blade propeller. This motor is powered by 12v DC, provided by eight D Cell batteries. The motor circuit is switched and the switch is controlled by a VEX 393 motor, which is controlled by a VEX cortex. VESCO is coded to make 2 descent and ascent cycles during each product demonstration run. The program was built with a 5 minute delay to allow the operator ample time to close and seal the float housing and to position it properly in the water during the product demonstration period. The cortex requires 7.5 volts DC and is powered by a separate set of five 1.5V D batteries. Three 7.5 amp fuses ensure the VESCO is electrically safe. Given that VESCO 1.0 is our first attempt at a profiling float we intentionally chose to make the design simple and chose to use materials, devices and systems that we were already familiar with in order to improve reliability and improve our chances of meeting the project deadline. Initially we designed the VESCO to power itself both up and down in the water column. After much discussion we decided to double the battery life of the system by only powering the float in one direction and letting gravity or buoyancy power the float in the other. This left us with two options, 1.) make the float slightly negatively buoyant and power it back to the surface or 2.) make the float slightly positively buoyant and power it down to the bottom. After analyzing the pros and cons of each system (Figure Q), the team chose the powered descent, automatic accent, option.



Jack and Dom at work
Credit: N Scott

Option	Bouyancy	Battery extention	Coding advantage	Recovery location	Ranking
Powered Descent	Slightly positive	2X	None	Surface	1st
Powered Ascent	Slightly negative	2X	None	Seafloor	2nd

Tradeoffs and Decision Matrix for Powered Ascent vs. Descent
Figure Q: Credit: N Dodsworth

NEMO 2.0

Build vs. Buy, New vs. Used

Choosing how to source components for NEMO 2.0 was of critical importance. Components can be purchased commercially, custom built in-house or reused from an earlier model. Each choice comes with its own pros and cons. Making wise sourcing decisions can mean the difference between success and failure and can significant affect the final cost of the project. Brother Rice Robotics spent considerable time ensuring we had a complete understanding of the sourcing tradeoffs for each critical component on NEMO 2.0. We then discussed, debated and voted democratically on where/how to source each component. The tradeoff matrix we used when deciding how to source many vital components of NEMO 2.0 can be seen below in figure R.

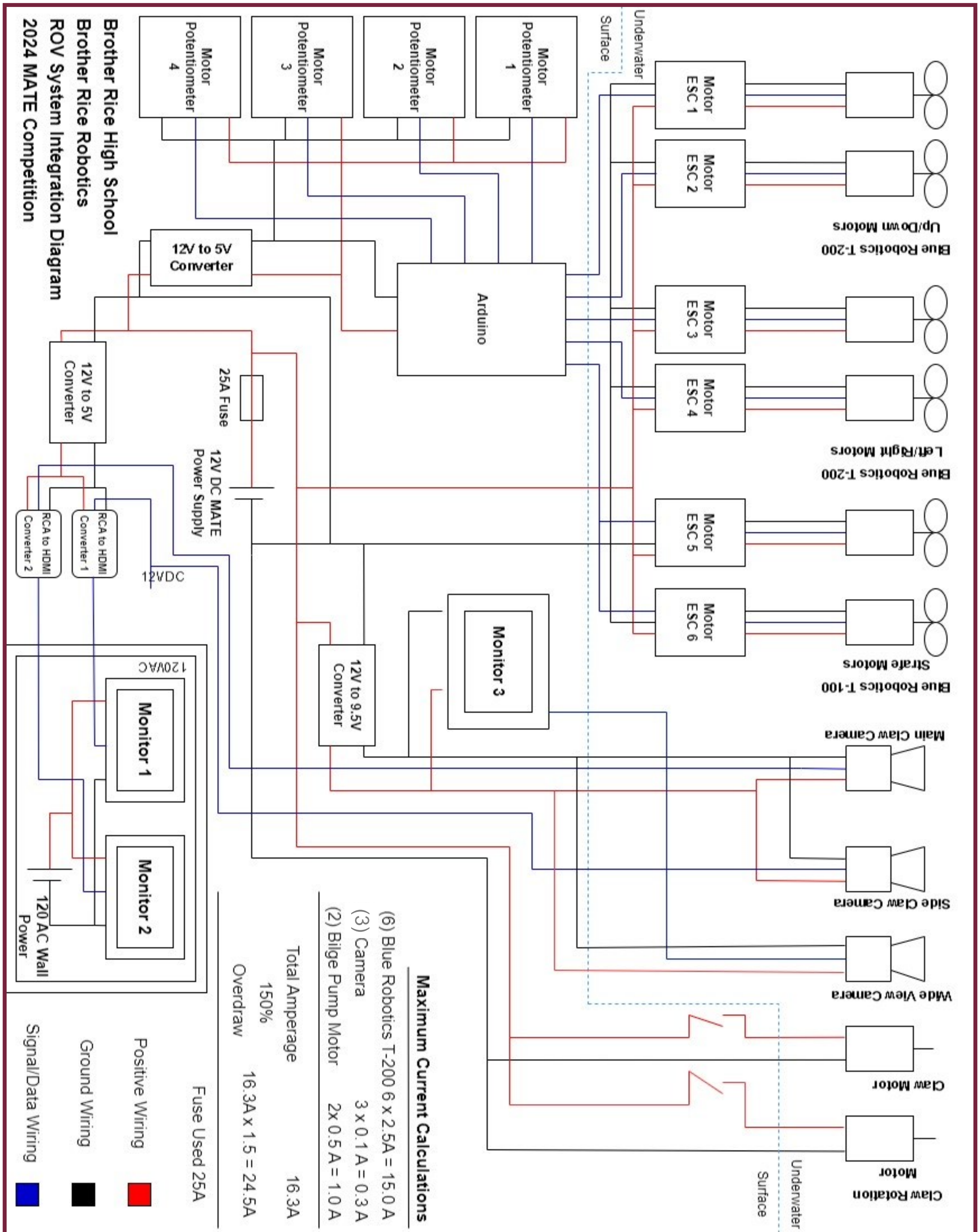
Sam Machining a Custom Part
Photo Credit: N Scott

	Build		Buy		Reuse		
Component	**Pros**	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**	**Final Choice**
Claw Gripper	Can customize exactly	90deg rotation is complicated, time consuming, realiability	Saves time, reliable	Costly, not customizable	Saves time and money	Cannot rotate 90deg, unreliable	**Build**
Thrusters	Exact customization	significant requied knowledge, waterproofing, reliability	Save time, reliable, compatable with existing T200's	Costly	Saves time and money	T-100's do not function at full thrust or controlability	**Buy**
Water Tight Enclosure (WTE) # 2	Exact customization	significant requied knowledge, waterproofing, different buoyancy profile than WTE #1	Saves time, reliable, same buoyancy profile as WTE #1	Costly	Saves time and money	Existing WTE is not large enough to neatly contain all the required wiring	**Buy**
Topside Control Box (TCB)	Exact customization	Time consuming, added cost for new materials	Saves time and more reilable	Costly, non-customizable to our exact components	Saves time and money	Some shortcomings will have to be changed/updated	**Re-use**
Buoyancy Reduction Vessels (BRV)	Exact customization	Time consuming, reliability, water proofing	Would save time and increase reliability but this exact part does not exist for purchase		This part does not currently exist in our inventory		**Build**
Frame	Exact customization	Time consuming, troubleshooting required	Saves time, troubleshooting not required	Unessisary cost, tough to find a purchased frame that meets our exact specs	Frame worked excellent in '23, is still in good shape and has room for tool and compent evolution in 24	Nothing major, but will need touch up paint	**Re-use**
Tether	Exact customization	Time consuming and costly	Saves time, confident there will be no issues	Significant cost, may not have the amount and gauge of wires we desire	Tether worked well in '23	Needs mods for an additional camera and bilge pump motor and will also need a new sheath	**Re-use**

Build, Buy, Reuse Tradeoffs and Decision Matrix
Figure R: Credit: S Lapenas

NEMO 2.0

System Integration Diagram (SID)



NEMO 2.0 System Integration Diagram
Figure S: Credit: M Griffin

Safety

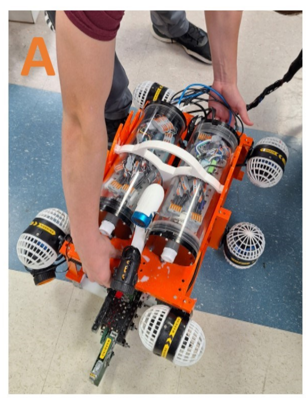
Safety is a top priority at BR Robotics. Team members are trained how to safely use the tools and materials required to build the NEMO 2.0. Team members underwent training on how to safely use drills, handsaws, belt sanders, hot glue guns, soldering irons, and heat guns. We had training on how to properly clamp materials as well as training on how to properly and safely use electricity. We have a designated cutting/drilling table and a designated "hots" table in our shop. Care is taken to ensure the shop and all work tables stay neat and organized. When in the pool area we ensure that at least two team members are always present. Running and roughhousing on the pool deck is never allowed. Team members are trained to know where the life preservers and AEDs are located. As an added bonus to ensure the safe operation of NEMO 2.0 by our customers we have created a safety procedure checklist (Fig. T) that is included with NEMO 2.0. Users should follow this checklist during setup, operation and take down of the ROV, to ensure the pilots/ crew and all ROV components remain protected. NEMO 2.0 comes equipped with numerous, built in, onboard safety features, these were discussed earlier on page 9 and in figure H.

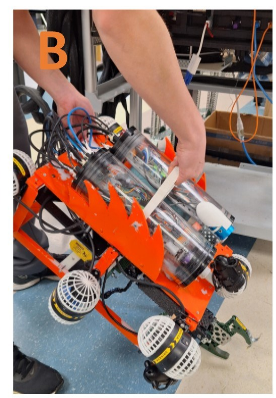
Brother Rice Robotics NEMO 2.0 Operations Checklist

Updated: 4-25-2024

	Pilot and Crew Considerations
☐	Ensure that all individuals have closed toed, grippy footwear
☐	Ensure that all individuals minimize loose/baggy clothing
☐	Ensure that all individuals understand their roles and responsibilities
	Pre-powerup Procedure
☐	Visually inspect the operating area for potential hazards
☐	Position the cart within 3m of the water
☐	Chock all 4 cart wheels
☐	Ensure that all wires are properly connected to the TCB
☐	Adjust monitor positions
☐	Plug the power strip into a 120v outlet
☐	Grab front and back of ROV frame to remove from cart
☐	Place ROV near the waters edge
☐	Visually inspect the ROV for damage/issues
☐	Remove tether from cart spool and coil neatly near ROV
	Powerup Procedures
☐	Turn on the power supply
☐	Listen for the correct motor chime pattern
☐	Ensure camera feeds are working
☐	Perform a motor functionality test
☐	Perform a claw functionality test
☐	Adjust camera angles on ROV if needed
	Launch Procedures
☐	Use the lift handle to lower ROV into the water
☐	Submerge the ROV and tilt backwards to fill the BRVs
☐	When BRVs stop bubbling release the ROV

	Retrieval Procedure
☐	Use lift handle to remove ROV from water
☐	Place ROV on waters edge
☐	Grab the back of the ROV and tilt forward to drain BRVs
☐	Grab the front and back of the ROV frame and place on the cart
☐	Coil the tether on the cart spool
☐	Ensure that both controllers are hooked on the cart
☐	Tilt the monitors down into their traveling positions
☐	Remove the 4 wheel chocks
	Continual Maintenance of the operating area
☐	Ensure that the operating area is well organized and free of tripping hazards
☐	Ensure that all tools and equipment are placed on/in their designated positions
☐	Continually ensure that excess tether is neatly coiled on the ground





Proper Hand Placement For ROV Lifts

A— Front/back frame lift

B—One hand handle lift

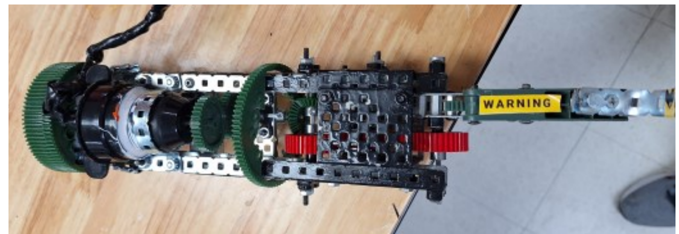
C—Tilt lift to drain BRVs

Photo Credit: N Scott

On Deck Operational Safety Checklist
Figure T: Credit: O Roa

Testing Methodology

Every part of NEMO 2.0 has been rigorously tested for functionality and reliability. Early in the build each component was tested as efficiently and effectively as possible. An example of this is the evolution of our claw manipulator. After completing the mechanical changes to the drive train of the claw it would have been inefficient to have immediately attached the claw to the ROV and wired it up to it's motor. Instead, we conducted multiple rounds of intermediate testing and made many adjustments and changes along the way with the performance data we collected. First we tested it by simply moving the claw by hand. We looked for issues, felt for smoothness and friction and got a general sense of how the claw and gear train were working. Next we attached the claw motor and wired it up to its switch and operated the claw with it clamped to the workbench. This helped us determine if the speed was appropriate, if gears were slipping and if the motor was strong enough to do the work we envisioned. This round of testing led us to add a 3:1 gear reduction to both slow the claw speed and increase torque to help the claw work more reliably. Finally we attached the claw assembly to the ROV as designed, "dry" tested it on the bench to ensure it was still working as planned and then took it to the pool to "wet" test it. Nearly every component on NEMO 2.0 went through a similar testing process. Once all systems were working as desired it was time to put the entire ROV through its own round of testing in the pool to ensure that each system was functioning harmoniously with each other system. The pilots and crew took over putting the ROV through its paces, practicing each MATE '24 task, spending extra time on the most difficult tasks, brainstorming strategies to make each task simpler, determining an "order of events" (the best order to complete tasks in order to earn the most possible points during the pool demonstration) and then practicing this routine until they were confident and competent in their roles.



Claw Manipulator Bench "dry" Test
Credit: N Scott

Troubleshooting Strategies and Techniques

In engineering problems are the name of the game and troubleshooting is the tool used to solve those problems whenever they arise. At BR Robotics we have honed our troubleshooting expertise over many seasons, and have condensed this knowledge into a 5-step troubleshooting procedure that can be seen in figure U on the next page. Effective troubleshooting requires that the engineer does not make assumptions or jump quickly into isolation or solutions. This will assuredly waste time, effort and most likely money on a solution that at best might only partially fix the issue. When an issue arises that needs troubleshooting we first spend considerable time observing and analyzing the issue and work hard to gather actual data that can be used to design a solution and to allow us to measure how effective our solution is. Next we study what ROV systems might be contributing to the issue. We use all this data and information to plan the most effective way to begin isolating components to find the problem. Isolating components is effective but it is very time consuming and the ROV is out of commission during the entire isolation process, slowing down the build and pilot/crew training.

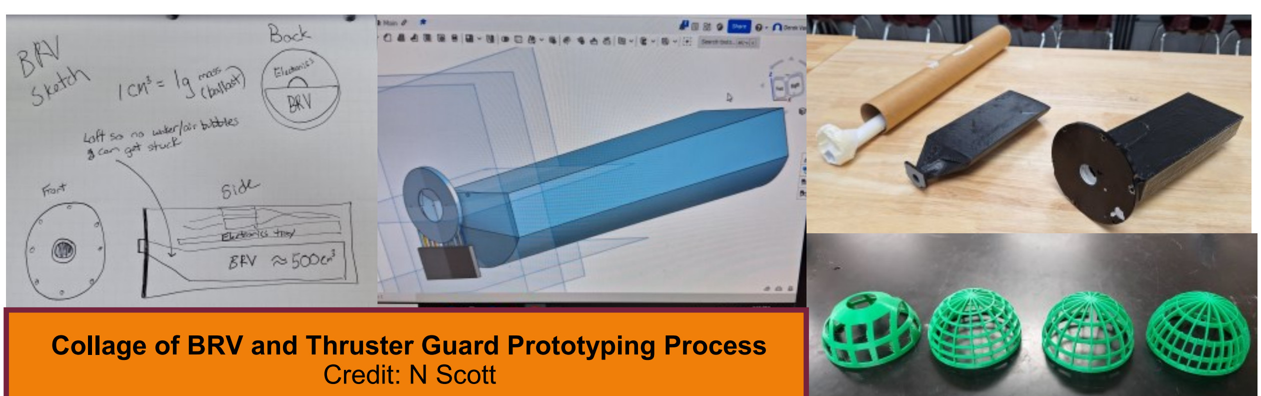
Isolation is the fourth step in our process. During this step we find creative ways to bypass individual components in a systematic way until the ROV begins to work as intended. That component is then the issue and must be repaired and changed to work better, which is our final step. We spent considerable time troubleshooting a thruster control issue. Our left thruster and both strafe thrusters suddenly began to work as a motor group as opposed to individually. After gathering data about the issue and determining what systems might be involved, we determined that it must be an electrical signal issue. We chose to start at the beginning of the signal pathway which is the controller. We swapped to a backup controller and got the same results. We swapped in a spare Ethernet cable and got the same results. We traded out and reconnected the 4 signal wires from the Ethernet port to the Arduino and even re-downloaded our code, thinking it may have been corrupted. Nothing fixed the issue. Finally the Ethernet port itself was suggested we transferred all the signal wires to a spare port and the issue was switched. Apparently the left motor terminal and strafe motor terminal had somehow began touching inside the port, resulting in the mixed up signals for those 3 thrusters We installed the new port and the problem was disappeared. To aid in motor/signal testing we utilized a “mini-test pool” (plastic bin w/ 5gallons of water) to allow us to run our motor out of the pool without burning up the thrusters, as they are water lubricated and cannot be operated “dry”.

BR Robotics Troubleshooting Procedure		
Step	**Title**	**Action**
1	Observe and Analyze	Gather as much quantitaive and qualitative data about the issue as possible
2	Determine the System/s	Based on the data determine what system/s might be involved in the issue
3	Brainstorm/Plan	Brainstorm possible causes and a plan to isolate and confirm the issue
4	Isolate	Remove/bypass systems/components to confirm what the issue is
5	Repair/Innovate	Repair the issue or innovate an improvement that fixes the issue

Brother Rice Robotics Troubleshooting Procedure
Figure U: S Lapenas

Prototyping and Testing

Prototyping and testing is key to BR Robotics keeping customer costs as low as possible and meeting project deadlines. We strive to find the fastest and cheapest ways to bring our ideas to life. This often starts with a paper sketch that is studied and modified significantly before any prototype is created. We create a physical, full size model of the component from paper/cardboard and check for feasibility and fit. We then model the component in CAD and 3D print. We continue to iterate as many versions as needed until the component is working as desired, and passes all the tests that it needs too. Images of this process for our very difficult BRV system can be seen below as well as the iterative prototyping process our thruster guards underwent.



Collage of BRV and Thruster Guard Prototyping Process
Credit: N Scott

Project Accounting

BR Robotics began the 2023-2024 season by estimating and projecting costs. After determining the amount of seed money BRHS was willing to contribute the team made projections as too how much would need to be spent on each ROV system. These projections can be seen in figure V. The team emphasized the need to cut costs wherever possible so as not to go over budget as the team had no leftover funds from the year before. Throughout the build, costs were recorded, including reused parts, so a total ROV cost and the '24 final budget, could be determined, see figures X & Y. BR Robotics has standing donors ready to cover travel expenses if the team is successful enough to make it to the World Championship. Our proposed travel costs can be seen in figure W.

Type	Budgeted Amt.	Description (as of 10/15/23)
Donation	2000	Yearly seed money for our program
Electronics	100	May need misc electrical supplies
Bouyancy	400	Need a 2nd WTE
Propulsion	250	Enough for 1 replacement motor
Materials	100	May need misc structural supplies
Fasteners	25	May need misc fasteners
Adhesives	50	May need misc adhesives
Tether	100	Need a new sheath and a few wires
Camera	200	Need a new "nav" camera
Claw/Tools	50	May need misc claw/tool supplies
Vesco	500	Estimate of VESCO cost
Misc	225	Slush fund for any overages
Total	2000	

Proposed Project Costing 23-24
Fig. V: M Griffin

Estimated Competition Expenses for 24 Season		
Regionals	Category	Amount
	Travel (rental/gas)	100 (gas only)
	Lodging	0
	Food	0
	Activities	0
	Entry Fee	250
	Total Expenses	100
*** BRHS will cover the gas and fee for regional attendance*		
World Champ	Category	Amount
	Travel (rental/gas)	1000 (gas only)
	Lodging	5000
	Food	500
	Activities	500
	Entry Fee	250
	Total Expenses	7250
*** Donors are lined up to cover WC expenses if we make it*		

Estimated Team Travel Expenses
Fig. W: M Griffin

Type	Amount
BRHS Donation	2000
Total '24 Costs	1945
Balance	55

Simplified Final Budget for 2024
Fig. X: M Griffin

Component/System	Source	Description	Cost
Thrusters	Reuse	2 T-200 & 2 T-100 & 4 ECS	950
Thrusters	New/Build	2 T-200 & 2 ESC	512
Frame	Reuse	HDPE sheets and sticks	38
Frame Fasteners	Reuse	Misc from McMaster Carr	23
WTE 1	Reuse	Blue Robotics 4" x 15" Acrylic	400
WTE 2	New/Build	Blue Robotics 4" x 15" Acrylic	400
O-rings	New/Build	4" enclosure seals	35
Tether	Reuse	12g MTD wire x 2, ethernet x 1, 20g x 2	125
Tether	New/Build	20g x 2 (for claw rotate motor)	10
Tether	New/Build	Velco protective sheath	58
TCB	Reuse	Box, wires and connectors	50
TCB	New/Build	New wires and connectors to better organize the box	25
LED Cameras	Reuse	2 LED fishing cameras	281
Infrared Camera	New/Build	1 Infrared fighing camera w/ temp, depth & 9" monitor	143
Camera Feed	Reuse	VGA to HDMI convertors	50
Large monitors	Reuse	24" computer monitors	93
Drone controller	Reuse	Repurposed drone controller with 3ft. ethernet	40
Claw controller	Reuse	3D printed box and 3 way switch	9
Claw controller	New/Build	3D printed box and 3 way switch	9
Thruster Shrouds	Reuse	3D printed	15
Lift Handle	New/Build	3D printed + 2 peices of HDPE	15
Claw manipulator	Reuse	Most of the claw and pump motor were repurposed	45
Claw manipulator	New/Build	Rotation motor, vex gears & the "cradle"	40
Cart	Reuse	Cart was repurposed into the new cart system	90
Cart	New/Build	Shelf, VESCO hook and paint	15
BRV	New/Build	2 Waterbottles, misc PVC parts and 10 rubber gaskets	35
Electronics	Reuse	Arduino and 4 voltage converters	50
Paint	Reuse	Orange and black latex left from 2023 build	25
Stickers	New/Build	Eyes and warning labels from Stickeryou.com	56
Adhesives	New/Build	Hot glue sticks and waterproof epoxy	100
Zip ties	New/Build	Variety pack	12
Heat shrink	New/Build	Variety pack	17
VESCO Electronics	New/Build	Vex cortex, wires, fuses, 393motor, connectors, 3 way switch	331
VESCO Housing	New/Build	PVC pipe, endcaps, PVC cement, rubber boot	49
VESCO Motor	New/Build	500 GPM Bilge Pump Motor	22
VESCO Shroud	New/Build	3D printed in house	5
VESCO Interior	New/Build	Vex metal, HDPE, D Battery holders x 2	32
VESCO Batteries	New/Build	13 D Batteries	24
		Cost of new parts on NEMO 2.0	1482
		Cost of reused parts on NEMO 2.0	2284
		Cost of VESCO 1.0	463
		Total Cost of NEMO 2.0	3766

Itemized Budget for NEMO 2.0 and VESCO 1.0 for 2024 Season
Fig. Y: M Griffin

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	Brother Rice Roobtics NEMO 2.0 Basic Troubleshooter
	ROV Not Powering on
1	is the ROV is plugged in to a 120v wall outlet?
2	is the 120v wall outlet and/or GFI working properly?
3	is the cart powerstrip on?
4	is the power supply plugged into the powerstrip?
5	are the front and back powersupply cords plugged in properly?
6	has the powersupply fuse blown?
7	If the ROV still will not power on the ROV will need intensive troubleshooting
	Thruster/control Issues
1	turn ROV off and wait 30 seconds to allow for residual power to leave the system
2	turn ROV on and see if same issues occur
3	turn ROV off
4	is the controller Ethernet cable plugged in securely on both ends?
5	are the 12v power and motor signal cords plugged securely into the back of the TCB?
6	are all signal wires form the controller Ethernet port to the Arduino secure?
7	are any 12v power wires inside the TCB loose or damaged?
8	is the 5v power conterter for the Arduino functioning properly?
9	is the arduino power light illuminated?
10	are an wires loose of damaged in the WTE?
11	If the thrusters still do not function properly the ROV will need intensive troubleshooting
	Claw Issues
	Claw not working at all
1	is the Ethernet cable from TCB to claw controller plugged in securely?
2	do all claw wires in the TCB appear connected and in good condition?
3	If the claw still does not function properly the ROV will need intensive troubleshooting
	Claw Working But Not Fully or Smoothly
1	check the claw geartrain, roataion geartrain and rotation cradle for damage/foreign objects
2	lubricate all black VEX bearings
3	If the claw still does not function properly the ROV will need intensive troubleshooting
	Camera Issues
	Claw Cameras 1 and 2
1	are the claw monitors plugged into the powerstrip?
2	are the claw monitors turned on?
3	ensure that debris is not covering the camera lens
4	are the exterior HDMI cables plugged securely into the TCB and both monintors?
5	are the 2 cam power plugs and 2 yellow signal plugs attached securely to the back of the TCB?
6	are the white signal convertors in the TCB powered on?
7	are the internal HDMI cables plugged in securely?
8	If the camera still does not function properly the ROV will need intensive troubleshooting
	Navigation Camera
1	is the navigation camera monitor turned on?
2	is the cam power on the backside of the TCB securely connected?
3	ensure that debris is not covering the camera lens
4	If the camera still does not function properly the ROV will need intensive troubleshooting
	Water Tight Enclosure Leak
1	are all endcap bolts and all cable penetrators tight?
2	remove the endcaps, clean, dry and re-seat endcap gaskets
3	remove enclosure flanges, clean, dry and reseat all flange gaskets
4	reassemble WTE