VALOR MARITIME INTERNATIONAL

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Lindsey McLean	Internal Systems Engineer
Chris Gowens	Software Engineering Manager
Laci Bex	Lead Design Expert
Michael Ely	Pilot
Jaden Tanakura	Chief Engineering Officer
Hugh Kim	Visual Systems Engineer
Kalea Carsley	Electrical Engineer
Joshua Libby	Engineering Technician
Reed Knutson	Tether Engineer
Emily Kim	Lead Controls Engineer
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CONTENTS

Fig 1: The VMI Team

ABSTRACT

Valor Maritime International is a company of 14 students from Aloha, Oregon, which designs and manufactures Remotely Operated Underwater Vehicles (ROVs) for use in underwater situations where humans can't get to easily. This year, we are proud to exhibit our newest ROV, A.N.T at the 2021 MATE competition.

A.N.T. is designed for maintaining ocean health, including maintaining devices like seabins: large, water-bound trash bins. It can manipulate a seabin power system, replace mesh catch bags, and remove debris from the bottom of the ocean with a pneumatic gripper. A.N.T also features a host of cameras and computer software to identify coral species, as well as a Micro-ROV which can inspect pipes and collect sediment samples.

With ocean pollution rising rapidly, all of these features are essential for maintaining the health of our oceans. Maintaining and cleaning seabins allows them to keep filtering debris from the ocean, protecting wildlife and making the ocean a more enjoyable place for people, while relocating coral can also stimulate growth in previously unhealthy colonies.

A.N.T is our best ROV yet, and what we believe to be the best in class for maintaining healthy waterways. This year, we have made numerous improvements over last year's robot, upgrading the design, chassis, motors, and electronics to create our best possible robot. Protecting the future of ocean health is no small feat, but by educating and engineering, we can teach people how to create that future for themselves.

OVERVIEW

Valor Maritime International is a small, long-standing ROV company, composed entirely of students from Valor Christian School International. Our company has taken part in the MATE competition every year since our school's founding in 2016. This year, we are proud to present A.N.T, our flagship underwater remotely operated vehicle (ROV), which has been designed to complete tasks relating to the theme of Excite, Educate, Empower: Students Engineering Solutions to Global Problems. Its functionality includes performing tasks like "depowering and repowering a seabin," mapping points of interest on a "coral reef," and removing a "trap full of eels." As a team we have used our skills to make A.N.T capable of completing all of these tasks and several more to help protect our environment.

TEAMWORK

TEAM COMPOSITION

This year saw a mix of newcomers and returning talent, making for a very diverse and unique team. At the beginning of the year, we held a discussion to gauge everybody's strengths and interests and assign their positions. The result was a team that was motivated to build and enthusiastic to learn. We elected Elijah Schaefer as our CEO because he had the most experience with MATE. As CEO, he provided direction and support for the team as a whole, and on individual projects. Our CFO was Kaylee Sorenson, whose timeliness and organizational skills have kept our management organized, and our engineers well-equipped. Brooklyn Watkins, our Marketing Officer, was elected because she had her sights set on graphic design, and this opportunity has allowed her to get practical experience in the graphic design field. On the technical side of things, Olin Littlejohn took up the position of Chief Technical Officer, fronting our ROV systems branch and giving him engineering experience as he prepares for a career in aerospace engineering. Working closely with Olin were Lindsey McLean, an Internal Systems Engineer, Christopher Gowens, our Software Engineering Manager, and Emily Kim, Software Engineer, who made sure the computers inside the ROV had the necessary software and hardware integrations to complete its tasks.

The ROV, dubbed A.N.T, was designed by Laci Bex, the Lead Designer of our three previous robots.

The control systems branch was led by Jaden Tanakura, Chief Engineering Officer, whose team was responsible for constructing the camera and tether systems. Working with Jaden were Hugh Kim, a Control Systems Engineer, our two Tether Engineers, Reed and Joshua, as well as our two Engineers Nadia Pavloff and Kalea. Because our team this year has been larger compared to previous years, we have had more hands on deck to accomplish more in a shorter span of time, giving us the opportunity to build our best ROV yet.

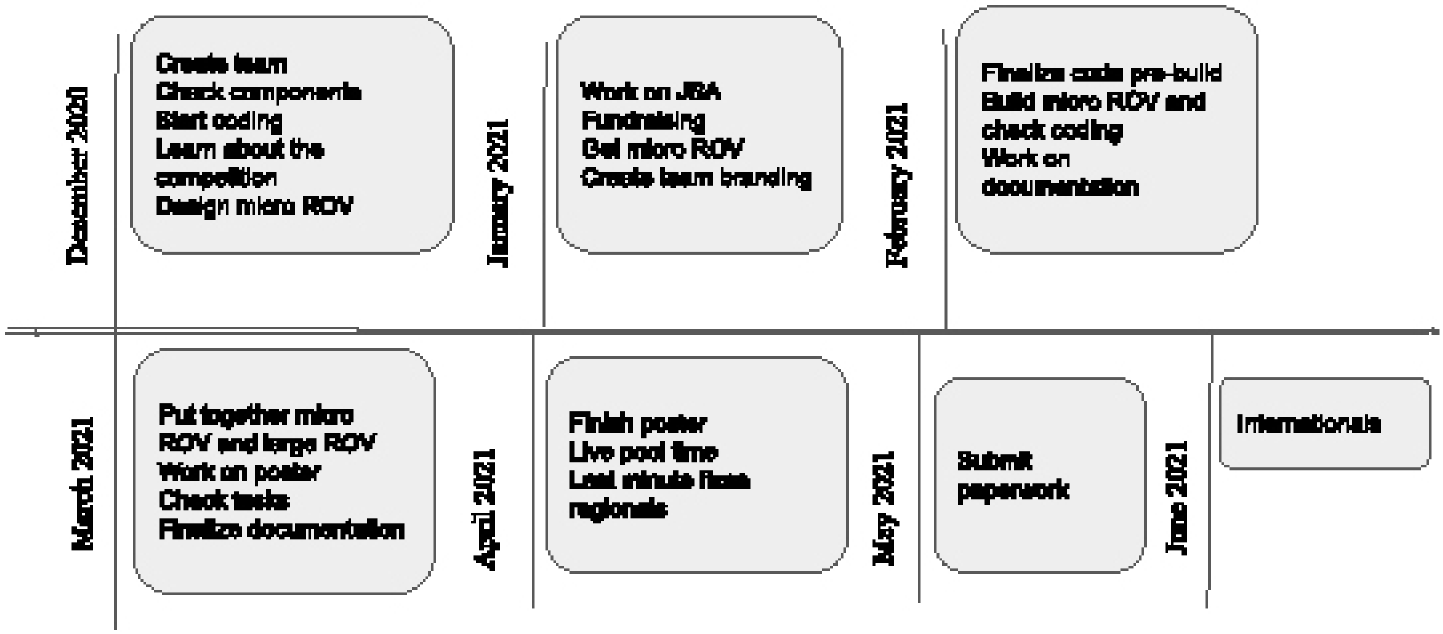


Fig 2: Timeline of Activities

Schedule and Planning

Keeping a tight schedule and adhering to our deadlines was a simple and effective way to make consistent progress on our ROV development, and build the foundations for coordination amongst the members of our large team. The deadlines were structured in such a way that we could immediately build off of the progress made and keep a consistent workflow. In addition, each person had their own set of deadlines which were created with the guidance of their department's officer. Our CFO kept a tight budget and ensured that funds were raised and supplies were budgeted and distributed properly. The CTO oversaw the software development of the ROV, as well as our research and development, while our Chief Engineering Officer met deadlines for the ROVs construction. As with any project problems inevitably arose, whether big or small, which affected our schedule. When faced with these challenges, our team followed checklists and protocols which were established towards the beginning of the year. The first step was to consult our CEO, Elijah Schaefer, for his opinion on the situation. If the team was still having difficulty, we turned to our mentors for advice. Such problems arose several times through the course of development, but our team was able to adapt to and overcome each issue.

Encouraging learning and collaboration to solve problems is a primary reason that we were able to have a knowledgeable, cooperative team, despite being substantially larger than previous years.

Company Evaluation/Market Assessment

Our company was able to work together successfully even during a pandemic to build a top quality robot. After all the struggles we went through to get where we finally are. Our failures lead to success and the robot finally worked.

DESIGN RATIONALE

ENGINEERING DESIGN RATIONALE

Our ROV was designed using 3D modeling software and was professionally laser cut out of delrin for a sturdy and clean cut design, which was inspired by our ROV from two years ago. We designed this robot by taking into account the flaws and successes of our previous design, and improving on its flaws. The biggest issue with the old ROV was that having six T-100 motors overloaded the ROV electronics system, and made it require constant maintenance. This year we decided to drop two motors, but upgrade the remaining four to T-200 motors. We also wanted to upgrade our internal control box since the last design was very jumbled, making it difficult to work on. This year we designed the ROV to contain a clear, tubular housing for our internal control system. This control system housing fits in well with our design and allows for easy access to the internal wiring, while keeping all of the individual systems separate from one another. This year, we decided to make full use of the horizontal space of the robot for a layered configuration. This configuration allows our systems to be spaced out, and allows each system to be easily removed for inspection or maintenance. This also means that we can have our main camera put in a more advantageous position, since the electronics and the camera are all on the same layer. The main camera is housed in the domed front of our control housing. The dome displaces the water and allows the camera to see in a 180 degree field of view, which is further increased by the swiveling mount attached to the front camera. This year's design allows for all of the necessary systems to be incorporated into a design which allows for efficient use and easy access for maintenance, while also being sleek and professional.

INNOVATION

Every year we build a robot is a chance to improve our designs and innovate our robots. This year, our innovations were directly focused on improving the flaws of our previous robot, which included redesigning the chassis, reevaluating our electronics system, and improving internal accessibility for maintenance. Incidentally, all of our innovations for this year were directly related to each other. Before we started designing the chassis, we created a rough draft of our Systems Integration diagram (SID), since last year our system was overloaded and required constant attention. The biggest change this year was using 4 T-200 motors instead of 6 T-100 Motors. This change allowed us to fix our electronics issues by allocating less resources to the motors, and also allowed us to design the robot chassis with a greater consideration of our other systems, such as the pneumatic claw and the five cameras we wanted to include. We also designed our electronics system to fit into a long acrylic cylinder, enabling us to slide the electronics out and work on a specific module. This year's innovations were

monumental in making our robot more accessible and user-friendly, as well as giving it greater endurance in the water.

PROBLEM SOLVING

With any project, problems will inevitably arise. At VMI, we strive to be prepared for problems, but we also understand that even more unexpected things can happen. However, by looking at past experiences in the company and encouraging members to do further research, we are able to plot out and solve our problems in a consistent, educative way that aligns with the spirit of MATE.

The first step of the problem solving process is to identify the problem. Team members would start by reverse engineering their work individually and retracing the steps they took in the construction process. A prime example of this can be found in the development of our motor system, and the propulsion team's struggle to control the actions of the individual motors. With so many variables (the speed controller's motor outputs and pin outputs, the Arduino programming, and the Arduino pin inputs, and others) it was difficult to determine how to make a particular motor run. The first step to fixing this problem was to establish a color-coding system for the wires of each motor. This simple system made it much easier to follow the wiring of a specific motor and identify where issues occur. The propulsion team also had difficulty using pin 6 on the Arduino `hat' to control a motor. They were able to control the motors without the "hat" using pin 6, so the team identified the problem was with the "hat" itself. To solve this problem, they first tried redoing the solders on the "hat." When that did not remedy the problem, the team replaced the "hat" entirely.

Creating the code and implementing it required a lot of research. Since our main computer programmer left, we had to rely a lot on internet guides for arduino and python, as well as forum websites such as stackexchange to figure out the answers to our problems. While there wasn't much information about our situation specifically, we were able to piece together information from a variety of sources to figure out what needed to be done. This also allowed us to train a new programmer who will be able to code and train future programmers for the company.

SYSTEMS APPROACH

Every year, we hand design and manufacture different robotic systems to meet the needs of the mission requirements. This year's mission included multiple tasks that utilized the camera and claw systems of the ROV, as well as the micro-rov. Because of this, we decided to aggregate our systems resources into these three systems. While having other sensors such as pressure and temperature sensors can be beneficial for piloting in general, we decided to instead rely on the 5 camera system to provide all of the spatial information we needed for piloting; with four external cameras positioned in strategic locations and one internal camera with tilt capabilities.

This year we have also upgraded our claw, giving it a greater surface area to manipulate with, and integrating it into the front of the robot so it sits almost flush with the front when not in use. Our micro-rov has been updated to feature a more compact, cylindrical design with a brushless motor. This year, we have opted to attach a touch fastener to the end of the micro-rov, allowing it to adhere to a material sample at the end of a pipe for extraction.

Vehicle Structure

Every part of the ROV was designed to be of use to the vehicle. The ROV was specifically designed within a 3D modeling system in order to make sure that the ROV would meet our exact specifications, and was then laser cut from delrin, a sturdy thermoplastic. This year, our ROV is operating on a 4 motor configuration to gain the best control and precision while not overwhelming the speed controllers, as this was a problem with our 6 motor configuration during the last competition. We have also included a clear, acrylic casing for our ROV's internal control systems. This allows for the increased organization and accessibility of our internal wiring. We have also included specifically designed areas of our ROV to house different attachments, such as a micro ROV, a pneumatic claw, cameras, and any other attachments that could be needed.

Fig 3: The ROV ANT CAD design.

This year, our software has been rebuilt from the ground up to identify coral species more efficiently, utilizing all of the cameras on our robot. Each camera has been positioned in a unique way to give us several different views, allowing the pilot to have more spatial awareness of their surroundings. The robot is valued at around $4,500, although this year's total expenditure is around $1,500. Over half of the total worth is due to the laser cutting of the delrin frame, donated by Micron Laser for free, and many parts were reused or were unused from years prior.

This year's robot has a similar size and weight profile as our last ROV, as we wanted to improve on its design, not scrap it completely. The robot weighs 6.80 kilograms.

Vehicle Systems

Cost-efficiency was a serious consideration in the selection of the components and materials used in the final ROV. For this reason, many parts such as the motors were reused from MATE competitions in prior years. The team also used many parts from different science classes around the school, such as motors from a drone class, and Arduinos from an engineering course. The team also made use of the school's 3-D printer, and designed and printed many parts of the ROV more cheaply than they otherwise would have been able to. When considering the materials options for our chassis, we initially considered using High Density Polyethylene (HDPE) due to that fact that its density is similar to that of seawater, which would help our ROV approach neutral density. However, our laser-cutting vendor informed us that HDPE would melt during the laser-cutting process, so we want back to the drawing board. In the end we selected Polyoxymethylene (POM) to make up the shell of the ROV. We chose POM for its lightweight but sturdy nature.

Part of the MATE challenge this year involves the extraction of material from a long pipe with a narrow diameter. This put a significant size and material constraint on the mini-ROV subsystem which was tasked with accomplishing this part of the mission. The mini-ROV could not be larger than the pipe in which it was to fit, which in turn meant that the motors had to be within a specific size as well. The motor chosen for the mini-ROV also had to be capable of both forward and backward motion, as it would have to enter the pipe and come back out before reattaching to the main ROV. This analysis was done similarly with other subsystems and components, and in this way, the mission constraints and objectives were instrumental in the components and design of the ROV.

Control and Electrical Systems

The ROV was controlled through the controller interfacing with the Arduino on board the vehicle. There were two programs written for the control of the robot, the first regarding the controller outputs, and the second dealing with translating those outputs into motor rotations. The program for managing controller outputs was created on the Atom application and implemented into the list of codes that directly connects to the joystick and to the Arduino as well to send commands to the brain by moving the joystick. The joystick sends a string of five characters, dubbed a packet, to the arduino inside the "brain" of the ROV, which then interprets the packet to rotate the motors. The arduino parses the received packet, breaking it into its five different characters.

The first character of the packet, V, initializes the program. The second through fifth characters each correspond to one thruster motor. Each thruster motor responds to three commands: forward, reverse, and stop. If a given motor receives an R it will reverse, if it receives an F it will go forward, and if it receives an S it will stop. An example packet would be: VFSSR, which would mean that the first thruster goes forward, the second remains stopped, the third remains stopped, and the fourth goes in reverse. The Arduino on the robot receives ten packets from the controller per second, allowing for seamless control.

All of this is powered through our control switch. This switch is connected to our power control block which constantly sends power to all the systems. Our switcher receives power, and allows the power to be toggled for any given system. The switcher can control power for five things total. For our robot the first of these is the overall power, this will turn all electronics on or off. The next three switches will control the pneumatics, external cameras, and control systems while the last one hasn't been decided on yet. With the electrical and control systems in place, the pilot can efficiently control the ROV motors to complete the tasks.

The ROV tether consists of one 14-gauge 12 VDC power cable, four analog video cables, two Cat 5 cables for data connection to the Arduino and network connection to the raspberry pi, and two air hoses. All of these cables are bundled using a blue Flexo PET braided sleeve which can be coiled around the ROV, making it easy to transport. This tether also allows all of the cables connected to the ROV to be tightly packed which makes it safe and convenient.

The complete Systems Integration Diagram can be found in Appendix A.

PROPULSION

The A.N.T. propulsion system contains four Blue Robotics T-200 thruster motors spread throughout the ROV. This type of motor was selected because of its underwater efficiency and relatively affordable price. Four motors were determined to be the optimal amount as it allows for considerable propulsion and rotational capabilities. Two thrusters were placed above and behind the “brains” of the robot (the segment containing the Arduino & speed controllers), while the other two were placed beside and below the “brains.” The motors that face the brains provide upward and downward propulsion capabilities, while the motors in the back of the robot allow for forward and backward movement and the ability to rotate left and right. This motor placement allows for the ROV to move to the areas where it will perform its mission tasks such as retrieving an object from a tube and photographing coral reefs.

BUOYANCY AND BALLAST

The subsea buoyancy foam adds buoyancy to the robot, and the tether weighs it down and thecram of the robot. Both of these factors help to make the ROV neutrally buoyant. Since the tether is located on the back of the ROV, there is more weight on the back. Because of this, we thought that we would need more weight in the front but it turned out that we didn’t need any ballast and only added buoyancy. We achieved neutral buoyancy through the use of subsea buoyancy foam. At first, we thought that we would need more foam near the front of the ROV since the claw seemed to be weighing the ROV down as well. But, when we put it in the water, it was much more buoyant in the front, so we took it off again. We kept experimenting until we found the optimal amount of foam for our ROV.

PAYLOAD AND TOOLS

In order to gain maximum visibility, our robot contains 5 cameras. One internal camera allows for a wide range of views within the safety of our glass dome at the front of the robot. Our four other external cameras are strategically placed around the exterior of the shell. One is placed behind the hydraulic claw in order to gain an advantageous view of all the missions at hand. The next one was placed beneath the robot, so that the pilot would be able to visibly see whether he is interfering with the wildlife while maneuvering around the coral. The third camera is placed as a periscope on top of the robot. That way the pilot can have a good sense of direction when bringing items to the surface of the water. Lastly, the final camera is placed behind the mini-rov. This way we can gain view of both the mini-rov, and have another angle at the claw and challenges. The four external cameras originally had only one foot of wiring from the output to the camera. We adjusted this by stripping the wires of the covering and soldering the cameras onto extension cables that would fit

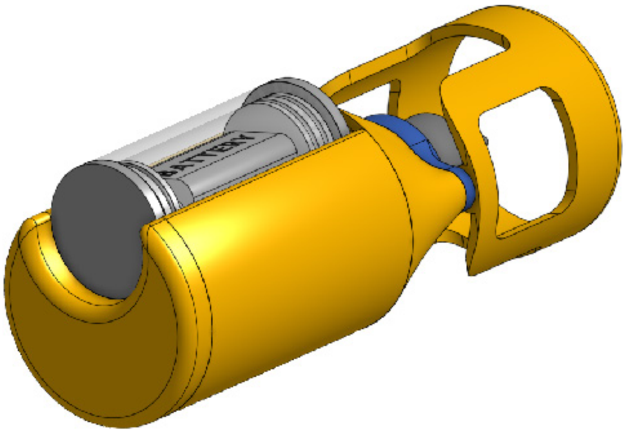


Fig 4: Micro ROV the Wasp CAD design

through the tether. The issue that arose with this is that the cables were no longer waterproof since they had been modified. In the end our solution to this was putting heat shrinks over every solder to ensure there is no water damage to the electronics.

A.N.T sports a pneumatic powered claw that has been specifically designed for this year's tasks. The claw was first designed in CAD alongside the rest of the robot chassis, and was then laser cut out of delrin. This gives the claw a high degree of stiffness and dimensional stability, while also lowering the friction created from the large amount of surface area at the front of the claw. The claw has also been retrofitted with a rubber sleeve to maintain grip.

In addition to the main ROV, ANT features its own micro-rov. This micro-rov is designed to swim down a pipe in order to collect a sediment sample, and has its own claw and propulsion. The micro-rov is built to the same standard as the main ROV, in relation to safety and our design philosophy.

BUILD VS. BUY. NEW VS. USED

BUILD VS. BUY

Building our own parts versus buying others is a complicated matter. On the one hand, building our own parts allows us a high degree of customization, allowing for the parts to be made to our design exactly. On the other hand, buying parts gives us assurance that our parts are high quality and consumer-grade. This year our most significant outsourced components were our four T-200 motors, a direct upgrade to the six T-100s we used in prior competitions. The decision to sacrifice two motors but upgrade the remaining four has allowed us to allocate more space on the robot to other parts, most notably the claw pneumatics, while keeping the same level of propulsion power and maneuverability. The most significant component that was built in-house is the control box, which bridges the gap between land and water, allowing us to pilot our ROV. The control box is designed to house all of the electronic components that belong on land, including the monitor linked to the cameras and the controller that our pilot uses to control the ROV. This control box consists of a medium-density fibreboard exterior fastened onto a metal cart. This method of construction provided us both the sturdy housing we needed while also allowing the sensitive electronics to be supported by the metal cart.

NEW VS. USED

Reusing parts in robot construction is oftentimes a good alternative to re-buying parts every year. Unfortunately not every part can be reused year after year, as then we would just be making the same robot over and over again. At VMI we aim to reuse as many parts as we can. Our philosophy behind reusing as much as we can stems from the same philosophy that drives the MATE competition: promoting sustainability and environmental awareness. By reusing as much as possible, we are reducing the amount of single-use packaging and other materials that we throw away. This is especially relevant as this year's MATE theme includes the "Ubiquitous Problem of Plastic Pollution." Reusing parts and committing to this idea allows us to start working on one of our primary goals before we even get into the water.

Of course, there are practical reasons for reusing parts alongside the ethical considerations. A lot of parts are built to last; parts such as the pneumatic parts are specifically designed to be water-resistant, and even with extensive testing we aren't running them 24/7, which means the parts aren't under a lot of stress.

Our philosophy extends as far as it can while still ensuring the safety of our team. Certain parts like the 3D printed shrouds that surround the motors are thoroughly inspected before being reused. If there are any defects due to wear-and-tear, the shroud is discarded and a new one is created. While this does mean that new materials need to be used, we are not willing to compromise the safety of the engineers, operators, and spectators for any reason.

SAFETY

At VMI, safety is our number one priority when designing and engineering an ROV. Everything from the power systems to the actual systems they power are designed to minimize risk and adhere to MATE safety standards. This means that as a company, we are willing to spend extra time and money to develop systems that are safe to use.

All team members are also required to follow a dress code: No loose fitting clothes, long pants, closed toed shoes, and hair pulled back. Face masks are also required due to COVID-19. They must also be instructed on how to use a tool by a senior member of the team, and must successfully undergo a trial use of the tool overseen by a senior member, before being allowed to operate the tool on their own.

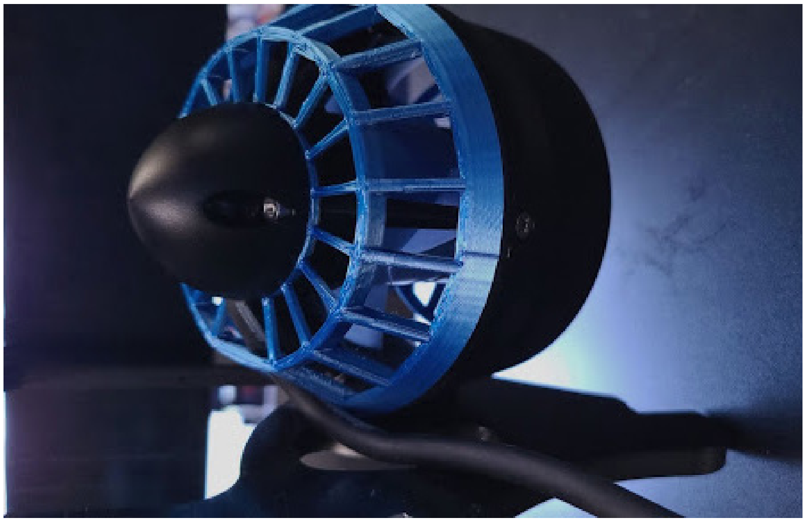


Fig 5: Safety Shrouds on T-200 thrusters

Job Safety Analysis documents are developed by a designated safety officer, and are constantly reviewed and applied to the workplace. All team members are required to memorize the basic safety procedures, and apply them to their work.

The ROV and its control system also complies with all of the safety standards of MATE, examples of which are listed below.

SAFETY CHECKLISTS

Physical safety checklist

- Securely attached all items to ROV.
- All hazardous items identified and covered.
- All propellers completely shrouded.Reduced hazard of all sharp and jagged edges on the ROV by filing them down.

Electrical safety checklist

- All wiring securely fastened and properly sealed to the ROV.
- There are no exposed wires and all splices in the tether are properly sealed.
- Tether is properly secured at the ROV.
- Brushless motors were electrically sealed after purchase.
- There is no exposed wire or copper and all wiring is securely fastened and sealed.
- All splices in the tether were mended prior to competition.

Control system safety checklist

- Anderson Power plugs are used for electrical attachment.
- Attachment point is connected to a single powersource.
- Circuit breaker is placed in close proximity to the power supply attachment point.
- All electrical components are covered inside the enclosure.
- Proper strain relief and abrasion protection is used for the wires passing through the enclosure.
- 120VAC wiring is clearly identified and separated from the DC and control voltages.
- Properly typed connectors are used for for each specific task.

Hydraulic system safety checklist

- All pressure lines are stamped with the proper 300 psi specifications.
- All valves meet the minimum pressure rating of 300 psi.
- Attachment to the pressure source is secured.
- Maximum pressure was set to 150 psi to ensure safety.

CRITICAL ANALYSIS

The key to vehicle testing and troubleshooting is specificity and simplicity. The fewer independent variables in play, the easier it is to determine what exactly went wrong and where, and the simpler it is to address. For vehicle testing, it meant that the ROV was treated first as its several "subsystems" or components, such as the mini-ROV, main thruster system, motor control systems, and camera system. Before integration into the final product, each subsystem was tested independently for errors.

When working with a subsystem such as the main thruster subsystem, the easiest way to troubleshoot is with replacement parts. For example, when a motor was not receiving power, the team tried changing the parts between trials like using a different motor. If it still did not work they would try other things such as using a different speed controller output another, another pin number on the Arduino, or a different power source until the problem was found and corrected.

Another troubleshooting strategy was alternative coding, or codingalterations to test specific functions on an Arduino. For example in the mini-ROV subsystem, if the code that allows UDP signals to control the ROV's forward and backward movement does not work, then the team would then try a simpler method and a simpler code, such as controlling the ROV over serial communication, to see if the components were still working. Even things as simple as having the motor run forward for two seconds and then backward for two seconds can allow engineers to see whether the problem was with the code, wiring, or physical components and make the appropriate adjustments.

Prototypes were also used extensively throughout the assembly of the ROV in order to find the most cost and material-efficient solutions. For example, the camera subsystem involves a camera attached to the face of a servo arm. Several different prototypes of the camera subsystem were designed using different servo arms to see which would fit within the given size constraints and allowed for engineers to determine which servo arm would be optimized to perform its necessary rotations.

ACCOUNTING

BUDGET

At the beginning of each competition year, the VMI executives met to establish a budget that would keep us organized and knowledgeable about our finances. Once this was done, the old robot was scrapped for parts and our workshop was organized to keep track of what parts were being used. Each part was put on an itemized list and given to the CFO to estimate the value of the parts. In addition, all purchases were cleared by the CFO before they could be made, and receipts were immediately given to the CFO so they could budget accordingly.

Travel expenses were estimated based on gas prices and flight data at the time, including gas to regionals and back, as well as two-way flights to Tennessee for fourteen students and two mentors.

The completed budget can be found in Appendix B.

ACKNOWLEDGEMENTS

We want to acknowledge and give thanks to the people and companies who have helped us make it this far into the MATE competition. Our team has been given lots of support and we want to thank our supporters for their help.

We want to give a big thank you to the companies:

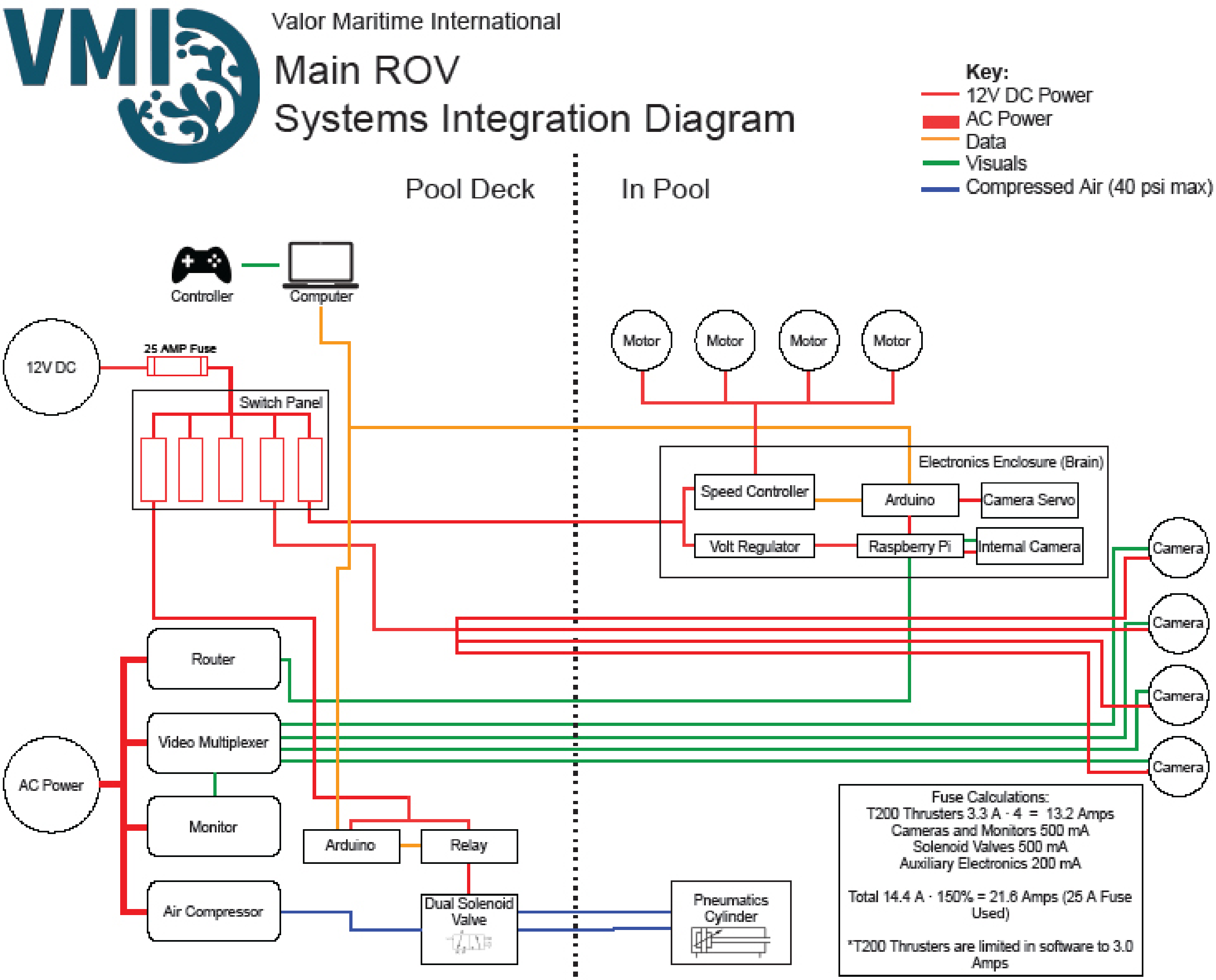
- Micron Laser Technology
- Big Frog
- STEM Oregon
- MATE ROV Competition
- Valor

We also want to thank the families:

- The Neill Family
- Edward McLean
- Wendy Abel
- The Forbes Family

Thank you so much for your contributions and support to VMI. Thank you!

APPENDIX A


Valor Maritime International
Main ROV
Systems Integration Diagram
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12V DC Power
AC Power
Data
Visuals
Compressed Air (40 psi max)
Pool Deck
In Pool
Controller
Computer
12V DC
25 AMP Fuse
Switch Panel
Motor
Motor
Motor
Motor
Electronics Enclosure (Brain)
Speed Controller
Arduino
Camera Servo
Volt Regulator
Raspberry Pi
Internal Camera
Camera
Camera
Camera
Camera
Router
Video Multiplexer
AC Power
Monitor
Arduino
Relay
Air Compressor
Dual Solenoid Valve
Pneumatics Cylinder
Fuse Calculations:
T200 Thrusters 3.3 A · 4 = 13.2 Amps
Cameras and Monitors 500 mA
Solenoid Valves 500 mA
Auxiliary Electronics 200 mA
Total 14.4 A · 150% = 21.6 Amps (25 A Fuse Used)
*T200 Thrusters are limited in software to 3.0 Amps

APPENDIX B

Category	Description	Type	Projected Cost	Budgeted value
Mechanical	Frame Materials	Purchased		
	Pneumatic System	Re-Used		
	Electronics enclosure and penetration	Purchased	$300	$300
	PLA Fillement	Purchased	$50	$50
Electrical	Thrusters	Purchased	$800	$800
	Sensors	Purchased	$200	$200
	Raspberry Pis/Arduinos	Re-Used	$200	--
	Wires, solder, other materials	Re-Used	$200	--
	Deck Control System	Re-Used	$700	--
	Tether cables	Re-Used	$300	--
	Micro-ROV thruster and Camera	Re-Used	$50	--
Travel	Gasoline	Purchased	$60	$60
	Food and Drink	Purchased	$1,000	$1,000
	Airfare from PDX to BNA	Purchased	$3,000	$3,000
Other	Marketing Poster Print	Purchased	$200	$200