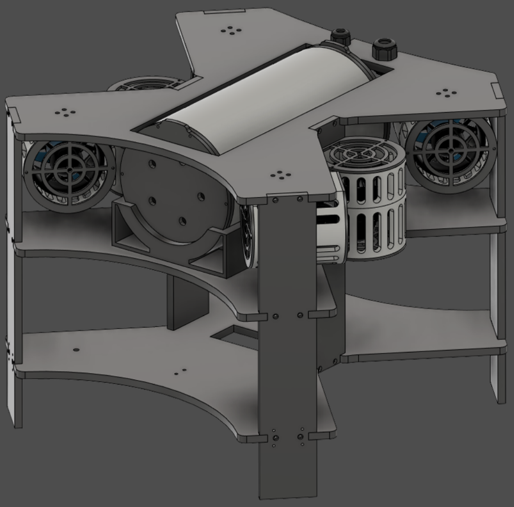
kelpie_robotics:
university_of_ottawa



```
{
  product_name: “KELP-I”,
  company_location: “Ottawa, Ontario”,
  category: EXPLORER,
  competition_year: 2022,
  school: “University of Ottawa”,
  mentors: [
    “Jason Demers”,
    “David Knox”
  ],
  team_roster: [
    “Juan Hiedra Primera, CEO - 3rd Year”,
    “Valerie Grant, CFO - 3rd Year”,
    “James Wang, COO - 3rd Year”,
    “Stefan Todorovic, CTO Software - 3rd Year”,
    “Sebastian Larrivée, CTO Electrical - 3rd Year”,
    “Ethan Bowering, Safety Officer - 3rd Year”,
    “Jason Gonzalez Pulido, Mechanical - 3rd Year”,
    “Mihir Kishore Jakhi, Mechanical and Electrical - 4th Year”,
    “Mohamad Ali Jarkas, Electrical - 3rd Year”,
    “Rikki Romana, Mechanical and Electrical - 3rd Year”
  ]
}
```

uOttawa

Technical Documentation

Abstract

Kelpie Robotics developed the KELP-I ROV to excel in underwater manipulation- and vision-based tasks in fresh- and salt-water settings. KELP-I is fully equipped with a camera array, a object manipulator, and safety features, to allow it to properly meet client requirements. Kelpie Robotics took great care to take environmental, social, and governance (ESG) factors into consideration when developing KELP-I, which led to a better overall product that is better prepared to meet market needs.

Our team of engineers - split into mechanical, electrical, and software subteams - worked tirelessly to create a product we are proud of, and that can reliably complete tasks expected of it. Cross-disciplinary efforts, constant iteration and testing, and progressive task management were implemented to meet deadlines and contract requirements.

Given that it is our first year as a company in the ROV space, we are excited to present KELP-I as our debut product, and to use the skills we learned through design challenges to produce better products as time goes on, and to grow our skills as engineers.

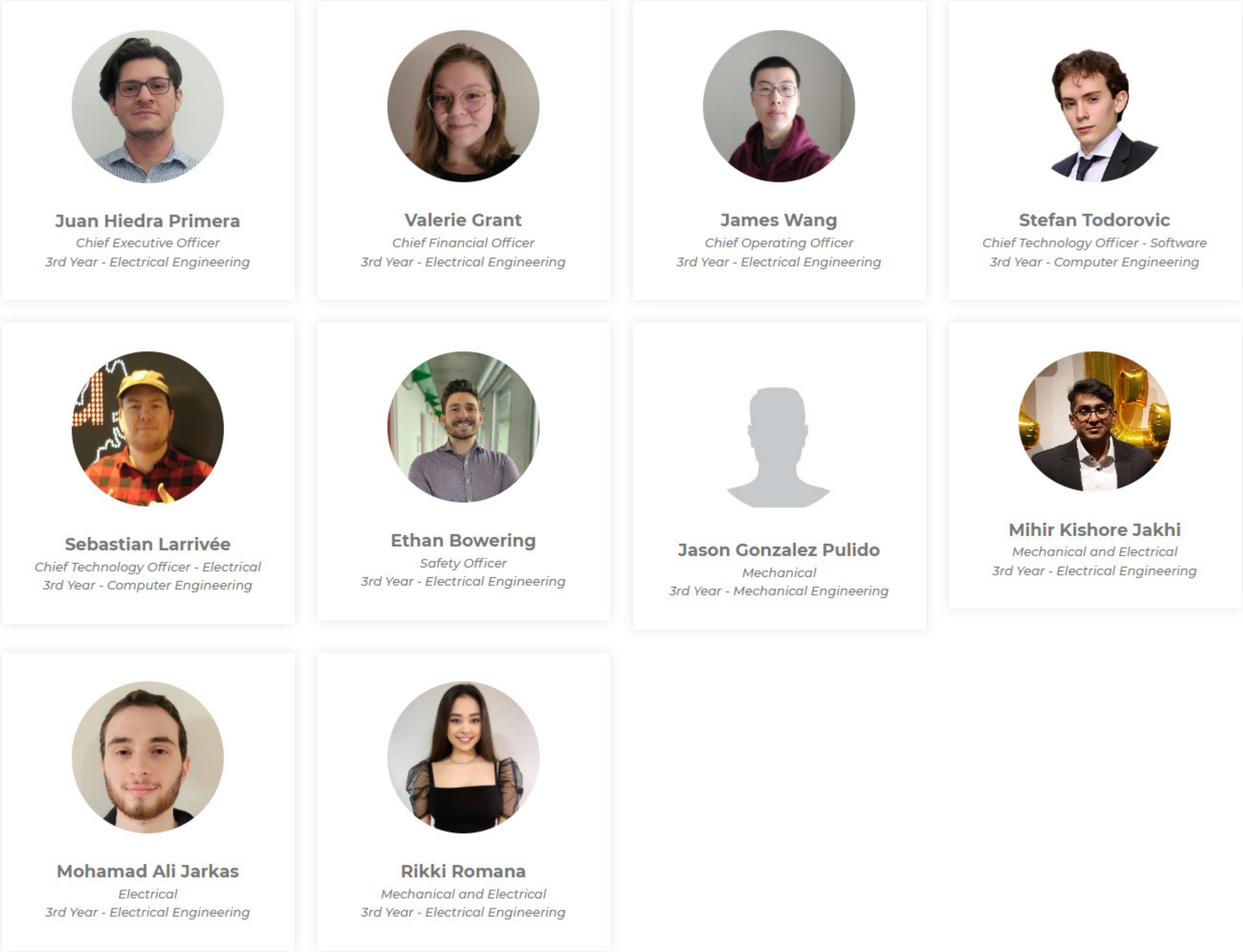


Figure 1 - The Kelpie Robotics team (not pictured: Jason Gonzalez Pulido)

Table of Contents

Design Evolution

Due to this being Kelpie Robotics' first year of competition within the EXPLORER category, the ROV was designed de novo. Thus, iteration during the design process was critical to assure both quality and reliability of the ROV.We are thus confident that the ROV is sufficiently optimized for the tasks at-hand.

The frame of our vehicle has gone through extensive design refinement and a complete rework to meet standards and requirements set out by both the competition and our faculty advisors. The electrical systems of the robot have been optimized to bolster function and power delivery. During an early test of the ROV, it came to light that the thrusters were taking too much current from one 48V to 12V converter necessitating addition of a second one Another issue that arose throughout testing was that the single-board computers were taking excessive current for the original 12V to 5V converter, so a 48V to 5V converter with a larger current rating was ordered to replace it. These improvements will remain an iterative process in order to maximize both the electrical safety and performance of our product.

Furthermore, the software and control arrays of the vehicle have also gone through several changes, specifically on how the physical control system works. The bulk of the vehicle's systems originally worked off one Raspberry Pi. This however led to several performance and bandwidth issues which was resolved through the addition of a second Raspberry Pi.This helped ease the load and also added some redundancy to the system as now one Pi controls the thrusters, the gripper and one camera, while the other Pi handles the other camera. This distribution results in higher overall stability and allows the vehicle to better accomplish tasks.

Mechanical Components

Frame

The vehicle's frame is largely inspired by a quadcopter design, due to its innate weight distribution qualities and thruster placement points.The overall weight of the completed vehicle is 13.82 kg. Our frame consists of three different plates. The top and middle plates assist in holding the electronics enclosure at an optimal electrical system tether connection elevation. We also determined that the top plate was the best position for our thrusters as this allows for the most efficient wire runs into the electronics enclosure as well as providing superior vertical stability for the vehicle's weight distribution. The quadcopter shape of the top plate also allows for efficient placements for our four horizontal translation thrusters to maximize all manner of horizontal translation. This plate also has our strain relief system and marks where the tether connects to the vehicle. Finally, the bottom-most plate is used as a mounting point for our cameras as well as our robotic gripper. This is a choice we made since many of the mission tasks this year involve interacting with objects close to the bottom of the pool. The middle and bottom most plates also feature several holes and cut-outs to allow for better fluid drainage. This feature directly allows for less turbulent fluid flow and generates less drag for the vehicle, which in turn assists with the vertical mobility of the vehicle. Additionally, the holes on the bottom plate provide more mounting points for future attachments and cameras beyond the scope of the current competition. All the pieces of the vehicle's frame are constructed out of UHMWPE. We chose this material due to the ease of cutting the components of the frame as well its durability, considering its weight. The density of the material also allows it to be neutrally buoyant in water. This aspect allows the vehicle to float just under the surface of the water and allows us to have better maneuverability when piloting the vehicle.

Electronics Housing

The electronics housing of our vehicle is the Blue Robotics 6” Watertight Acrylic Enclosure, an off the shelf solution. This enclosure was purchased ast it is trusted to be well designed and watertight, and rated for depths far greater than those used in the competition setting. We determined that a custom-designed enclosure in our first year of operation adds a degree of uncertainty that, considering the current team competency, would interfere with electrical and control systems.. With this in mind, we hope to obtain the knowledge and expertise to develop our own enclosure in future competing years. A properly-designed custom solution will be considered in subsequent iterations as the current solution provides many challenges in terms of clearance for all of our electrical components and their associated wiring runs.

The inside of the enclosure houses a custom-made UHMWPE electronics tray that holds our power distribution bus bars, DC-DC converters that power the ROV’s operations, and the microcontrollers and single-board computers that command the function of the entire vehicle. This tray is cut specifically to fit inside the endcaps of the cylindrical enclosure. In addition to this, we have also designed various countermeasures to ensure adequate spacing of certain sensitive components such as our thruster ESCs. A special 3-D printed scaffold was created to prevent shorting of the ESCs through undesired movement. A rectangular platform was also created to go over our two bus bars to provide a mounting point for our two computers. All electronics within the enclosure are mounted to these pieces via double-sided tape to ensure no shifting occurs. Currently, both the power conversion and the vehicle control systems are situated within the same housing; a solution for separating this will be considered in future iterations. This housing is made watertight through various O-Rings that are cleaned and lubricated with silicone grease which creates a tight compression seal. The various power and data cables enter the enclosure through potted penetrators. These penetrators are potted using marine epoxy and allowed to cure for 72 hours, undisturbed, to ensure a water-tight seal.

Thrusters and Shrouds

Our vehicle uses a total of six Blue Robotics T-200 thrusters. The horizontal thrusters are mounted on a 45 degree angle on the underside of our top plate. This orientation allows our vehicle to have mobility in all four cardinal directions, as well as rotation around a fixed pivot, required for successful operation and completion of the mission tasks for the competition. Two vertical thrusters are also mounted on side panels, between the top and middle plates. All 6 thrusters are also equipped with a 3-D printed shroud that encases the motor which also features an acrylic faceplate. The design of the shroud is meant to protect the thruster itself from unexpected impacts but also is designed for optimal fluid flow.

The shrouds are designed to meet IP20 specification,and to protect the shroud from any objects that would obstruct its operation, as well as any users from injury. The specific design of the shroud is divided into the canister and faceplate; the canister has slots along the side, designed to allow for better water flow through the front and line up internally with the thrusters to encourage flow and minimize cavitation, while the faceplates take inspiration from standard fan grills and use a concentric pattern to minimize surface area covered by material while maximizing fluid flow through the face plates, and keeping the maximum allowed opening size to stay within specification.

Buoyancy Calculations

Object	Count	Volume (cm3)
Bottom Plate	1	1.515e3
Top Plate	1	1.190e3
Middle Plate	1	1.561e3
Hook Connectors	2	2.767e2
Mount Connectors	2	2.232e2
Regular Connectors	2	2.770e2
Shrouds	6	2.249e2
Thrusters	6	1.900e2
Enclosure Holder	2	1.650e2
Camera Rig	2	3.070e2
Claw	1	2.570e2
Enclosure	1	5.840e3
Weights	4	1.126e2
Total Volume		15803.4 cm3
Total Weight (g)		17355.64 g
Density		1.098 g/cm3

Table 1 - Buoyancy Calculations

Electrical Systems

See a comprehensive SID of our ROV in Appedix (A).

Topside Control Unit (TCU)

Our topside control unit consists of a portable computer and an ethernet switch. The portable computer is responsible for retrieving inputs from the pilot controller, displaying camera and sensor feeds, and managing the client portion of the client-server communication between topside and on-board systems. The portable computer approach was chosen due to the ease of use and portability of the setup. The input retrieval scripting uses XInput protocols to poll the state of all buttons and axes on the controller used. The camera feed is displayed through Open Broadcasting Software (OBS) in order to overlay sensor information on top of the camera feed in a simple manner. The enclosure holding the network switch also houses the connection from our topside power supply connection to the tether's power wiring. All of these connections use waterproof cable glands in order to add strain relief onto the wiring, and are easily accessible to facilitate modifications and maintenance.

ROV Onboard Electronics

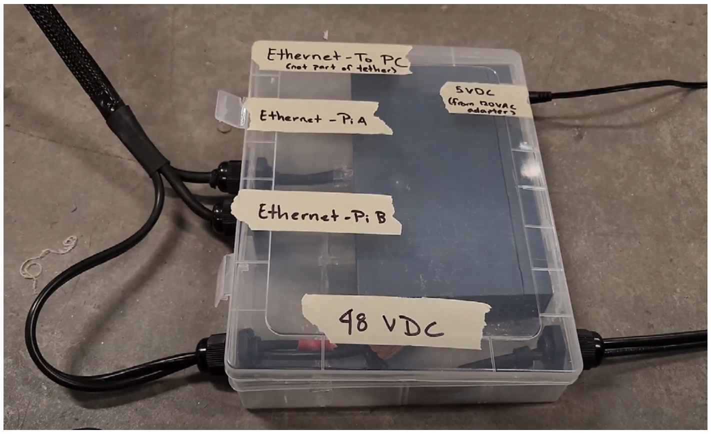


Figure 2 - TCU (photo credits: Juan Hiedra Primera)

The electronics on the ROV consists of power delivery, control systems, and video streaming hardware. The power delivery component of the ROV consists of two 48V to 12V converters alongside a singular 48V to 5V converter. The 48V to 12V converters are capable of outputting 12 volts at 30 amps, whereas the 48V to 5V converter is capable of 5.15 volts at 10 amps. The 48V to 5V converter is actually a buck converter that was tuned to the desired output voltage. One of the 48V to 12V converters is connected to the two vertical thrusters to allow rapid movement of the ROV in the vertical plane. The other 48V to 12V converter is connected to the four horizontal thrusters and the claw. More thrusters can be connected to this 48V to 12V converter because they are run at lower speeds which allows for micro-adjustments and accuracy. The 48V to 5V converter is directly powering up both of the Raspberry Pis which are then used to control the Arduinos and to send the video stream from the webcams up to the topside control station.

The Arduinos are situated on a separate board and connected to the thruster ESCs, the claw H-bridge, the temperature sensor, the leak detector, and the PMBus of the 48V to 12V converters. The PMBus is an I2C-based protocol used to receive monitoring information such as input voltage, output voltage, power, and temperature. This is useful since we can use it to limit power consumption of the thrusters and create a feedback loop. Since the Raspberry Pi is connected via USB to the Arduinos, the Raspberry Pi can also remotely update the code of the Arduinos should the need arise.

Tether

The tether is 20 meters long and sleeved. It is constructed out of two types of wire which are 12 gauge copper wiring and CAT 7 shielded ethernet cable. Both are rated for outdoor use, suitable for an underwater ROV.. We used 12 gauge copper wiring for power delivery due to it being the most appropriate gauge for carrying the amount of current required by our vehicle. The bare minimum required was 16 gauge but we opted for the safer option and chose 12 gauge to allow us some room to adapt. The shielded ethernet cable was used to ensure that no interference or signal loss would occur during operation and was primarily a stability choice. The buoyancy calculations for the tether were done via foot segments, which were then converted over to the metric system. We then balanced the tether in these same increments with non-porous construction foam. This was done to ensure that no fraying of the buoyant material would occur in order to ensure operational longevity.

Software

The software architecture consists of a server and client-side application, designed using sockets in Python3. The server side of the application is run on the ROV's onboard Raspberry Pi computer. The job of the server is to accept TCP commands from the topside client and relay those commands to one of the two onboard Arduino Nano microcontrollers. The server multithreads multiple sockets, one for motor control and another for receiving/transmitting sensor data. The data is transmitted between the Arduinos and Raspberry Pi over serial communication through the onboard USB ports. A key feature of the server-side is its ability to reestablish connections with the Arduinos and client should an unintended disconnect occur.

The client-side of the application connects to the available sockets of the server and is responsible for capturing inputs from the gamepad, recording sensor data, performing machine vision tasks and communicating with the server. The client sends raw data over TCP which is then processed by the intended rov microcontroller with a response being provided over the connection.

This architecture has followed best practices for object-oriented programming as all major components are separated and can be easily modified should the architecture need to change. For example, the script capturing the gamepad returns raw values that could then be processed or passed into another script. Additionally, the serial communication module is separate and can easily adjust should the physical architecture of the ROV be changed, such as if the Raspberry Pi computer was removed from the ROV and the Arduinos communicate directly with the topside computer.

Mission Related Tools/Attachments

Gripper

The gripper serves as the main functional tool used for the tasks performed by the ROV. It handles the majority of the missions involved in this season's competition. These include, but are not limited to, replacing the damaged inter-array power cable, pulling the pins for the cables, as well as the ghost net, replacing the buoyancy module, picking up and dropping off of the mort, and pruning the seagrass. At the start of the design process of the mechanical arm the initial plan was to develop and design our own mechanical arm that would perform the set of tasks that were set for the teams. In the end the Blue Robotics "Newton Subsea Gripper" was selected in place of this design idea. To purchase this gripper device over manufacturing one would ensure the functionality of the arm and the best fit for the timeline that the team had. We hope to further the implementation of our design process in future years of the competition as the knowledge that our members gain throughout these processes flourish.

Figure 3 - Gripper (photo credits: Blue Robotics [5])

Claw Heads

One of the larger benefits that this purchased gripper provided is the opportunity to modify the provided gripper claws to allow for more versatility to the functionality of the arm. By modifying the gripper claws within fusion and 3D printing our customized claws, the gripper is now able to complete a larger variety of mission tasks. For starters, the claw was modified to have a larger opening by extending the claw's height and length. With modification the claw is now able to reach further downwards from its attachment point to get the various tasks off the bottom of the pool. This allows for the claw to collect the mort and seagrass more consistently. The initial claw heads are 15mm in thickness, 70.4mm in length, and create a 62mm opening. Our modified claws are 102.4mm in length, create a maximum opening of 90.3mm and reach 14.15mm further downwards than their counterpart. The modified claw's overall shape and thickness are unchanged from the original claw design to maintain the tight space that the closed position provides in order to have a tighter grip on the mission tasks. Furthermore, we've attached an additional set of claws on both sides of the main claw to create a three-headed gripper. These extra claws are connected through the use of 15cm threaded rods and nuts. Each claw is spaced 45mm apart, and the purpose of this extended claw design was to create a larger bed with more stability for props to rest in by having three connection points to the props instead of one. The modified claws were 3D printed for a strong and lightweight claw design and execution.

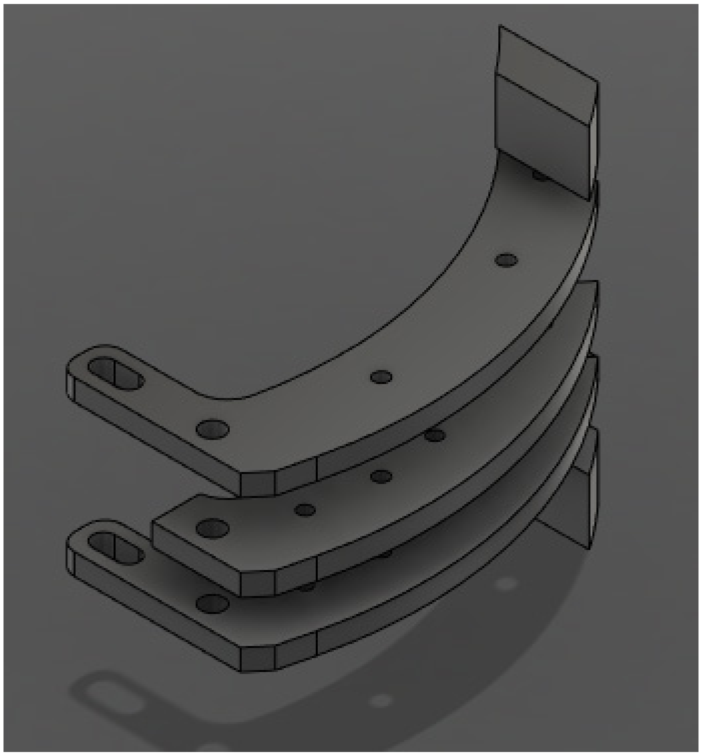


Figure 4 - Part of the claw (photo credits: Jason Gonzalez Pulido)

Magnet Claw Aspect

Along with a longer claw design, modifications were made to include a set of large ceramic magnets which would be used to pull the pins on the mission tasks for the inter-array cable and the ghost net. The ceramic magnets are 22mm by 44mm, with an added thickness of 9.5 mm to the ends of the claws. The magnets are fastened into the claw to maximize performance of the gripper attachment and increase its versatility in the mission tasks.

Camera Attachment

The camera attachments are used to provide vision to the pilot of the ROV during the mission task runs. Our expertise in the software side of the cameras allowed us to use two cameras for the operation of the ROV. Various mounting points were created to provide a selection of points of view for the ROV pilots to choose from. The primary setup involves a front facing camera which is situated at the back of the ROV and an additional camera facing the opening of our claw. The back camera is situated in such a way which would provide the largest field of view for the operator. An additional mounting option for a downwards facing camera is also included for the potential of completing tasks such as the shipwreck mission. The cameras have been waterproofed by enclosing them in a 3D printed enclosure that has been filled and sealed with epoxy. The ends of the cameras contain penetrators which have been potted and waterproofed, and are being fed straight into the Raspberry Pi's for their operational purposes.

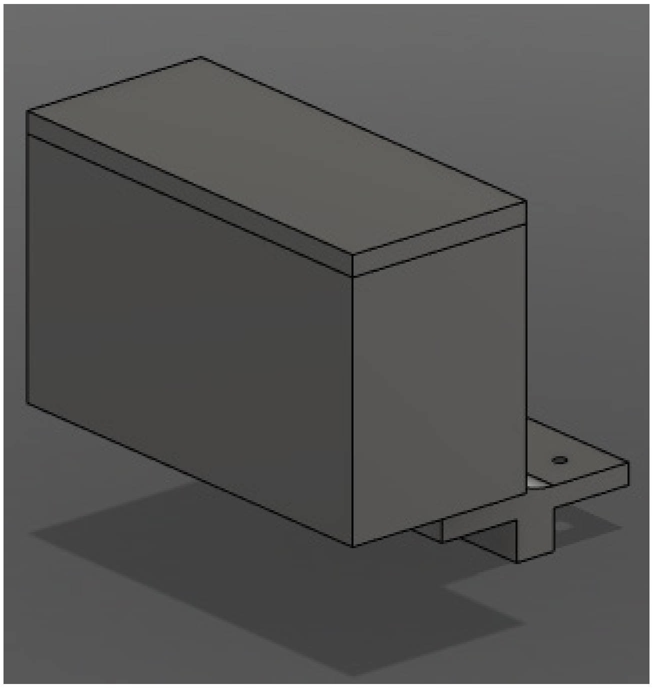


Figure 5 - Camera Enclosure (photo credits: Mihir Kishore Jakhi)

Troubleshooting and Testing Techniques

The troubleshooting and testing of the robot was largely done through several pool tests as we felt that this method gave us the largest amount of data and feedback on what worked and what did not in a competition-accurate setting. Prior to this, the majority of our testing was done via connecting the electronics and control systems portion to our power supply and running our code. This method of testing was done prior to our pool tests to iron out any coding errors and bugs prematurely. It also revealed issues in our power delivery and onboard processing systems. The influx of data from the subsequent pool tests was largely used to tune our thruster control and power algorithm. Another byproduct of this testing was improvements to the functionality of our gripper attachments along with balance/buoyancy tuning with the vehicle itself. The majority of our troubleshooting actually occurred within the workspace where we exhaustively tested and tweaked our written code to prioritize stability. Overall, we believe that these two practical forms of testing were quite effective in highlighting issues with our vehicle and allowed for magnitudes of improvement in functionality.

Safety Breakdown

At Kelpie Robotics, safety and functionality go hand in hand when it comes to the engineering design process. With any new technical advancements, a new set of risks came along with them. It was important for the members of the team to identify these risks and assess them to find ways of reducing these potential dangers. Safety checklists, training, and workplace protocols help to eliminate potential dangers of the manufacturing process.

COVID Safety Protocol

With the COVID pandemic still affecting the operation of many of the facilities that we used throughout the build process, it is important to note the safety protocols that were put in place to ensure that the members on the team remained healthy throughout this time period. Masks as well as social distancing were used whenever possible.

Workshop Safety Protocol

- Throughout our work on the vehicle we expect to work with or in hazardous conditions. We mitigate these risky situations by making sure that we use proper PPE alongside adequate training. These standards are enforced not only by us but by the staff that regulates these workspaces. In general our safety protocols for the workshop mirror the ones that are enforced by our university's team workspace and machine shop. These include but are not limited to:
- Wear safety glasses and gloves at all times when operating a machine or working on pieces that generate a lot of debris.
- Always inspect the machines before usage.
- Always make sure that the machine is set to the right configuration for the task at hand (i.e speed, height, etc).
- Always make sure that you possess the correct training required for the operation of the required machines.
- When in doubt, ask for help with a piece or correct operation of a machine.
- Ensure that the workspace and/or machine is clean both BEFORE and AFTER usage.

Training

Training our team members is a key aspect of our safety protocols. In order to even work within our team's workspace, all members had to complete a basic Dry-Lab and Risk assessment test administered by our university. In addition to this basic requirement, any team members that would be using heavy shop machinery would have to take several basic training courses that taught the proper handling of these machines. This training included basic mill, lathe and drill press training. Team members who expected to work with epoxy and other items that are deemed volatile or harmful to the respiratory system were also given training on how to use our ventilated room. Further training for specialized machines will also be provided on a required basis and is offered by our university.

Vehicle Safety Features

The most significant safety features we have for the vehicle are the leak sensors and the strain relief situated on the top plate of the vehicle. The leak sensor is a very basic transistor based circuit which triggers when water from a potential leak completes. This is then indicated in the topside suite where the pilots will call for the vehicle to be brought in. Strain relief was also used wherever tether wiring enters a rigid body (such as the frame or topside electronics enclosure). In the case of the on-board tether entry, the strain relief method used is a metal mesh attached to a cable gland, which provides maximum strain relief to the tether at the point where it enters the frame. In the case of the topside electronics enclosure, waterproof cable glands were used for all cables entering and exiting the enclosure, ensuring strain relief is properly applied to every cable and lowering the chance of water ingress into the enclosure.

Logistics

Project Management

Our team follows a classic management structure and as such has a proper hierarchy and chain of command. We have six total team leads and four regular members. Out of the six team leads we have two Chief Technical Officers. These individuals handle the operations of our software and electrical sub teams. The mechanical sub team is managed by the CEO and CFO, which are our team co-captains. Tasks are evenly distributed among team members, including the leads, in order to optimize productivity and progress on the vehicle. The CEO, COO, and CFO work together to secure funding and sponsorships as part of their responsibilities.

In order to split up the design and construction of our vehicle, we had several different sub teams each headed up by a Chief Technical Officer (CTO). This was done to effectively delegate tasks for each sub-system of the vehicle. We used Trello to organize and assign tasks to each team member. This greatly optimized our workflow after we got past the design stage and began constructing our vehicle. This also ensured that certain important parts of the vehicle were complete before we moved onto the following parts.

Figure 6, 7 - Strain Relief (photo credits: Juan Hiedra Primera)

Project Cost and Budget

Kelpie Robotics is in its first year of operation, and as such the budget contains a majority of costs that can be considered preliminary purchases. The microcontrollers, single-board computers, thrusters, and the ESCs are items that we hope to use in future years of the team as we iterate on our current design.

The following budget covers the overall cost of production for KELP-I as well as attendance and participation costs for the competition. The difference in the allocated budget in comparison to the used budget is fairly significant. Having only been a formed team for less than a year, we had less knowledge on the items we were planning on using and went through many iterations of the design and power systems throughout the entire build process. In some areas of the budget we tended to spend more and thus funds were moved around to account for this change in costs. Unexpected costs such as duty fees when purchasing from international companies as a Canadian team also resulted in the moving of funds. At its current state, Kelpie Robotics plans to pay for all flights and lodging for its employees while at the competition. Using this year's budget as a basis for future years, Kelpie Robotics hopes to have a budget that more accurately covers the cost of production for the next iteration of its ROVs.

Conclusions

Challenges

As a new team, Kelpie Robotics has faced many challenges throughout the design process.Due to our limited experience with how to design an underwater vehicle, the CAD and design stage took us the longest from a mechanical standpoint. This was our first real hurdle as for several months we could not find common ground for a design between our team and our faculty advisors. Through organized resolution and regular meetings with faculty advisors, we managed to come to a design both the team and faculty were pleased with, and learned the value of regular and frequent discussion with stakeholders in the design process.

The next large hurdle came when we began populating the electronics enclosure itself. We had designed the electrical system assuming that our initial design would be adequate for the load we would set upon it. This was found to be false upon our first real full systems test where we discovered that not only was our power delivery method to the thrusters inadequate, but our onboard processing method of one Raspberry Pi for two 1080p cameras as well as control of all six thrusters, came up short. This resulted in many clearance issues when we tried to fix these issues. This taught us that as well as we designed these systems, in theory, real world applications and testing are quite different and more demanding in terms of resources. We reflected on this and decided it is best to spend some more time to make sure our design is extremely robust on paper and allows for expansion in the future, while still allowing for plenty of time to test the practical implementation of the design.

Lessons Learned and Skills Gained

The most important lesson we learned is that we need to spend more time planning out our designs. In addition to this we need to accommodate for further expansion within all aspects of our vehicle to ensure that we are able to deal with any issues or shortcomings that may occur. Another key thing we learned is that we need to be more vigilant about our deadlines being met for key design and testing practices. Going forward, we can resolve these problems with better team communication.

Being a first year team, we learned lots of new skills which range from the engineering aspect of the competition, to the business and management aspects. We learned how to properly design and improve a robust electrical system for a vehicle along with the mechanical frame. These larger branches have taught us many smaller skills such as basic machining and electrical testing. The business and management aspect largely taught us how to apply and receive funds from our sponsors to build our vehicle. This also includes promotion of our team as a part of the University of Ottawa.

Future Improvements

Several improvements are planned for our vehicle's design. One of the largest changes will likely be the design of our electronics enclosure. This is largely due to the many clearance issues we faced while working with our current cylindrical enclosure. Through our testing, we found and applied solutions for many of the electrical and control systems issues. However, these fixes resulted in more components within the enclosure thus causing clearance issues. The solution to this would likely be a custom enclosure that is large enough to allow for quick additions. The specifics of this will be discussed at a later date post competition.

Another important improvement would be the creation of our own robotic arm. The objective behind this is that it allows us to create an arm with more articulation and function, which will be useful for subsequent years. A more flexible arm will be a great asset to the overall function of our vehicle.

Acknowledgements

Kelpie Robotics would like to acknowledge, in no particular order:

- The John McEntyre Team Space and Donor Fund, for providing us a space to work in, mentorship, and funding; in particular, our mentor Jason Demers, and workshop manager Alexandre Vendette.
- The University of Ottawa and the Faculty of Engineering Engineering Endowment Fund, which provided us funding.
- Our main sponsors, Lockheed Martin Canada and RBR, provided financial sponsorship and technical mentoring.
- SolidWorks, for providing us copies of their application.
- Our Giving Tuesday and GoFundMe sponsors, for their financial contribution to the team.
- The MATE Centre, for making the competition possible.

References

[1] Murata Power Solutions, DSE/DAE/DCE Series. 2022. p. Murata.
[2] MATE, "EXPLORER CLASS COMPETITION MANUAL", MATE, 2022.
[3] Blue Robotics, "T200 Thruster", Blue Robotics, accessed 2022
[4] Blue Robotics, "Cast Acrylic Tube – 11.75", 298mm (6" Series)", Blue Robotics, accessed 2022\
[5] Blue Robotics, "Newton Subsea Gripper", Blue Robotics, accessed 2022

Appendix A: SID

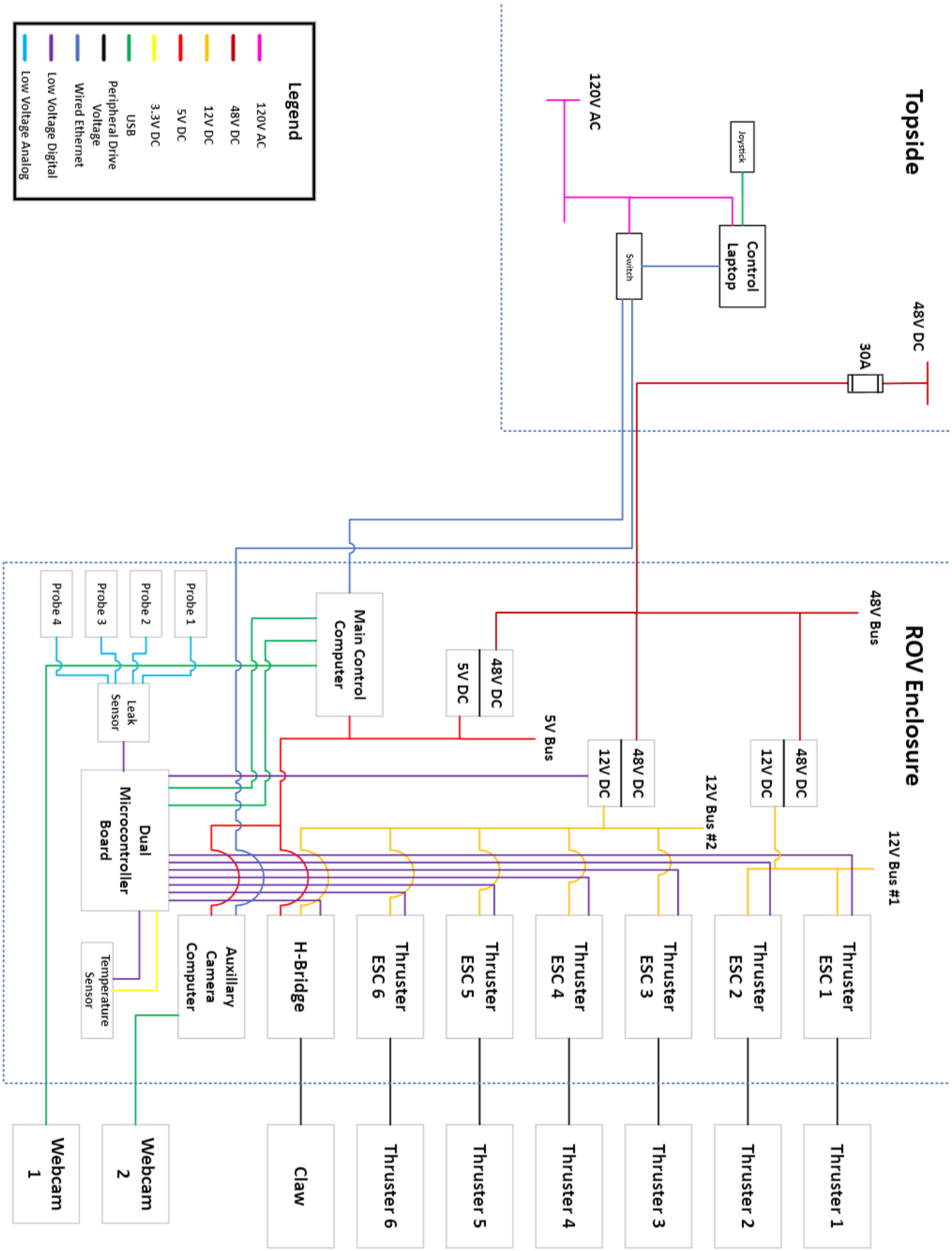


Figure 8 - SID (photo credits: Mohamad Ali Jarkas, Sebastian Larrivée)

Fuse Calculations

$$Horizontal\ Thruster\ Power\ Draw:\ 12V\ @\ 8A\ =\ 96W$$

$$Vertical\ Thruster\ Power\ Draw:\ 12V\ @\ 13.5A\ =\ 162W$$

$$Total\ Thrusters\ Power\ Draw:$$

$$Horizontal\ Thruster\ Power\ Draw\ *\ 4\ +\ Vertical\ Thruster\ Power\ Draw\ *\ 2\ =\ 708W$$

$$Raspberry\ Pi\ Max\ Power\ Draw\ =\ 5.1V\ @\ 3A\ =\ 15.3W$$

$$Total\ Raspberry\ Pi\ Power\ Draw\ =\ Raspberry\ Pi\ Max\ Power\ Draw\ *\ 2\ =\ 30.6W$$

$$Claw\ Power\ Draw\ =\ 12V\ @\ 6A\ =\ 72W$$

$$Total\ Power\ Draw\ =\ 708\ +\ 30.6\ +\ 72\ =\ 810.6W$$

$$Fuse\ Size\ =\ Total\ Power\ Draw\ *\ 1.5\ /\ 48V\ =\ 25.3A$$

Due to the >25A size, we decided to use a 30A fuse.

Appendix B: Safety Checklist

PRE POWER/SET UP

1. Check within a 2m radius around the vehicle for any debris or hazards.
2. Check that the power supply is turned off.
3. Verify ROV is watertight with pressure test
4. Verify that pressure test port cover is replaced and tightened
5. Ensure that the electronics enclosure is properly sealed with all plugs properly secured.
6. Ensure that the power pole connector on the tether is connected to the power supply.
7. Ensure that the tether ethernet cables are connected to the network switch.
8. Check that the topside control laptop is connected to the network switch.
9. Ensure that the controller is connected to the laptop and working.
10. Ensure that the power supply is plugged in.

POWER UP/INITIALIZATION

1. Laptop is powered on
2. Deployment team places ROV in water while keeping it stationary
3. Deployment team observes ROV for signs of leakage
4. If no issues are present, proceed to launch.

LAUNCH

1. Pilot and Co-Pilot call for the launch of the ROV.
2. Tether Manager prepares for launch.
3. ROV deployment members release ROV and announce ROV is released
4. Co-pilot announces “Power on” as 48v power supply is turned on
5. Verify network connection to ROV from laptop
6. Pilot and Co-Pilot begin controlling ROV and start missions.
7. If ROV loses contact refer to Lost Communications sections

LOST COMMUNICATIONS

1. Steps to be followed in order until connection is regained or all steps are completed
2. Co-pilot verifies physical connections between laptop and ROV
3. Pilot attempts laptop reset
4. Co-pilot cycles power supply
5. Co-pilot announces “Power off” and turns off power supply
6. Deployment team pulls ROV to pool side
7. Proceed to step 2 of ROV retrieval

FAILED LEAK TEST

1. Co-Pilot announces “Power off” and turns off power supply
2. Deployment team pulls ROV to pool side
3. Proceed to step 4 of ROV retrieval (go to step 4 of Failed Leak Test when complete)
4. Troubleshoot ROV leak
5. If troubleshooting resolves issue, retry mission by restarting at step 1 of Pre Power/Set up

ROV RETRIEVAL

1. Pilot steers ROV to pool side
2. Co-Pilot announces “Powering off”

3. Co-pilot powers off power supply
4. Co-Pilot announces “Ready to retrieve ROV”
5. Deployment team removes ROV from water

CONTROLLED POWER OFF

1. Co-Pilot announces “Powering off”
2. Co-pilot powers off power supply
3. Deployment team packs up ROV and equipment

Appendix C: Budget Breakdown

Income	**Budget**	**Type**		
JMTS Donor Funding	$2,925.94	Income	Note: Covers operational expenses separately	
Student Funding	$2,574.00	Income		
Engineering Endowment Fund	$2,831.40	Income		
Total Income	**$8,331.34**			
Production Expenses	**Budget**	**Type**	**Description**	**Project Budget**
Frame & housing	$719.94	Purchased	UHMW, Acrylic Tube, End Caps, O-rings, Vent and plug	$745.68
Thrusters	$1,041.30	Purchased	(6) T200 Blue Robotics Thrusters and ESCs	$1,310.40
Tether & Connectors	$240.74	Purchased	Sleeving, Ethernet (2), Power (2), Buoancy controls	$156.00
Electronics & Connectors	$631.98	Purchased	Control systems, Power Converters, sensors, Penetrators, Cameras	$924.30
Mission Tools	$852.20	Purchased	Gripper, Float Materials	$780.00
Mission Control Centre	$20.27	Purchased	Cable Glands, Desktop switch	$142.35
Consumables	$226.81	Purchased	3D print Filament, Wires, M3 Screws, Epoxy, Oring Lubricant	$254.48
Total Production Expenses	**$3,733.24**		**Total Project Budget**	$4,313.21
Operations Expenses	**Budget**	**Type**	**Discription**	**Project Budget**
Lodging	$14,000.00	Estimated	Airbnb for team of ten(10) for six (6) days, flights	N/A
Mission Props	$451.86	Purhcased	MATE Mission Props	$585.00
MATE Entry Fee	$400.00	Purchased	MATE Entry Fee	$400.00
Power Fluid Quiz Fee	$25.00	Purchased	MATE Power Fluid Quiz Fee	$25.00
Total Operation Expenses	**$14,876.86**			
Employee Paid Expenses	**Budget**	**Type**		
Competition Meals	$1,000.00	Estimated		
Transportation	$500.00	Estimated		
Estimated Employee Fees				
Net Balance	**$4,598.10**			
Total Expenses	**$18,610.10**			