DOBYNS-BENNETT HIGH SCHOOL

KINGSPORT TECHNOLOGIES

Technical Report 2021

TEAM ROLES

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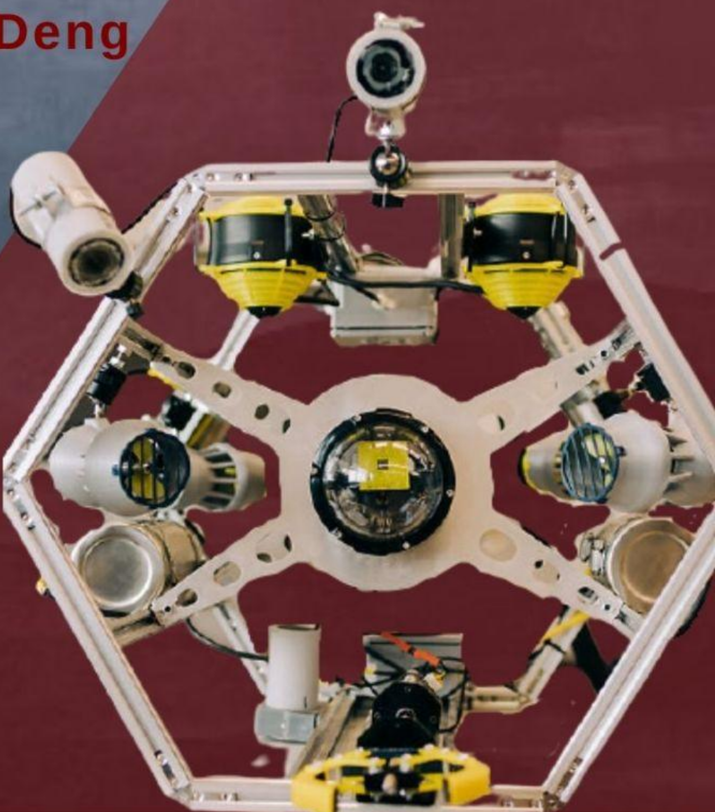

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Kingsport Technologies

Abstract

Remotely Operated Vehicles (ROVs) are underwater robots that are connected to an operator through a chain of cables that transmit command and control indicators to and from the underwater vehicle and the operator/control box. The parts of an ROV include: the payload, designed as an arm; cameras, which allow the ROV to navigate subsurface terrain; thrusters, which enable the ROV to propel through the water; and more, listed throughout the Tech Report. These ROVs are used to easily explore the unknown depths of the ocean and perform tasks while being controlled at surface-level. ROVs are built and designed differently to optimize performance in various environments. Where our company is located, ROVs will primarily be used to assess and reduce plastic pollution, evaluate the impact of climate change on underwater ecosystems, and improve inland water care. However, their purposes range from testing water composition to cleaning up ocean oil spills.

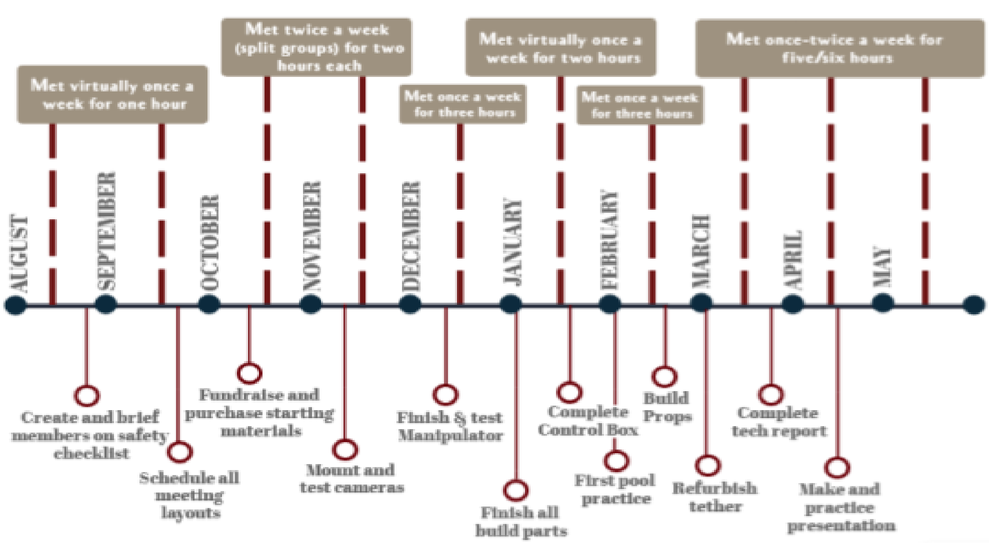
Kingsport Technologies was founded in 2018 (previously DBH_2O). We exist to advance marine technology and exploration while prioritizing sustainability and the elimination of toxic materials that contain chemicals that are detrimental to the environment. The ROV has many innovative features. Its most prominent include an aluminum frame with adjustable, stainless-steel buoyancy devices, streamlined 3-D printed features that reduce waste, and a customizable glass capsule holding all necessary onboard technological components.

Project Management

Kingsport Technologies is headed by a team of directors (CEO, CFO, and COO) who coordinate project management including meeting times, finances, and project deadlines. Each member of the team is assigned to specific sub-teams which are responsible for completing objectives to build and support the ROV. These tasks are assigned based upon areas of interest and expertise. During our build season we scheduled weekly 4 hour meetings to bring all team members together to integrate their individual responsibilities and troubleshoot the ROV. We also arranged additional practices when needed. When we were unable to meet in person due to COVID-19 restrictions, our team used the Google Meets platform to collaborate. During this time we utilized online resources such as design schematics for the thruster shrouds and strengthened our community outreach. Our team set specific deadlines for milestones of the ROV build process to ensure that the project was running smoothly (see schedule below).

In person meetings were held in a robotics lab where all members had access to tools, supplies, and equipment in an environment where safety protocols could be optimized. Some of these resources include wires for building electrical components and a 3-D printer to create custom designed parts.

2020 - 2021 Schedule



Engineering Design

The general design of the ROV is presented in a hexagonal shape (Figure 1). This allows us enough space to house all of the necessary components while providing angles to place them as well as allowing room for additions. We felt that these benefits outweighed the additional size and weight of the hexagonal structure.

Figure 1

The frame and shape of our ROV was constructed using aluminum bars (Figure 2) to provide a rigid structure. These bars are connected using fasteners and contain slits on all four sides that allow us to mount attachments such as cameras and thrusters (Figure 3). Aluminum was selected as it is safer for the environment, easier to use, and more sturdy than other materials such as PVC. This durability is partially due to aluminum's strength to weight ratio which ensures that our ROV is sturdy while still having a reasonable mass.

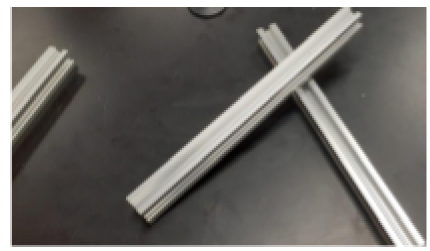


Figure 2

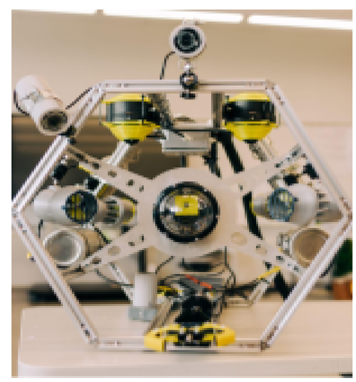


Figure 3

During the design process, our team developed multiple customized designs for components of the ROV. These designs include a 3-D printed manipulator and shrouds for the thrusters (Figure 4). By building our own parts we were able to customize our ROV and be cost efficient.

Our problem solving process helped us find solutions to issues that arose with our ROV. Many of these issues were resolved through trial and error and exploring multiple alternative solutions in a systematic manner. For example, the increased weight of our aluminum design required us to brainstorm solutions to make our ROV neutrally buoyant in the water (as discussed later in the buoyancy section).

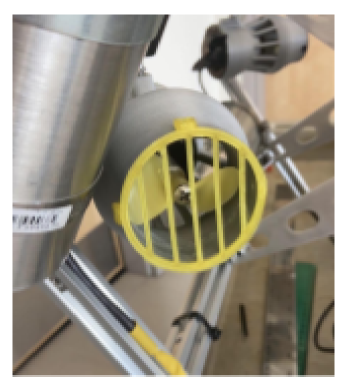


Figure 4

Control / Electrical System

The ROV electrical system is summarized in the system integration diagram (SID) located in appendix A. The ROV has multiple programmed components, including two Raspberry Pis programmed in Python, two Arduinos programmed in C++, and multiple Sabertooth motor controllers. One of each of the control components is located in the control box while the other set is in the capsule on the ROV.

The control box on the surface (Figure 5) contains:

- ➔ x2 - Sabertooth Motor Controllers
- ➔ x1 - Camera Power Filter
- ➔ x1 - 12v to 5v Stepdown module
- ➔ x1 - Raspberry Pi 4B
- ➔ x1 - Arduino Mega 2650
- ➔ x2 - Electronic Speed Controllers (ESCs)
- ➔ x1 - Watt Meter
- ➔ x1 - 15 Amp Fuse

Figure 5

The capsule (Figure 6) on the ROV contains:

- ➔ x1 - 12v to 5v Stepdown module
- ➔ x1 - Raspberry Pi 4B
- ➔ x1 - Arduino Uno
- ➔ x1 - Adafruit Motor Shield
- ➔ x1 - Raspberry Pi Camera Module V2
- ➔ x1 - Google Coral

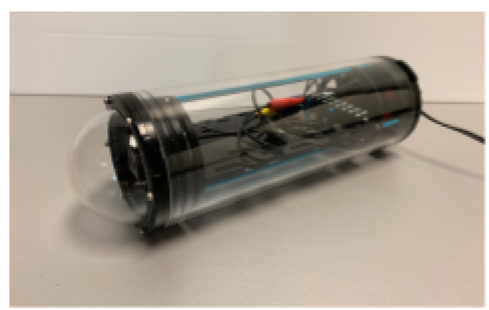


Figure 6

The Raspberry Pis do the majority of the processing work while the Arduinos are used to interface with the rest of the ROV. Both Pis are set up to deploy the Arduino code and begin running their own code upon booting without the need for human input. The information is translated from the onboard computer through the tether. We use a PlayStation controller to communicate with the Raspberry Pis, which in turn control the Arduinos that then control the stepper motor for the manipulator and the thrusters. This, along with intricate code, ensures precise movement and successful missions. Our system is fully digital, which has many advantages, such as precision and ease of use.

Raspberry Pi Alpha (Surface)

The Raspberry Pi unit acts as the main hub that connects to all other parts directly (except Arduino Beta, with which it communicates indirectly) and does all of the heavy calculations. The Pi has six python files on it, each with its own task:

- ➔ main.py - Calls functions from the other files and passes information between them
- ➔ controller.py - Takes information from the PS4 controller using the pygame library
- ➔ motor.py - Takes the data from controller.py and calculates power output for each thruster
- ➔ arduino.py - Encodes thruster information for data transfer and sends it to Arduino Alpha via USB
- ➔ ethernet.py - Controls communication with Raspberry Pi Beta over ethernet
- ➔ camera.py - Displays the camera and image recognition data to the screen

Arduino Alpha (Surface)

This Arduino handles all of the thrusters. It takes and formats the data from Raspberry Pi Alpha before distributing it to the motor controllers and ESCs.

Raspberry Pi Beta (Onboard) (Figure 7)

Pi Beta is in charge of image recognition, as well as the manipulator. It uses four python files as such:

- ➔ main.py - Calls functions from the other files and passes information between them
- ➔ arduino.py - Encodes manipulator for data transfer and sends it to Arduino Beta via USB
- ➔ ethernet.py - Controls communication with Raspberry Pi Alpha over ethernet
- ➔ imageRecognition.py - Takes information from the camera and uses OpenCV for image recognition

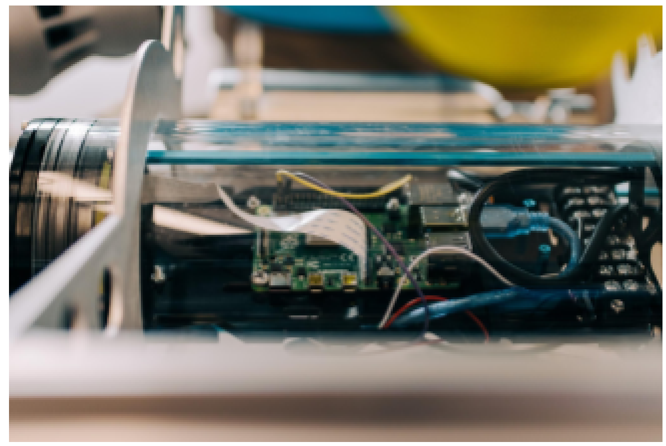


Figure 7

Arduino Beta (Onboard)

This Arduino has a stepper motor driver shield mounted to it. Its purpose is to control the manipulator with data from Raspberry Pi Beta.

Tether

The ROV tether is 12 meters in length (Figure 8) and encases all wires that connect the ROV to the control box. The 12 m length was chosen to optimize mobility of the ROV within the given size of the environment while maintaining enough voltage to power all components. The tether holds our analog video wires, motor wires, ethernet wires, as well as wires for the manipulator mounted at the front of the ROV. These wires are housed within an adjustable sleeve that easily accommodates the addition and removal of integral parts. We chose to utilize a coil-like mesh to contain our wires within the tether to optimize access to the wires if needed and to reduce the number of

Figure 8

plastic fasteners necessary. Easier access to wires enables us to quickly replace components and having fewer zip ties aligns with our goal to be more environmentally conscious.

A critical aspect of the tether is that it does not adversely affect the maneuverability of the ROV. While the tether's diameter is relatively small, its weight can still affect the ROV's neutral buoyancy. To avoid this, we added pieces of foam (Figure 8) throughout the tether so that ROV's buoyancy is not affected. In addition, tether management is critical to ensure that no manual force is applied to the tether that would negatively affect ROV movement. This allows for the ROV to move smoothly and easily at greater depths by managing the stress on the tether and counteracting the forces that are imparted by the tether.

Propulsion

To maneuver our unique frame, we have six thrusters that allow the ROV to move in all directions. It is important for the ROV to be able to ascend, descend, and shift left and right to complete various tasks. We have two Blue Robotics[1] T-200 thrusters (Figure 9) and four smaller Johnson bilge pump thrusters. The two T-200s are placed towards the center of the ROV to assist us on the vertical axis. The T-200 thrusters have a higher cost and power consumption; however, the propulsion that they provide counteracts the weight of the ROV and allows it to quickly and efficiently ascend and descend to complete missions. We chose to reuse four Johnson bilge pumps (Appendix D) because their propulsion is suitable to move the ROV. The Johnson bilge pumps are positioned in a 45 degree angle vector at the corners of the ROV to allow us to rotate and move along the horizontal axes.

Figure 9

Buoyancy and Ballast

An important aspect of our ROV design is its easily adjustable buoyancy. Our first attempt to achieve neutral buoyancy was to attach pool noodles to various points on the frame. However, this method became ineffective because it was difficult to find the appropriate amount of upward force from the pool noodles to make the ROV neutrally buoyant. Our current design uses partially filled water bottles (Figure 10) as ballasts on the sides of the ROV. The water bottle design allows us to easily calibrate the buoyancy of the ROV by adjusting the amount of water in the bottles in precise and sequential increments. By beginning with large volumes of water to approximate neutral buoyancy, and subsequently adjusting with small increments, our team was able to determine the exact amount of water in the bottles to achieve neutral buoyancy.

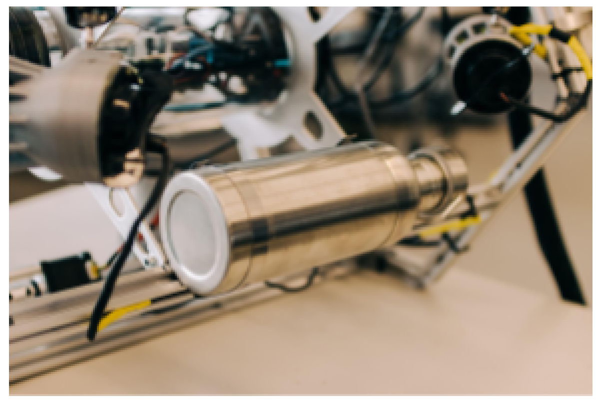


Figure 10

Payload and Tools

Figure 11

Cameras

The ROV is equipped with three analog cameras to provide a general view for completing tasks. These cameras are positioned to provide a front view, a payload view, and a bottom view. There is another high-definition, digital camera in the central capsule of the ROV for a more detailed frontal view. This camera is continuously displayed on a smaller screen at the surface. The front view general camera (Figure 11) is the primary camera that helps the driver locate the objects needed to complete the tasks. The payload camera presents a direct view of the manipulator for easier use and functionality. The bottom view camera shows the bottom of the pool and allows us to observe anything that the ROV passes over, giving us an accurate layout which is necessary for multiple tasks. All of the video feed runs through the tether and is delivered to a large monitor on the surface. We have a system set up to conveniently change camera views at the flip of a switch. This allows us to focus on one view, while still being able to access the others with ease. Each camera is secured to an acrylic disc within a 2 in x 4 in PVC pipe using hot glue. To waterproof the cameras[3], the empty space surrounding the wiring is filled with epoxy. The epoxy polymerizes to seal the spaces while also being non-hazardous to the environment. This dramatically extends the camera's lifespan by preventing water damage, which can cause the pictures to become blurry or the cameras to fail. Furthermore, the cameras are mounted to the frame in a sturdy but exchangeable way and additional cameras are available in case a malfunction requires a quick replacement.

Primary Manipulator

A majority of the tasks involve grasping and replacing certain objects. For example, task 1 requires disconnecting the power connector and subsequently removing the mesh catch bag from the seabin. Other tasks require replacing an eel trap and retrieving debris. These tasks are ideally suited to a claw-like tool. We designed our primary manipulator (Figure 12) to mimic this design. The manipulator is attached to the lower half of our ROV and it is powered by a NEMA 17 stepper motor, which was given to us by our sponsor OpenBuilds[2]. This motor has a low rpm that results in greater torque. This extra torque allows the ROV to grasp a greater range of objects with larger mass. The manipulator serves multiple purposes

Figure 12

throughout the mission as it is the primary tool for completing tasks.

The manipulator consists of two different components, the linear actuator and the gripper system. Our company decided to construct the linear actuator out of aluminum because it is lightweight, strong, and does not rust allowing for an efficient and robust design. Our team decided to create our own, custom gripper system design and then print it using a 3-D printer. Not only was this decision cost efficient, but also it enabled us to customize our manipulator. One of our custom features includes the ability to rotate the manipulator in both a horizontal and vertical position, which allows us to grasp a greater variety of objects. The system, located at the terminal end of the manipulator, is made out of Polylactic Acid (PLA). We chose PLA because it is stronger than other 3-D printing materials. In addition, it is a plant based bioplastic that can be recycled and remelted into new filament (PLA Bioplastics[4]).

Our gripper design works with the linear actuator system to form a functioning manipulator. The linear actuator is powered by the NEMA 17 motor, which is connected to a lead screw by couplings and rotates the lead screw thus translating the energy produced by the motor into the gripper system. The motor is attached to an aluminum metal plate which houses the lead screw. The center of the gipper system is directly attached to the lead screw and the movement of this pivot point is what allows the manipulator to open and close. The bottom of the payload was specifically designed to secure the manipulator to the metal plate where the lead screw and motor are attached. The larger rectangular pieces that make up the sides of the gripper system are for structural support and to create the manipulator shape. The smaller rectangular pieces located in the middle of the manipulator are attached to a block which is connected to a lead screw. The pivot points located on these smaller rectangular pieces allow the movement of the manipulator. Overall, the different pieces located in the manipulator work together to create a functioning manipulator that allows us to pick up and transport items during tasks.

Safety

Safety Philosophy

Kingsport Technologies places safety at the utmost importance. Safety is maintained throughout our company by following all safety guidelines and ensuring that company members are properly trained in all aspects of construction. Throughout the development of our ROV, Kingsport Technologies went through many safety inspections in order to assure the safety of both employees and consumers before the product was introduced to the water. A few of the actions taken include applying warning labels to various parts of the ROV, ensuring that multiple people are on standby to separate wires when necessary, and confirming that propellers are always protected by shrouds. Throughout the construction and deployment of our ROV, we adhered to the following safety checklist:

Safety Procedures

- Wearing appropriate clothing and closed-toed shoes
- Wearing safety goggles and being with a trained adult while using power tools
- Adhering to all pool safety guidelines set forth by the school and our chief operations officer
- Being constantly aware of surroundings (including people and equipment)
- Confirming that all tools and equipment are properly inventoried and stored
- Checking that components of the control box are properly wired, secured, and labeled before use
- Recording new safety procedures and briefing members on them frequently
- Waterproofing all electrical components that will be submerged in water
- Securing any loose cables or wires with strong and appropriate fasteners
- Making sure procedures are followed through correctly and fully

➔ Having at least one person trained in CPR and basic water rescue on deck during pool practice at all times

Structure and Electronic Safety

When designing the electronics and control systems, the importance of safety is non-negotiable. Due to the ROV being submerged, everything on it must be waterproofed. All onboard electronics are contained inside of a capsule in the center of the ROV. All wire connections have been shrink wrapped or sealed in a box with wax. All of the surface-side electronics are kept secure inside the control box away from the water and shielded from potential splashes. The box has fuses and capacitors to help keep the electronics from being damaged, which may harm the user.

Additionally, the capsule, purchased from Blue Robotics[1], holds the connections that are on board watertight. The wires that enter and leave the capsule have been sealed with Wetlink Thixotropic 80A potting compound and are contained within Blue Robotics[1] cable penetrators to ensure that water will not come in contact with the connections.

All wire connections in the tether that will come in contact with water have been soldered and shrink wrapped. This certifies that water cannot come in contact with bare wire. Also, the tether has connections that allow it to attach to a solid surface, which prevent the control box from being pulled into the water.

Our ROV also has all components tightly secured to the frame with metal fasteners to ensure that nothing will fall off and harm anyone. It is vital that every component is safely mounted. To prevent injuries, we have checked for and eliminated any sharp edges on any part of the ROV's structure. These adjustments to the ROV are crucial and allow tasks to be completed safely.

Figure 13

The shrouds on all of the thrusters were produced and attached to prevent the user's fingers from entering the path of the propeller. The shroud design incorporated for the T-200 thrusters (Figure 13) was obtained from Blue Robotics[1] and then 3-D printed. This design covers the exposed space on the top and bottom of our vertical T-200 thrusters. The dome-shaped shrouds above and underneath the thrusters have slits of 3 mm to allow for maximum water intake while meeting the safety requirements. A similar design was customized to fit both the Johnson bilge pump and micro-ROV propellers.

Environmental Safety

Along with the safety of our employees and customers, our company prioritizes safety of the environment in the development of our ROV. As previously mentioned, this year our frame is made from aluminum instead of polyvinyl chloride (PVC). Aluminum does not produce the toxins that PVC does and can be reused for longer periods of time. Additionally, we have reduced the amount of plastic used in the robot by switching mainly to metal fasteners. The use of single-use polyethylene foam (pool noodles) was reduced as we converted to reusable bottles for buoyancy. Also, the PLA[4] we use for 3-D printing is a bioplastic derived from plant-based materials and can be both reused and recycled.

Testing and Troubleshooting

After the completion of our ROV, we began vehicle and vehicle-part testing. Prior to entering the water, we tested each system individually to ensure that it was working properly (e.g., opening and closing the manipulator, activating the thrusters, and testing all camera views). We also ensured that all components were satisfactorily waterproofed by a thorough visual inspection. Once entering the water, our team retested each part individually while submerged. Afterward, we began testing basic maneuverability and buoyancy of the ROV. This eventually led to more advanced testing, such as using the manipulator to grab a prop to simulate mission-oriented tasks.

However, in the process of developing our ROV our team encountered numerous issues, such as camera failure or thrusters not properly working. In response to this, we developed a troubleshooting strategy to resolve these issues. Once a problem was identified, we gathered information to eliminate variables that may cause the problem. Then we attempted to recreate the problem using that information and determine the cause and possible solutions. Finally, we systematically implemented solutions until the problem was corrected.

For example, following a camera malfunction, where the camera would display distorted images to the monitor, our first steps were to determine the root cause of the problem. We began identifying and testing variables relating to the cameras, such as replacing the camera itself, changing the power source, and changing the monitor. This would allow us to determine which of the variables was causing the problem. In this case, it was ultimately determined to be a combination of both insufficient power and faulty cameras. To resolve this problem, we replaced the faulty cameras as well as providing more power to them.

Our troubleshooting strategy also aided us in testing prototypes and alternatives for component designs. Testing multiple designs allowed us to determine which solution was most applicable to our ROV. Each prototype was evaluated for its advantages and disadvantages and subsequent prototypes were created to optimize the advantages and minimize the disadvantages. For example, our team went through multiple manipulator designs. Our original design was unable to retrieve many of the necessary objects to complete the mission tasks. Our team realized that the root cause was that our manipulator was not powerful enough to grasp these objects, thus we decided to switch to a more powerful stepper motor in our current design.

Budget

For the 2020/2021 fiscal year, the company took many precautions when documenting our financial endeavors. At the start of the year, we created a budget (Appendix B) containing estimates for prices for parts to construct the ROV. Additionally, we took an inventory of parts that we already had and estimates of donations from sponsors. As parts were purchased, a project cost Microsoft Excel sheet (Appendix C) was created where members could add the purchased parts to the sheet as well as the expense of that item. This system helped keep track of not only the parts utilized to build the ROV but where the company's expenses were being spent. We also budgeted for travel expenses. With the competition being local, these expenses were minimal, as a majority of the travel expenses were donated from parents by paying for gas or food for the days of competition.

In order to raise money to purchase budgeted items, fundraising was vital. Acquiring sponsorships and partners were also ways to raise money for our company. One of our partners was Texas Roadhouse. Cards were sold for a lunch special provided by Texas Roadhouse and all of the profits made from the sales went directly to our company's budget. Another partner was OpenBuilds[2]. We were able to receive donations from OpenBuilds[2] in the form of multiple parts to create the frame of our ROV. In exchange for these donations, we recognized these companies through our many social media platforms as well as printing their logos on our company attire.

Fundraisers and cash donations were also important to the success of our company. Our most profitable fundraiser was a company yard sale that brought the team $1,200 in revenue. By writing letters to local and national companies with scientific research divisions, we were able to obtain additional cash sponsorships from companies who shared our interest in robotics. Eastman Chemical company provided one of these substantial donations. We also received cash donations from friends and family of our team.

In addition, before making big purchases, such as the T-200 thrusters, our company discussed the pros and cons in order to decide if the purchase was truly beneficial before making a full commitment. For our control box system, we decided to use some of the components from a prior triggerfish kit such as the sabertooth controllers, camera filter, and the power source instead of buying the components separately as we built our new control system. In addition, we decided to reuse the Johnson bilge pump thrusters from our previous builds for the horizontal thruster system. With the development of our current product, our company focused on using certain materials and creating specific designs that would allow our company to reutilize these materials in future builds.

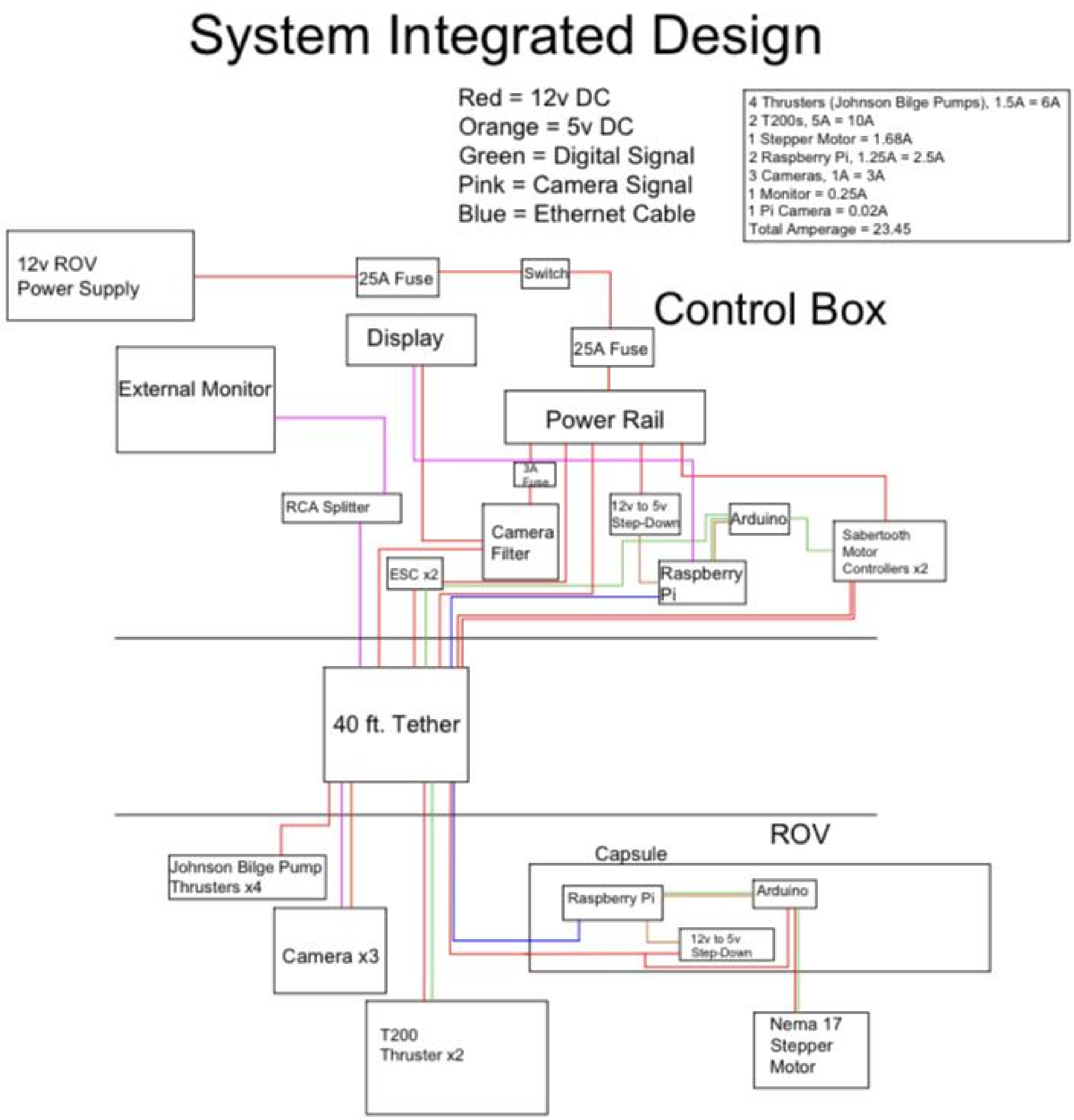
Acknowledgements

Kingsport Technologies greatly appreciates the support of the many people and companies that have helped throughout the year. We would like to give special thanks to Mrs. Amanda Blackburn for overseeing and managing our meetings and Dr. Michael Long for providing expertise and assisting us in the construction of our ROV. We would also like to extend our thanks to the Blackburn family, the Shao family, Eastman Chemical Company, Texas Roadhouse, and Openbuilds[2] for supplying us with funding and items needed to build our ROV. Special thanks to our parents for supporting us and being accommodating and willing to help when necessary. Finally, a sincere thank you to Streamworks and to the MATE Center for sponsoring this event.

References

1. Blue Robotics, Torrance, CA: https://bluerobotics.com/
2. OpenBuilds, Monroeville, NJ: https://openbuildspartstore.com/
3. Epoxy Waterproofing: EPOXY WATERPROOFING AND PATCHING COMPOUND.
4. PLA Bioplastics: https://bioplasticsnews.com/2019/07/02/all-you-need-to-know-about-pla/

Appendix A - System Integration Diagram (SID)



Appendix B - Budget

Category:	Type:	Description / Examples:	Projected Cost:	Budgeted Value:
Hardware	Purchased	Frame, Nuts, Screws	$150	$150
Hardware	Donated	OpenBuild Donations	$200	-
Hardware	Re-Used	PVC and Capsule	$250	-
Electronics	Purchased	Wire, Computers, Cameras	$1,500	$1,500
Electronics	Donated	Motors from OpenBuilds	$150	-
Electronics	Re-Used	Monitor, Thrusters, Arduino	$500	-
Travel	Donated	Gas, Food	$200	-
General	Purchased	Competition Fee	$200	$200
General	Purchased	Apparel	$500	$500
		Total Expenses:	$3,650	$2,350

Appendix C - Project Costing

Expenses:						
Type	Category	Item	Source / Description	Price	Quantity	Total
Purchased	Electronics	Raspberry Pi		$48.00	2	$96.00
Purchased	Electronics	12.2 m Ethernet Cable (CAT 6)		$9.59	1	$9.59
Purchased	Electronics	T-200 Thruster	Blue Robotics	$179.00	2	$358.00
Purchased	Sensors	ecnoLED Vehicle Backup Camera		$13.99	8	$111.92
Purchased	Hardware	Clear Acrylic Lens 2"		$14.57	1	$14.57
Purchased	Electronics	2 Micro SD Cards		$7.49	1	$7.49
Purchased	Electronics	Micro HDMI To HDMI		$7.99	1	$7.99
Purchased	Electronics	USB To RCA		$7.99	1	$7.99
Purchased	Electronics	4-way RCA Splitter		$9.49	3	$28.47

Purchased	Electronics	12v to 5v Step Down Module		$9.58	1	$9.58
Purchased	Hardware	1/4" x 8mm Flexible Coupling		$6.99	1	$6.99
Purchased	Hardware	Worm Gear Set		$21.99	2	$43.98
Purchased	Hardware	1/4'' shaft		$6.19	2	$12.38
Purchased	Hardware	Lead screw		$10.99	1	$10.99
Purchased	Hardware	Nut block		$7.49	1	$7.49
Purchased	Hardware	Threaded rod plate		$7.99	1	$7.99
Purchased	Hardware	Coupling		$6.99	1	$6.99
Purchased	Hardware	Spacers		$6.49	1	$6.49
Purchased	Hardware	Shim		$0.29	2	$0.58
Purchased	Hardware	Bearing		$0.99	2	$1.98
Purchased	Hardware	Lock Collar		$0.99	2	$1.98
Purchased	Hardware	Screws		$2.19	1	$2.19
Purchased	Electronics	Arduino Mega		$14.99	1	$14.99
Purchased	Electronics	8 Pin Connector		$12.99	1	$12.99
Purchased	Electronics	F to M Telephone Panel		$8.10	1	$8.10
Purchased	Electronics	3 port mini usb hub		$2.19	1	$2.19
Purchased	Electronics	Cable Leader		$6.99	3	$20.97
Purchased	Electronics	HDMI to RCA		$9.88	1	$9.88
Purchased	Electronics	18/8 50 ft. wire		$36.97	1	$36.97
Purchased	Electronics	Triggerfish Tether Kit		$93.00	1	$93.00
Purchased	Electronics	3-Way Wire End Terminal		$6.78	1	$6.78
Purchased	General	Competition Fee		$200.00	1	$200.00
Purchased	General	Apparel		$480.00	1	$480.00
Donated	Hardware	V-slot 20x20 Linear Rail (250mm)	OpenBuilds	$3.29	16	$52.64
Donated	Hardware	V-Slot 20x20 Linear rail (500mm)	OpenBuilds	$9.33	8	$74.64
Donated	Hardware	90 Hidden Tee Nut-Makerplink (10 pack)	OpenBuilds	$9.99	2	$19.98

Donated	Hardware	120 Angle Tee Nut-Makerplink (10 pack)	OpenBuilds	$9.99	2	$19.98
Donated	Hardware	V-Slot Gantry Plate- 20mm	OpenBuilds	$6.29	2	$12.58
Donated	Hardware	Adjustable V-Slot Hinge	OpenBuilds	$4.99	4	$19.96
Donated	Electronics	NEMA 17 Stepper Motor	OpenBuilds	$45.13	3	$135.39
Re-Used	Electronics	Seiki Monitor		$79.99	1	$79.99
Re-Used	Hardware	PVC piping		$200.00	1	$200.00
Re-Used	Hardware	Watertight Enclosure Capsule		$67.00	1	$67.00
Re-Used	Electronics	Arduino Uno		$23.00	1	$23.00
Re-Used*	Electronics	SeaMATE Triggerfish Control Box and Thruster		$618.00	1	$618.00
Purchased	Materials	Polylactic Acid (PLA)		$100.00	1	$100.00
Donated	Travel	Food	Parents	$50.00	3	$150.00
Donated	Travel	Gas	Parents	$5.00	10	$50.00
Income:						
Donated	General	Funds Donated	Chris Blackburn	$700.00	1	$700.00
Donated	General	Funds Donated	Shao Family	$200.00	1	$200.00
Donated	General	Funds Donated	Long Family	$400.00	1	$400.00
Donated	General	Funds Donated	Yard Sale	$1,200.00	1	$1,200.00
Donated	General	Fundraiser	Texas Roadhouse	$345.00	1	$345.00
Donated	General	Funds Donated	Eastman Chemical	$1,500.00	1	$1,500.00

Totals:	
Total Spent (Includes Re-used / Donated Parts):	$3,270.66
Total Raised:	$4,345.00
Final Balance:	$1,074.34

Appendix D - Build/Reuse Vs Buy

Shrouds for thrusters

Our shrouds were 3D printed using PLA because it is better for the environment, cost efficient, and more customizable. With a 3D print we were able to design our shrouds to fit our thrusters perfectly, to meet safety guidelines, and to have maximum propulsion and water flow.

Gripper for manipulator

Similar to the shrouds, we decided to print our gripper with PLA because we could print different ones that optimize effectiveness during missions.

Johnson bilge pumps

We reused our Johnson Bilge pumps because they are compatible with our ROVs needs and enable us to proficiently maneuver our ROV on the horizontal axis.

Cameras

We reused our cameras because they are all in good condition and we felt it unnecessary to purchase more cameras. This allowed us to save money and reallocate funds to other necessary components of our ROV. [5]

[5]More detailed thought processes on our decisions to build vs. buy can be found throughout the tech report in the individual component sections.