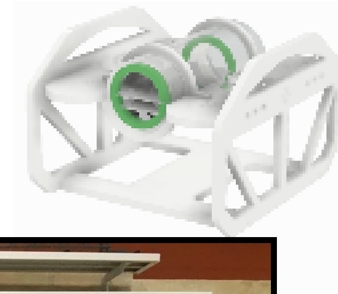
Kepler Enterprises Technical Documentation

San Antonio, Texas



Kepler Enterprises Team Members

Grant Kahl: Senior, CEO, Head of Mechanical Engineering
Lance Kahl: Freshman, CFO, Director of Training
Eric Love: Junior, CTO, Head of Technological Development
Jason Love: Freshman, Technical Engineer
Jake Love: Junior, CSO, Head of Safety
Brooke Culhane: Senior, COO, Technical Writer
Reece Traylor: Senior, Chief Electrical Officer

Team Kepler presents "Frosty" The Underwater Remotely Operated Vehicle

Representing San Antonio Schools: TMI, STEM, ISA, and Reagan High Schools

Mentored by Dr. Jeffrey Kahl

Key Sponsors: Robotics Club USA and K2 Solutions

Exploration, Innovation, Endless Possibilities

Table of Contents

Abstract

Kepler Enterprises is a robotics company that includes seven (7) members who have an interest in STEM and strive to push the boundaries of underwater exploration. Kepler Enterprises' is participating for the 5th year in the MATE ROV Competition. We have successfully built an advanced ROV, "Frosty", designed to complete the tasks outlined by the city of Kingsport, Tennessee request for proposal. Frosty is able to identify different artifacts and remove these artifacts carefully for further investigation. The ROV has capabilities to identify dam damage and conduct repairs, as well as deploying a mini-ROV, "Snowflake," to help examine water flow and identify muddy areas in a dam.

Frosty is also equipped with a multipurpose arm that allows underwater manipulation of levers, switches, and objects. It was designed to easily grasp and retrieve objects. In addition, it is equipped with a number of sensors, such as temperature and depth. Frosty is also outfitted with a high definition camera mounted to an adjustable gimbal providing on the fly adjustments for optimal fields of view. This enables the pilot to accurately engage with underwater obstacles and the environment.

In preparation for this year's MATE challenge, we overcame several obstacles and learned to be more disciplined as a team. We learned many new concepts and skills that allowed us to fabricate an ROV with a new thruster system, streamlined electrical systems, new materials. Team Kepler has designed and manufactured a unique and progressive ROV that meets the standards requested in the 2019 Kingsport RFP.

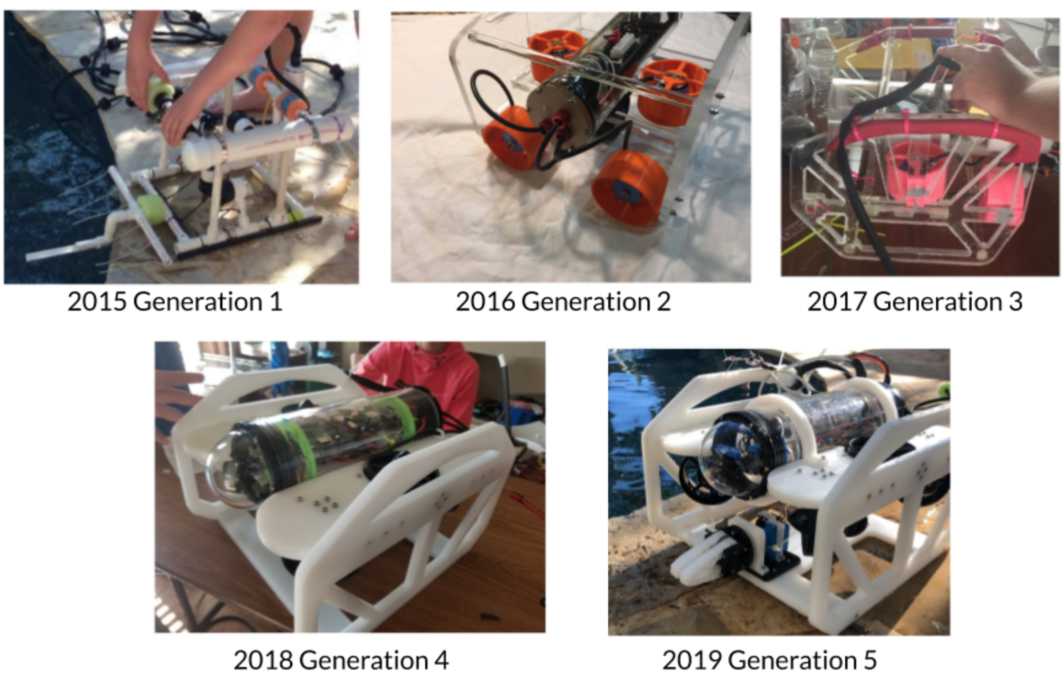


Fig. 1 Team Kepler's ROV - 5th year to participate in MATE

2. Team and Project Overview

2.1 Company Profile

Kepler Enterprises is a returning company in the MATE Competition. The company was created 5 years ago with the goal of cultivating an interest in underwater robotics in our community while simultaneously expanding our experience in the STEM fields. Kepler Enterprises is comprised of 7 high school students, each with experience in their respective roles. The core of our team is returning members who participated in the team that won the 2017 MATE Regional competition in Houston, Texas. The addition of new members brings a fresh, innovative perspective on pre-existing knowledge, helping to create interpersonal relationships that foster teamwork and effective communication skills.

2.2 Company Assignments

At the beginning of the year, each member was assigned a role based on personal interests and skills. Although roles were assigned, each member helped with multiple aspects of other jobs.

Mechanical Engineering Grant Kahl	**Electrical Engineering** Grant Kahl Reese Traylor	**Mini ROV** Eric Love Lance Kahl Jason Love	**Miscellaneous** Brooke Culhane Jake Love Jason Love
• Design and build next generation ROV frame to accommodate vector thrusters • Streamline frame design simplifying assembly • Design two rotational axis arm/claw for holding and grasping objects • Design and build the hydro tube for optimal organization of all electronic systems: cameras, ESC controllers, sensors, and control servos	• Design electronic tray for the hydro tube to facilitate wire organization • Design system integrated (SID) scheme • Update settings and control parameters for QGroundcontrol software with Ardusub firmware • Integrate programming and software systems with the mechanical and electrical system	• Design mini ROV to meet specifications outlined in RFP • Design and assembled LED array • Waterproof electronics including camera and motor • Construct shroud for safety • Make a connection to primary ROV	• Community outreach • Technical report preparation and edits • Ensure proper safety is practiced at all times • Manage team finances and sponsorships • Prepare team specification document • Waterproof all hydro tube penetrators for motors, sensors, and servos • Test and analyze current loads at maximum usage and standard operations

Table 1: Kepler Enterprises Assigned Technical Roles

2.3 Project Timeline Overview

Kepler Enterprises started designing the primary ROV Frosty in early October 2018 followed by the design and manufacturing of the mini ROV Snowflake in early March 2019. We took 2 months to design the ROVs. We began composing the technical report in January 2019. We took 3 months to complete the assembly of the ROVs and started testing in March 2019. As a team, we finished the final report in preparation for the Texas regional qualifier in Houston, Texas. The abbreviated Gantt chart (Figure 2) outlines an overview of timelines and a more descriptive Gantt chart can be found in Appendix D.

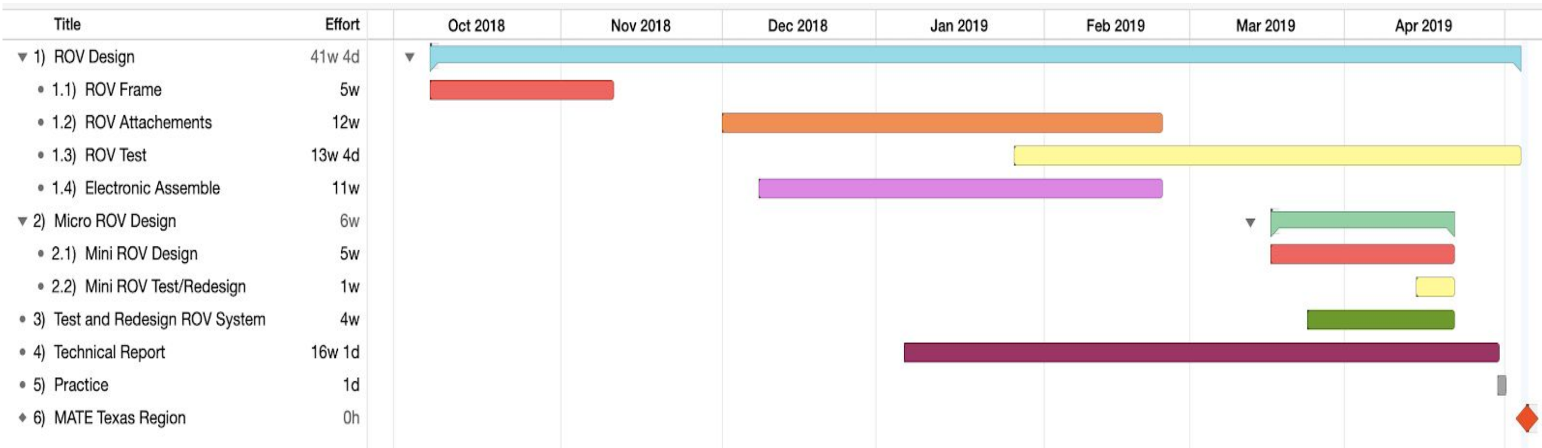


Figure 2: Gantt chart timeline overview

3. Design Rationale: Applications

3.1 Structure Material Choice

For the main structure of the ROV, the team chose High-density Polyethylene (HDPE) for its exceptional buoyancy, impact strength, and durability. HDPE has a wide range of applications such as sewage piping and rails for snowboarding because of its high strength to mass ratio. HDPE offers many safety advantages such as its shatterproof nature and its ability to resist many corrosive materials. Other materials have disadvantages such as aluminium being negatively buoyant, PVC being weaker and less versatile, and acrylic being very brittle, creating a structural liability. With a density of about 0.97 g/cm3, HDPE is much lighter than both aluminium and acrylic. Considering all of the positives HDPE has to offer, namely its customizability and lightweight that allows for safer and more advanced underwater flight, HDPE is the standout choice among its competitors.

3.2 Frame Design

The company designed the ROV frame to be maneuverable and adaptable. We knew we were going to be using a vector thruster configuration and the Blue Robotics 4 inch Enclosure so we had to design our frame around that. To make the ROV more maneuverable, we removed unnecessary material, making the ROV lightweight and more maneuverable. In addition, removing unnecessary material allows more water flow for the motors which maximizes their thrust efficiency. To make the ROV more adaptable we designed the frame so that it is completely put together by screws. This allows us to easily replace any part that breaks or easily modify any part. In addition, we designed the frame to have a flat base plate so that almost any attachment can be integrated into the ROV. Also, the screws used for assembling the frame were made flush with the material and all of the edges are chamfered, so Frosty can be more safe, streamlined, and hydrodynamic.

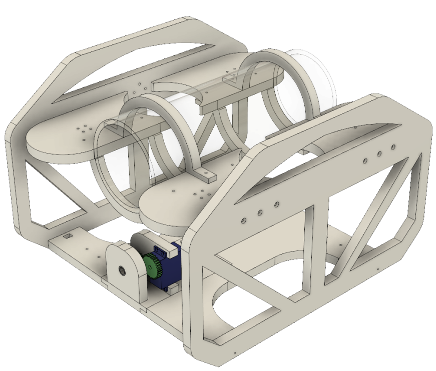


Figure 3: Kepler Enterprises modular frame design

3.3 Motor Vectoring

Figure 4: Blue Robotics T 100 Thruster

We re-evaluated the use the T100 motors from Blue Robotics (Fig. 3.1) because they produce maximum thrust with high efficiency. We transitioned from the standard x, y, z thruster systems to a vectored thruster system, allowing better control and improved maneuverability. In a vectored arrangement, each motor individually produces 1.25Kg or 12.26 Newtons of thrust in the forward direction and approximately 1 Kg or 9.81 Newtons of thrust in the reverse direction. This gives the robot a total thrust output of 5 kg or 49.05 newtons of forwarding thrust and 4 Kg or 39.24 Newtons of thrust in the reverse direction. The maximum current draw for all motors is 12 Amps which was determined based upon underwater testing and monitoring our amperage draw. All motor leads were cut to conform to the thruster and frame dimensions, with an average length of 30 centimeters long, and then potted with marine epoxy into specifically designed cable penetrators. The wire leads on the inside of the hydro tube were modified with MR-30 three pin connectors soldered onto to motor leads to connect to the electronic speed controllers (ESCs). The lift capacity of the ROV is 25.2 newtons, as there are 2 upward thrusters each producing a force of 12.6 newtons when upwards, and the ROV is neutrally buoyant. The vectoring system used by the motors is displayed in the figure below. The vectoring allows the ROV to move in every direction with control, power, and stability. This gives the driver excellent maneuverability over the ROV enabling a smoother driving experience that helps to complete the missions efficiently.

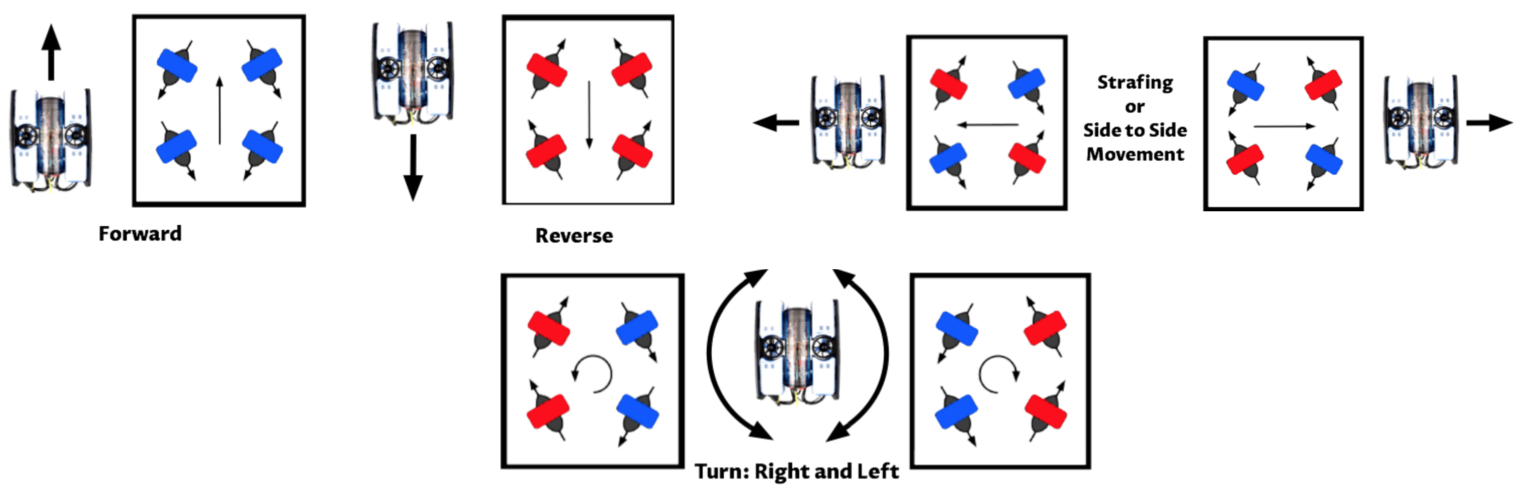


Fig 5: motor vectoring system

3.4 Optical System

Our design team evaluated various gimbal blueprints and cameras so that they could select the optimal layout to make sure that the pilot can efficiently navigate underwater. In previous seasons, we encountered many optical obstacles: glare from the sun, latency, fisheye and other types of distortion, lack of depth perception, and minimal field of view (FOV). To address the issue of glare, the team successfully designed and fabricated an anti-glare shield for the camera. In previous seasons we were not getting real-time images because of the display delay. The solution we found to compensate for the delay was the new communications cable in the tether reduces latency. In addition, much of the distortion is caused by the size of the lens, resulting in the general distortion listed above. Last year, we switched from a 2.5mm lens to a 1.8mm one to achieve a happy medium that minimizes the poor effects and solves the problems stated above. The camera we are using this season, the Sony IMX322, is 2 megapixels, 1080p, and can stream to our control system at 60 frames per second with minimal latency.

The gimbal is an important part in being able to navigate through the water. We designed the gimbal so that it can give the driver the maximum field of view and allow them to complete all of the missions. The gimbal also has the ability to self stabilize and give the driver a smooth driving experience.

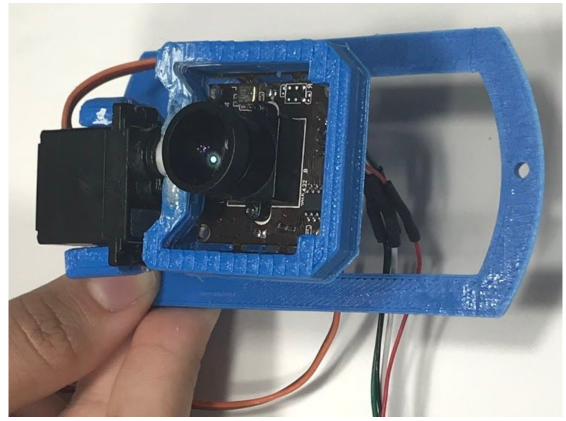


Figure 6: Camera Gimbal

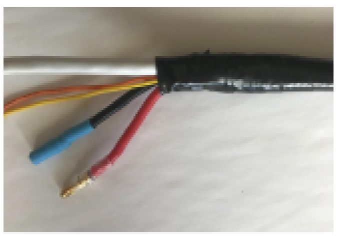


Figure 7: Topside tether connection

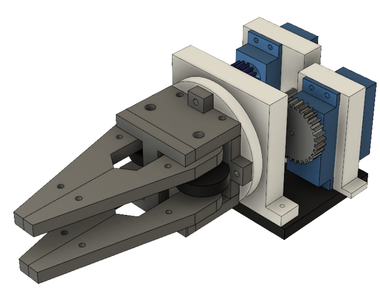
3.5 Tether

The tether is key for communications from the surface control and computers to the underwater ROV electronic systems. We want the tether to be unnoticed and neutrally buoyant, so as not to impede ROV mobility. Previously, we had some issues with the surface to ROV signals dropping connection at times. We found that the quality of the transmission lines was critical. For that reason, we upgraded our transmission lines from steel to pure copper, improving signal transmission. Our tether this year is composed of two 26 gauge silicone coated copper wires, two 14 gauge silicone coated copper wires, and a cat 5 cable for the mini ROV. The tether cables and hoses are wrapped in a braided nylon casing. We used silicon coated copper wires because they are a higher quality and are very flexible. To make the tether neutrally buoyant we used a silicon foam wire. Overall, we can meet the mission objectives with an improved tether with better signal connections, improved movement, and improved buoyancy management.

Figure 8: Tether Cross Section

3.6 Claw

Having a functional claw is necessary for completing all missions. The claw was designed as a multipurpose tool that could accomplish all of the manipulation needed for the missions. To achieve maximum capability, the claw has two axis of movement that allows the ROV to grasp almost any object in any orientation that it may need to. Our company selected the HS-646wp servo with a high torque and ip67 waterproof rated servo for the rotational axis and the MG-360 continuous servo with high torque and precision to control the gripper. We ensured that the servos were waterproof by coating the control board of the servo in nail polish, filling the inside of the servo with silicon grease, and encasing the whole servo housing with Flex Seal. This component was designed to grab and release multiple sizes and orientations of props with maximum control. We designed the claw fully in house and



derived a 6:1 gear ratio using a worm gear to increase the possible gripping force of the claw and to stop the claw from backing out in the case of a power failure. The claw is designed with a second axis that can rotate the base plate of the claw. The rotating plate allows our robot to interact with horizontal and vertical props giving us more versatility on the field. Kepler Enterprises designed the claw in entirety and its multiple components were manufactured on a CNC machine and various parts were printed on a MakerGear 3D printer.

3.7 Buoyancy

One of the most important aspects of an ROV is its ability to remain neutrally buoyant while submerged. Being neutrally buoyant means the forces acting on the ROV, in water, are equal. Therefore, a neutrally buoyant ROV does not sink or float, but remains static in the water. This allows for completely dynamic movement and is necessary to complete complex maneuvers and tasks. Through the use of simple calculations our company was able to discover the mass we need to add to make our robot neutrally buoyant. Applying Archimedes principle we knew that the buoyancy force the water applied up on the ROV must be equal to the force due to gravity. This meant that $m = \rho V$ where m is mass, ρ density of the fluid, and V is the volume of the substance displaced. We knew the mass of the ROV and thanks to use of our ROV's 3D models we knew the volume of our ROV. Along with a quick Google search for the density of freshwater we were able to plug in our values into our equation. Once we did we instantly discovered we were that the buoyancy force was greater than the force due to gravity meaning where positively buoyant. In order to make the ROV neutrally buoyant and balance our equation, we added additional mass via stainless steel rods and # 4 rebar to the front of the ROV. We decided however that we wanted our buoyancy to be slightly positive so in case of electrical failure the ROV would float to the surface. So we put slightly less mass than required to make our ROV neutrally buoyant.

3.8 Center of Gravity

The center of gravity (CG) plays an important role in controllability of the ROV. The CG establishes directionality. Understanding where the center of gravity is located and placement of center of gravity is important because it can drastically change how the ROV behaves.
Another factor that became apparent in determining CG was the placement of thrusters. We found that, although the center of gravity was perfectly neutral on the x, y, and z-axis in its stationary state, that the ROV had a tendency to nose up when applying forward thrusters. Therefore we knew, the center of gravity was incorrectly determined and it was experimentally aligned toward the backside of the ROV. The forward thrusters are offset towards the bottom half of the ROV on the vertical (z-axis), causing the nose of the ROV to rise when thruster were engaged. The diagram below depicts the 3 dimensional axis on the ROV. To fix this problem, we added the extra weight we needed for neutral buoyancy to the front of the robot. While this threw our stationary center of gravity off a little bit, it counterbalanced our center of thrust and allowed us to drive in a straight line when going forward or backward.

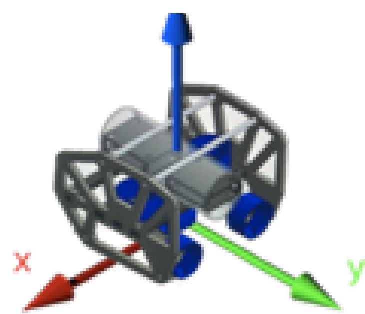


Fig 9: Center of Gravity

3.9 Mini ROV

Our team designed the mini ROV with simplicity and maneuverability in mind. The final design has only one axis of movement, and can navigate the turns of the pipe using a cage designed by our team. For safety purposes and to improve efficiency, the motor is fitted with a mesh shroud. The mini ROV is fitted with a ring of LED lights for visibility from within the darkened pipe. The camera mounted on the mini is a CCD camera that provides a 170 degree field of view and a clear visual field to the pilot. Power and communications are both provided through tethers that run to the ROV and up to the control station at the surface. The mini ROV is designed to be docked inside of a transport box that attaches to the claw. On the box there is a winch that unreels and reels the tether so that it is properly managed underwater..

Figure 10: Frontal and top views of micro ROV

4. Safety and Philosophy

Ensuring the safety of all company members is one of the most important aspects of the design process. Maintaining proper safety practices can help avoid accidents involving the ROV, damage to the environment, and more importantly ensure no company members are hurt or in any danger. Along with maintaining proper safety practices, all possible additions to the ROV which reduced these risks were made.

4.1 Construction Safety

At times, building the frame of the ROV included a number of safety hazards and potential risks. All possible safety precautions were taken while building the ROV to ensure that no one was hurt while building the frame. Cutting HDPE was done by a CNC machine and while around the CNC, all company members were required to wear safety glasses, masks, have their hair tied back, and wear closed toed shoes and long pants to minimize risk of injury in the case of a machine failure. While sanding the HDPE, gloves and safety glasses were worn, as pieces of HDPE could potentially fly off from the dremel. These were the main safety hazards in building the frame; everything was done to minimize the possibility of injury. Along with these main safety hazards however, the handling of hazardous materials such as CAA, epoxy, and other toxic materials created potential danger for the company members. During the handling of these materials, steps were taken to mitigate the risk associated. Gloves were worn at all times while mixing epoxies and applying glue or other CAA based materials and if there was contact with the skin, it was washed immediately under cold water. Safety glasses and masks were also worn to help reduce potential eye irritation or effects on breathing.

4.2 Electrical Safety

While a portion of the company was building the frame, another portion of the company was working on the brain of the ROV. While electrical work may not require as many power tools as building a frame, working with the electronics system of an ROV can still create a number of hazards. One of the main dangers of working with electronics was the use of a soldering iron, which presents the risk of burns and also the inhalation of smoke. To ensure that the soldering iron produced as little amount of problems as possible, it was always used by a properly trained member of the team in a well ventilated area. A mask and safety goggles were also worn while soldering. The use of a heat gun also presented the risk of burn, so team members wore gloves at all times when using one. At all times, the work space was clean and well kept to ensure there were no tripping hazards. Pants and safety goggles were required to be worn at all times when creating the electronics system.

4.3 Safety Features

The safety precautions added to the ROV were as follows:

Shrouded Motors: Unshrouded motors can present a serious safety concern, leaving blades open to maim fingers and hands. In addition to the fact that they present the serious possibility of injury a team membering, the high likelihood of getting tangled with a wire or debris could jeopardize the mission. Shrouded motors not only add a safety bonus but also a boost the efficiency and power output of the motors.

Kill Switch: The box has an integrated switch that kills all power to the bot. In the case of a leak or the occurrence of another malfunction while in the water, the kill switch is crucial to potentially preventing a short circuit or other damage to the ROV.

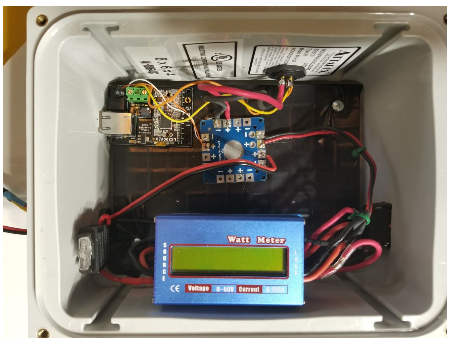


Figure 11: Surface power control box

Fuses: The fuses are another preventative measure on the ROV. There is one fuse located in the control box. In the case that there is an overload of current, the fuse will stop the excess amount of electricity from hurting the electronics and can easily be replaced.

Chamfered Edges: Another safety feature of the ROV is the lack of corners on the robot. Corners present the risk of cutting one's self. Eliminating corners entirely, makes the robot not only lighter but also safer.

4.4 On Deck Safety

A massive part of safety is on deck safety. Before going through a mission, company members go through a safety checklist which is included in appendix C. While on deck, there are no open toe shoes, safety glasses and life jackets are worn at all times, and prior to the ROV being put in the water, all tripping hazards or other dangers are cleared from the deck.

5. Waterproofing Mechanisms

5.1 ROV Waterproofing

Ensuring that we have a watertight seal on the ROV is critical to having a functional robot. A small leak on the ROV can fog up the camera and impede our ability to navigate the water. To ensure that we have a watertight seal, we used the Blue Robotics 4" Watertight Enclosure and cable penetrators which are specifically designed to keep a watertight seal. The watertight enclosure keeps a seal by using two flanges on each end of the tube which has two O-rings. We created a seal in the penetrators by threading the motor cables through the penetrators and hanging the wires straight above them. We potted the cables by putting marine epoxy in a syringe and inserting the epoxy into the penetrator making sure to get the epoxy in all of the cracks and crevices.

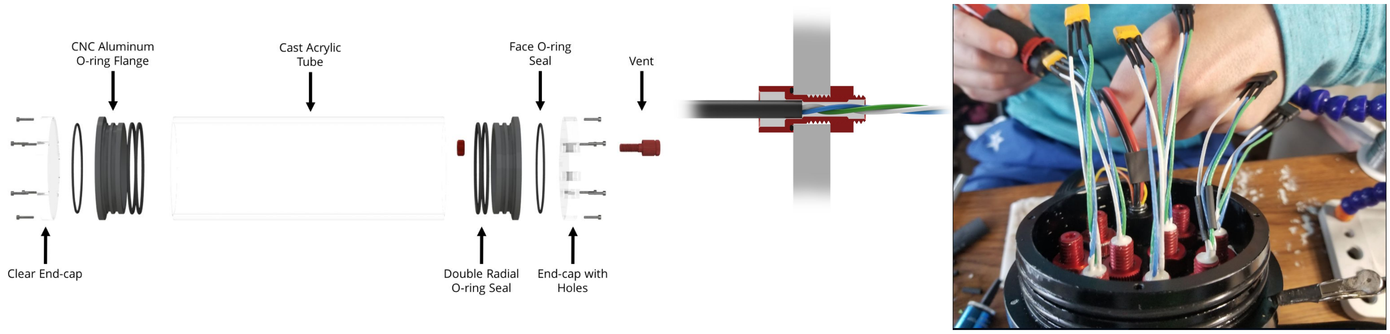


Figure 12: Waterproofing the Watertight Enclosure (WTC)

5.2 Mini ROV Waterproofing

Keeping a watertight seal on the mini ROV is crucial to completing the mission. The mini ROV camera and lights are encased in an epoxy resin within the PVC frame structure. We had lots of trouble with bubbling in the resin but through trial and error we found the correct mixture of epoxy. The motor was placed inside of a plastic shell and filled with toilet bowl wax to ensure a complete seal. Liquid electrical tape and heat shrink were used to waterproof the wires, certifying that no bare wires were exposed.

6. ROV Control and Programming

6.1 Control Station

The controlling software used is QGroundControl with a custom firmware , ArduSub, enabling additional support to QGroundControl for undersea vehicles. The ROV has an onboard Raspberry Pi running an OS with ArduSub installed. The Raspberry Pi communicates with the laptop via ethernet connection from the controlling laptop. We decided on using a raspberry pi because we could utilize this ethernet connection as it has a range of approximately 300 meters compared to a USB connection which only has a range of around 3 meters. Using an ethernet connection reduced the total amount of wires required to connect the ROV to the laptop. The Raspberry Pi connects uses a micro USB connection to the Pixhawk 3 the ROV controller. The Pixhawk send sends signals to the motors speed controllers, servos, and the camera gimbal. In addition to controlling motors and servos, we also have sensors that send signal back to the Pixhawk and get displayed on our camera HUD. The computer interface for the software is shown in figure 11.

Frosty is complete controlled and monitored with QGroundControl and minimal coding to change software parameters was needed to fine tune fine movements and calibration of servo and sensors.

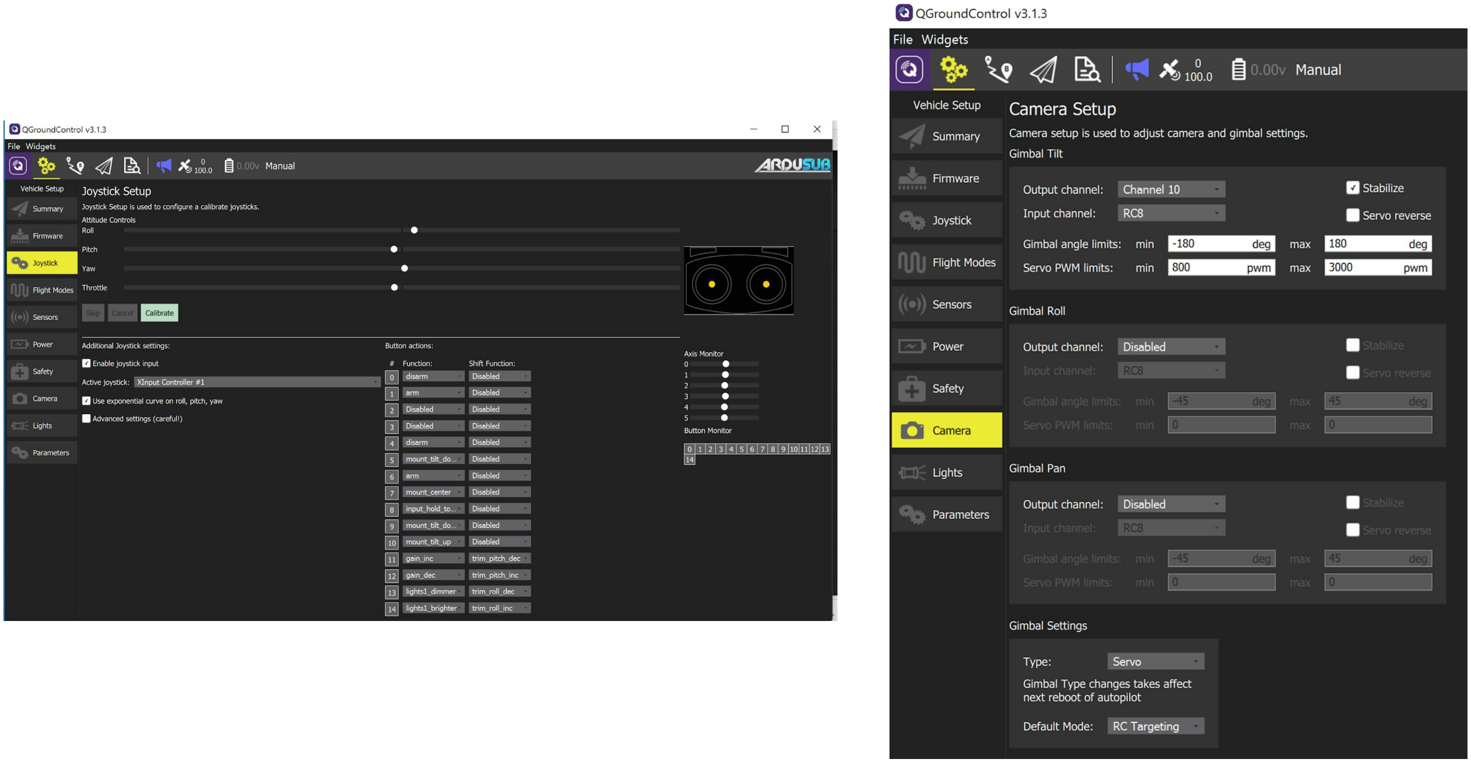


Figure 13: QGroundControl Panel

6.2 Control Configuration

In order so that the pilot can maneuver the ROV in the most effective manner, the process of selecting a control configuration has to be completed carefully, and the many criterion have to be carefully selected. Due to the ergonomics, modularity, and cost, we have chosen to use an Xbox ONE controller. Other ROVs may also have a different dual joystick arrangement, but the transportability and familiar feel it provides makes it the best choice. The Xbox controller can be configured in any way so that the electronics team can adjust any layout issues with ease. Rather than purchasing high cost joysticks and wires, we repurposed a team members controller to save time and money.

When we connect the controller with the computer using a Micro-USB to USB cable. QGroundControl automatically identifies the controller. From there, we can select a wide range button layouts from a drop-down menu or create our own. Below is our custom controller layout, which includes dead zones in the center of the joystick to make the movements more smooth. In addition, the QGroundControl software contains a self-calibrating system to add consistency to the controller. We have developed a user-friendly system to maximize the ease of operation.

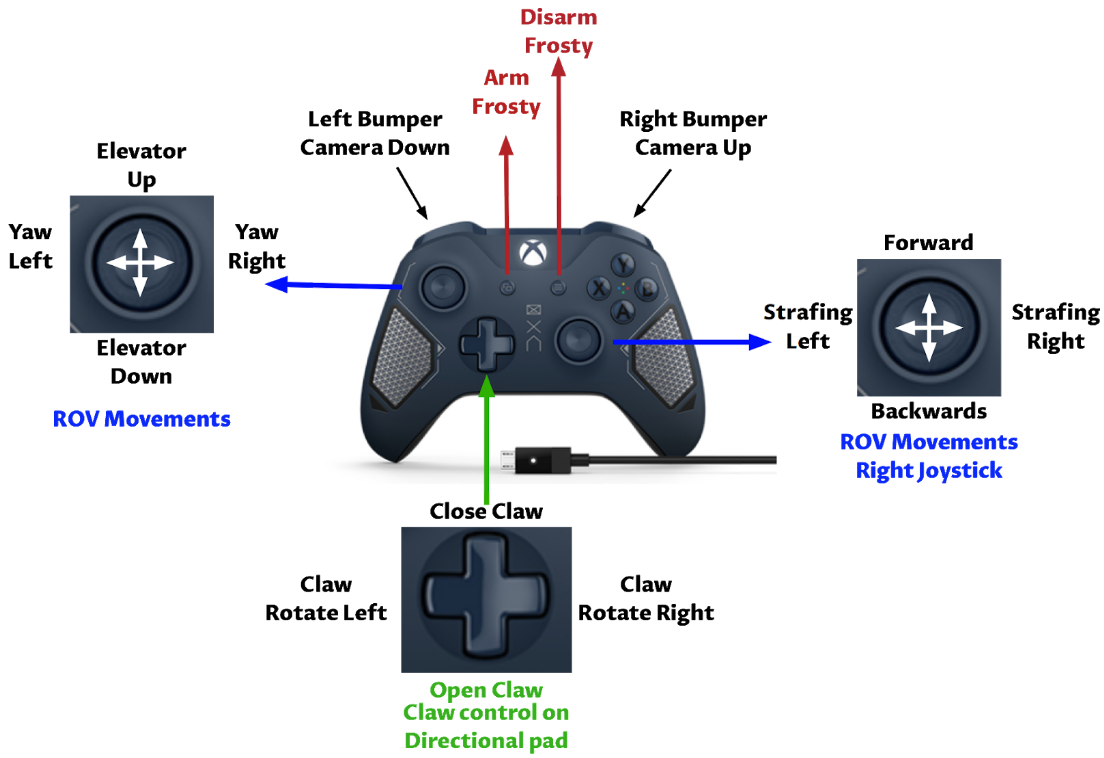


Figure 14: ROV customized controller layout

7. Critical Analysis

7.1 Dry Testing

Before even thinking about driving the robot, our team tested to ensure that Frosty had the ability to float, hold a seal, receive and process information from the control station, and send clear visual data back to the pilots.

Figure 15: Motor Number 2

After we waterproofed the ROV, we vacuum-sealed the hydro tube and monitored the pressure gauge for leaks. We tested several times to determine that the enclosure is sealed and watertight. When we first configured the thruster layout, we numbered the motors according to their electronic signature (see Fig. 13). After that, we observed the directional rotation on each to verify the programming.

With regards to the manipulator arm, after fabricating the various parts of the claw using a CNC machine and 3D Printer, we inspected, assembled and waterproofed the wires.

7.2 Wet Testing

Executing the mission is the culmination of all the work done before, and all the pieces are tested and perfected in this stage of development. With safety in mind for people that may be in the water, our goals are as follows: to make sure that the ROV is fully waterproofed, to acclimate the pilot to the conditions of piloting Frosty and the missions, and to be sure that the ROV is neutrally buoyant. After testing the ROV, we always check for leaks in the main electronics compartment so that nothing gets damaged. Using the pools at Kepler HQ and at TMI, we have practiced running the course, fine-tuned the buoyancy, and refined the strategy. While testing the ROV, we observed how the robot sat in the water and added weight based upon how much it floated/sank.

7.3 Technical Challenges

Waterproofing Micro ROV - The camera in the ROV proved to be a challenge to waterproof. The team decided the best method of waterproofing would be encasing the camera in epoxy. This, however, was more difficult than the team initially expected. Bubbles in the epoxy were a major issue and the process had to be restarted multiple times, taking up valuable time and resources.

Pixhawk Problems - The heart of the electrical system of "Frosty" is the PixHawk. The Pixhawk controls all onboard electronics, including the motors and the claw. The Pixhawk, however, stopped working around 2 months before the competition, causing the ROV to stop working altogether. The team quickly realized that the Pixhawk was dead, as it had been used for nearly 4 years and replacing the component solved the problem without issue.

7.4 Interpersonal Challenges

Scheduling - Each member of the team is involved with many activities, along with MATE, which made it difficult to schedule meetings where everyone could attend. Even with this setback, the team had weekly meetings with any teammates that could be there.

Communication - When designing and building the ROV, our team had difficulties effectively sharing ideas and staying on the same page. This made it harder to create a robot while incorporating everyone's perspective. To help improve communication, we used a group chat and updated each other on tasks, ideas, and the weekly meeting details as often as possible.

7.5 Lessons Learned

Technical Lessons Learned- An important lesson learned was crafting models and prototypes to test the effectivity of an idea before the team fully committed to it. Sketching and modeling proved to be very helpful in the design of the claw, and a good portion of the team's time was spent on this process. Countless sketches and prototypes were made on paper, in CAD, and even with LEGO^{Tm} pieces. This also helped us save time and resources down that we had previously wasted due to thoughtless craftsmanship.

Interpersonal Lessons Learned- The company quickly learned the importance of giving constructive criticism that led to the collective betterment of the ROV. Our team got easily distracted because of how close our friendship bonds are. It became important that we learned how to stay focused by working first then having fun later in order to use the minimal time effectively.

7.6 Troubleshooting Techniques

Troubleshooting is an integral part of any engineering project. Over the past 5 years, Kepler Enterprises has competed in the MATE ROV competition, the company members have learned how to effectively troubleshoot as a team. At times, however, Troubleshooting can be difficult and frustrating for even the most experienced members of the team. For this reason, the company decided to implement a series of standard troubleshooting procedures for each component of the project.

ROV:

Connection lost warning - Ensure all connections inside the brain of the ROV are solid and all plugs are plugged in properly. If all connections are solid and connection is still faulty, reset QgroundControl

ROV Disarmed - Check to ensure the Qgroundcontrol is properly setup

Control Box:

Fuse - Ensure fuse is not blown

Connection issues - Check all connections to the PDB

Micro ROV:
Control Box - Check potentiometers and all connections on the topside control box
Connection Issues - Check connection points at the end and beginning of tether and to the motor

8. Finances

Donations				
Item	Type	Quantity	Price Per	Total
T-100 Thrusters	Electronics	6	$119.00	$714.00
Life Vest	Miscellaneous	4	$12.25	$48.99
Total				$762.99

Re-Used				
Item	Type	Quantity	Price Per	Total
Raspberry Pi 1080p Camera	Electronics	1	$49.99	$49.99
Xbox controller	Electronics	1	$49.99	$49.99
HiTec Waterproof Servo	Electronics	2	$42.99	$85.98
Raspberry Pi	Electronics	1	$36.91	$36.91
Fathom X Board Set	Electronics	1	$159.00	$159.00
USB to Ethernet Adapter	Electronics	1	$41.99	$41.99
High Density Polyethylene Sheet ½”	Hardware	2	$85.18	$170.36
Loctite Marine Epoxy	Hardware	5	$5.40	$27.00
Syringes	Hardware	20	$0.83	$16.60
Assorted JST Connector Kit	Hardware	1	$9.99	$9.99
Watertight Dome End Cap	Hardware	1	$59.99	$59.99
Cable Fasteners	Hardware	2	$4.18	$8.36
26 Gauge Silicone WIre (M)	Electronics	20	$2.59	$51.80
14 Gauge Silicone Wire (ft)	Electronics	20	$0.56	$11.20
Cable Penetrators	Hardware	7	$3.40	$23.80
O-ring Set	Hardware	2	$3.00	$6.00
Watertight Enclosure	Hardware	1	$203.00	$203.00
High Density Polyethylene Sheet 1/4 inch	Hardware	2	$15.23	$30.46

Cat-5 Cable	Electronics	10	$3.80	$38.00
Total				$1080.42

Purchased				
Item	Type	Quantity	Price Per	Total
Pixhawk	Electronics	2	$94.99	$189.98
BLHeli S 30A ESC	Electronics	8	$12.50	$100.00
Continuous Rotation Servo	Electronics	4	$16.95	$67.80
4 Pin Waterproof Connector	Electronics	4	$12.99	$51.96
3.3V Step Up/Down	Electronics	2	$9.89	$19.78
PVC Pipe (ft)	Hardware	40	$1.59	$63.60
PVC Joints	Hardware	40	$0.40	$16.00
Corex Drain pipe 10 ft	Hardware	1	$38.99	$38.99
T-shirts	Miscellaneous	7	$13.99	$97.93
Sailor Hats	Miscellaneous	6	$2.33	$13.98
Captain Hats	Miscellaneous	1	$17.50	$17.50
MATE Entry Fee	Miscellaneous	1	$250.00	$250.00
Temperature Sensor	Electronics	1	$56.00	$56.00
CCD Camera	Electronics	3	$10.99	$32.97
Hotel Room	Travel	3	$150.00	$450.00
Gas	Travel	1	$150.00	$150.00
Food	Travel	1	$350.00	$350.00
Total				$1,966.49

8.1 Build vs. Buy

When choosing between whether to purchase or build an object it is important to weigh both the positives and negatives. Building an object is much more cost effective and gives the ability of customization. A part is able to be manufactured to meet specific requirements and adds the component of originality. Conversely, building an object requires more time to design and manufacture. Purchased items can be more expensive but oftentimes are more reliable due to the testing they endure and certifications they must meet before being placed on the market. On the other hand, purchased items are generic and must be modified to fulfill their specific needs.

8.2 New vs Reused

The ROV from last year, for the most part, was exceptionally functional at completing the tasks it was designed to complete. More importantly, however, the ROV was designed with versatility and modularity in mind meaning that in the design of the “Frosty” this year, the major components and core of the vessel were able to be reused but slightly altered for the specific tasks set by The Eastman Company. The frame was reused, as was the watertight enclosure and the electronic components inside, and the thrusters. The only new parts inside the electronics enclosure were a replacement Pixhawk, as the previous one was 5 years old and had to be replaced. The interior was redesigned as well, allowing for easier access to the electronics inside the capsule. New servos replaced the previous claw servos, and along with a newly designed claw, allowed for more grip strength and an overall improvement in the functionality of the gripper. Along with the new servos for the claw, many of the parts for the micro ROV were new. The motor was taken from an old ROV the company had in their shop, as was the camera. The fins were fabricated and as a result new, as was the shrouding around the motor in the mesh case. A mission specific this year was a temperature sensor and as a result, this was new, in order to accommodate for the tasks set forth. The vast majority of the ROV, however, is reused and when deciding on what new additions were to be made to the ROV, the company made team decisions based on the specifications of the missions.

9. Future Improvements

Although our company has engineered our ROV to successfully and efficiently complete the outlined tasks, we recognize the importance of improving our team every year. Improvements aren’t limited to only the robot, but they apply to our team as well. This year time management and organization created many setbacks and limited our team’s abilities. At the beginning of the season, we made a schedule but had to constantly set back our deadlines as time went by.

The ROV had many areas that could have been better optimized to carry out each task faster and more reliably. Wire management could have been improved with a better electronic rack. A camera in the back would also help to complete tasks where hooking onto a prop was required.

The Micro ROV had many areas we could have improved on too. With only one axis of movement, piloting it into the drain pipe was very difficult. Another aspect of the mini that could have been improved on was docking. To bring the micro ROV out of the pipe and dock on the robot, our team built a mechanism that slowly reeled in the tether. This made the mission time much longer, and it was not as reliable as we would have liked it to be.

10. Acknowledgements

10.1 Sponsors

We thank K^2 Solutions for allowing the team to utilize their CNC machine. Robotics Club USA has been a major monetary sponsor that has helped us purchase parts, tools, and provided storage. Dr. Richard Neiman MD donated team shirts and new motors for Frosty. The Texas Military Institute has provided a deep pool so that we can practice missions. Finally, the parents of all the company members have sacrificed time, money, gas, and their sanity so that we can compete at our best.

We are very appreciative for the opportunity to participate in the MATE program and we would like to acknowledge the following mentors for contributing to the success of our company:

- Dr. Jeffrey Kahl our mentor, who has supported us with technical and non-technical advice through our design process.
- Dr. Nieman for his generosity and providing the materials for the ROV thrusters.
- All of our parents for providing us with financial support and being supportive of crazy hobbies and willingness to explore new ideas.
- Mrs. Leslie Love for helping us with our presentation and giving us helpful tips for public speaking.

- TMI Episcopal School for allowing us to use their pool to test, analyze and practice product demonstration missions.
- MATE International ROV Competition for making this competition possible.

Figure 16 : Kepler Enterprises sponsor logos

THANK YOU

11. Community Outreach

Kepler Enterprises visited with several groups about the MATE competition. During these meetings, the team piqued the interest of various vendors that became supporters and sponsors for the team. For example, Ferguson Plumbing in Marble Falls donated and offered discounted supplies for field props. In addition, the team was featured on Spectrum News in preparation for the Texas regional qualifier.

San Antonio team preparing for international underwater robotics competition Spectrum News, San Antonio, Texas, May 2019; website URL: https://spectrumlocalnews.com/nys/central-ny/news/2017/06/21/san-antonio-team-prepping-for-international-underwater-robotics-competition-

Underwater robotics team from San Antonio impresses at international event, San Antonio Express News, July 2018, Website URL: https://www.expressnews.com/news/education/article/Underwater-robotics-team-from-San-Antonio-11264360.php

12. References

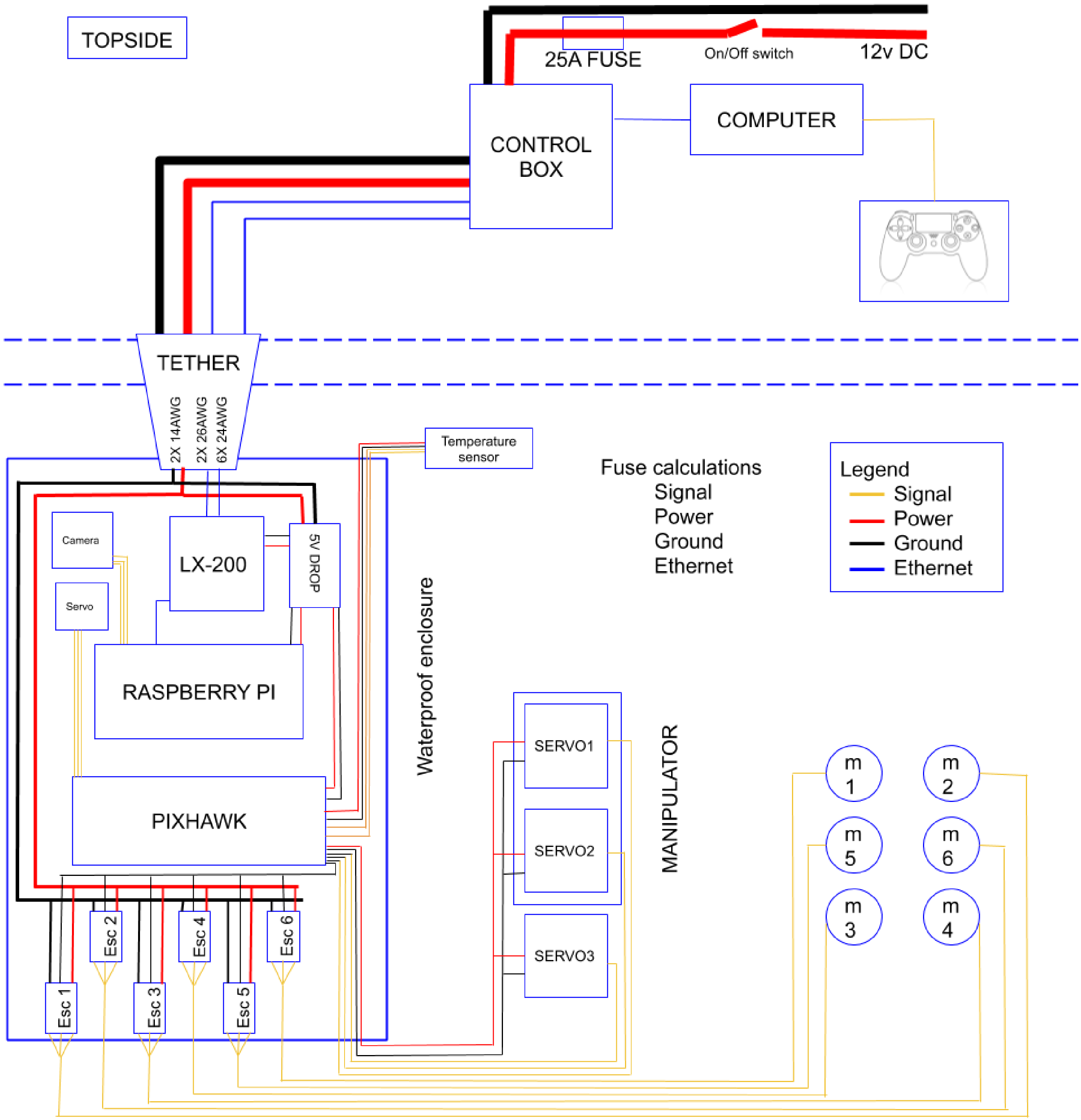
We built on our past experiences and worked with many new components and concepts utilized in this years ROV. We had to conduct extensive research and used a number of different resources in order to educate ourselves during our preparation:

1. Moore, Steven W., et al. *Underwater Robotics: Science, Design & Fabrication*. Marine Advanced Technology Education (MATE) Center, 2010.

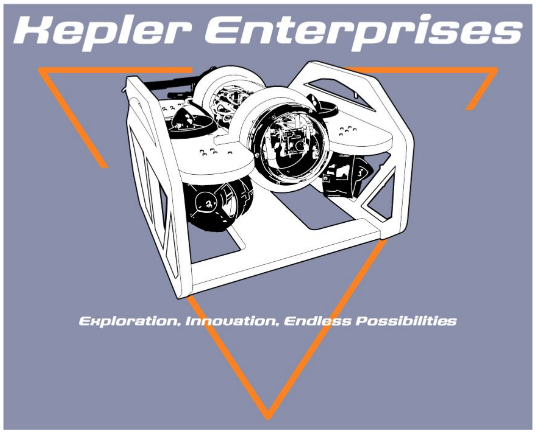
2. Antonelli, Gianluca. *Underwater Robots*. Springer, 2014.
3. Bohm, Harry, et al. *Build Your Own Underwater Robot and Other Wet Projects*. Westcoast Words, 2012.
4. Troupe, Thomas Kingsley. *Underwater Robots*. World Book Inc., 2018.
5. "MATE - Marine Advanced Technology Education :: TriggerFish ROV Curriculum." MATE - Marine Advanced Technology Education :: TriggerFish ROV Curriculum. MATE, n.d. Web. 24 Oct. 2015. <http://www.marinetech.org/triggerfish-and-arduino>.
6. "Index of Curriculum Lessons_year3." Index of /curriculum/lessons_year3. Cornerstone Robotics, n.d. Web. 29 May 2015. <http://cornerstonerobotics.org/curriculum/lessons_year3/>.
7. "The Physical Properties of Water." Marietta College, n.d. Web. 29 Oct. 2015. <http://www.marietta.edu/~biol/biomes/water_physics.html>.
8. "Hydrodynamics: Fluid Motion." Hydrodynamics: Fluid Motion. ReefQuest Centre for Shark Research, n.d. Web. 27 Oct. 2015. <http://www.elasmo-research.org/education/white_shark/hydrodynamics.htm>.
9. "Prototype Fish Robot, UPF-2001." Prototype Fish Robot, UPF-2001. National Maritime Research Institute, n.d. Web. 25 Oct. 2015. <http://www.nmri.go.jp/eng/khirata/fish/experiment/upf2001/body_e.html>.
10. "Blue Robotics Forums." Blue Robotics Forums. Blue Robotics, n.d. Web. 4 Feb. 2017. <http://discuss.bluerobotics.com/>.

13. Appendix A

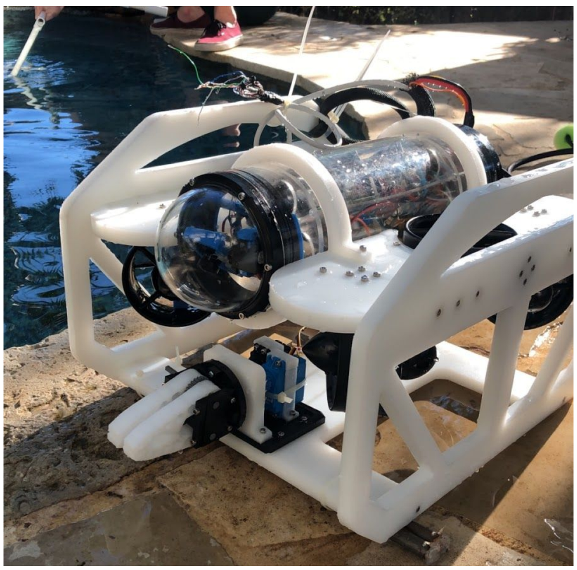
SID - System Interconnection Diagram



Kepler Enterprises



Returning Team: 5 Years (7 Members)
Rov Name: Frosty
Total Cost: $3,046 [91]
Size and Weight: 15.75” x 13.5” x 11”, 8.2 Kg.
Total Build Hours: 458 Hours
Safety Features: Shrouds, Cutoff Switch, Chamfered Edges, Inset Screws, Safety Fuse, Computer Regulate Control, Detachable Tether
Special Features: Rotating 2 Axis Claw, 170° Optical View Through HD Camera On Gimbal, Single Line Communication, Vector Orientation Thrusters
Distance to International Competition: 1,680 Kilometers



San Antonio, Texas

Appendix B: Team Members

Member Name (yrs on team)	Position	Grade
Grant Kahl (5 yrs)	CEO, Head of Electrical and Mechanical Engineering, Pilot	12th
Reece Traylor (1 yr)	Chief Electrical Officer, Deck Assistant	12th
Brooke Culhane (1 yr)	COO, Technical Writer, Deck Assistant	12th
Eric Love (1 yr)	CTO, Head of Technological Development, Co-Pilot	11th
Jason Love (1 yr)	Technical Engineer, Deck Assistant	9th
Lance Kahl (5 yrs)	CFO, Director of Training, Deck Assistant	9th

Jake Love (4 yrs)	CSO, Head of Safety, Safety Officer	11th
Dr. Jeffrey Kahl (5 yrs)	Mentor	N/A

Appendix C

Operational and Safety Checklist

In Lab:

- [ ] Safety PPE is worn depending on the situation
- [ ] Area clear/safe (no tripping hazards, items in the way)
- [ ] Equipment are maintained properly
- [ ] Keep the workshop tidy
- [ ] Make sure you have someone working with you
- [ ] Follow manufacture safety protocols on all equipment

Soldering:

- [ ] Wear safety googles and mask
- [ ] Clear the table
- [ ] Work in ventilated area

Handling Resin:

- [ ] Wear mask and gloves
- [ ] Prepare tissue paper
- [ ] Turn on the ventilation
- [ ] Clear the table

On Deck:

Setting Up on Deck:

- [ ] Area clear/safe (no tripping hazards, items in the way)
- [ ] Tether is laid out and managed by a team member
- [ ] Plugs are filled and covered with petroleum oil
- [ ] Plugs and sockets are connected securely
- [ ] Verify power switch is off
- [ ] Thrusters are properly shielded
- [ ] No exposed copper or bare wires
- [ ] Screws and nuts are tight
- [ ] Tether securely connected to ROV
- [ ] Single inline 25A fuse in place
- [ ] Preseure test WTC

Equipment Checklist

- [ ] Lift bags prepared properly
- [ ] Buoyancy devices ready to be used
- [ ] OBS ready
- [ ] All other attachments/ equipment neat and tidy

Power-Up:

- [ ] Ensure team members are attentive
- [ ] Call out, 'Power on"
- [ ] Power on
- [ ] Control computers up and running
- [ ] Call out, "Test thrusters"
- [ ] Perform thruster test
- [ ] Verify video feeds
- [ ] Test active manipulator

Launch:

- [ ] Call out, "Prepare to launch"
- [ ] Deck crew members handling ROV call out, "Ready'
- [ ] Launch ROV

ROV Retrieval:

- [ ] Pilot calls out, "ROV surfacing"
- [ ] Deck crew calls out, "ROV on surface"
- [ ] Stop thrusters
- [ ] Remove ROV from water

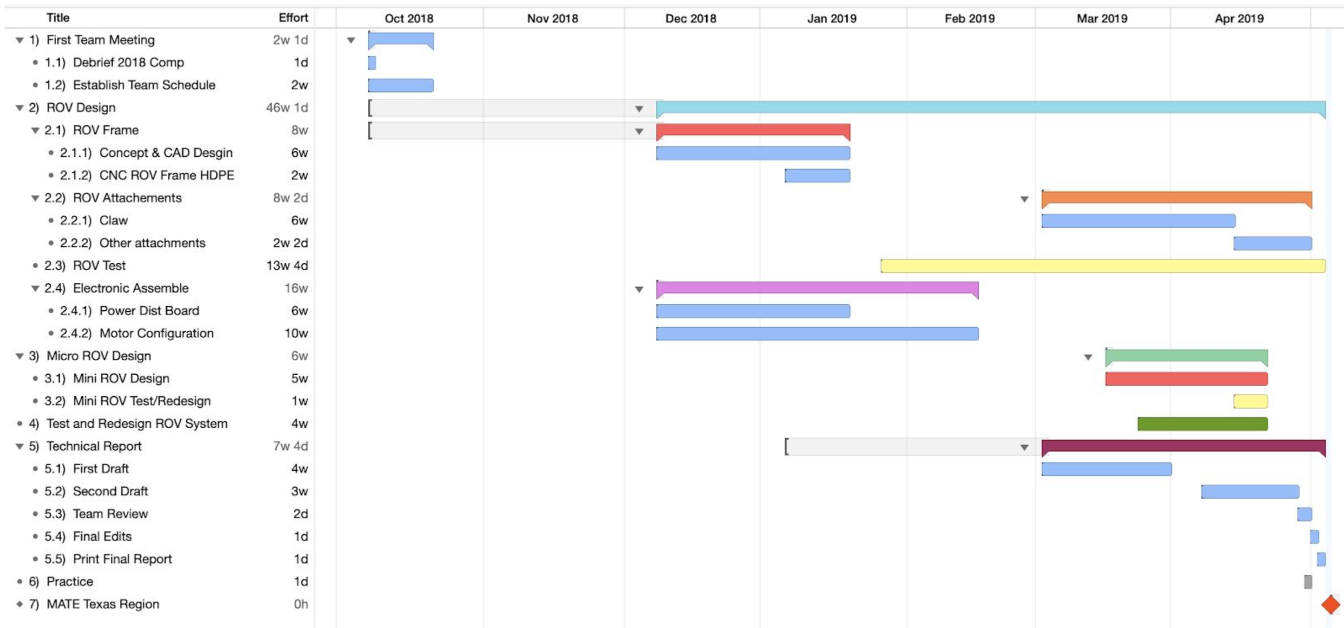
Loss of Communication:

- [ ] Restart ROV
- [ ] Check Status light
- [ ] Restart control program
- [ ] If communication restored, resume mission

Maintenance:

- [ ] Verify thrusters are free of foreign objects and are spinning freely
- [ ] Visual inspection for any damage
- [ ] All cables are neatly secured
- [ ] Screws and nuts are tight

Appendix D: Expanded Timelines



Appendix E: Team Member Bios

Grant Kahl- Is the Chief Executive Officer of Kepler Robotics. Mr. Kahl is a current senior at TMI Episcopal in San Antonio, Texas. This is his fourth year participating with MATE robotics and third year in the Ranger division. He has over 7 years of experience with the US FIRST robotics programs, one-year experience with Vex Robotics, and extensive experience building first-person view (FPV) racing quadcopters. Outside of school, Mr. Kahl has earned the rank of Eagle Scout and involved in many STEM-related activities and enrichment programs. He will be attending The Colorado School of Mines, where he will pursue a degree in mechanical engineering with an emphasis in space exploration.

Eric Love – Is the Chief Technical Officer and responsible for the organization's research and development, as well as the technical aspects of the ROV. Mr. Love is a junior at the International School of the Americas LEE. He runs track and cross country, as well as competes in pentathlon representing the United States. He tinkers with electronics and quadcopters in his free time as well as compete in various programming competitions. He hopes to attend MIT and obtain a degree in computer science.

Brooke Culhane - Is the Chief Operation Officer and is in charge of supervising the team meetings. This is her first year in MATE robotics. Ms. Culhane is a senior at Reagan High School, where she plays varsity volleyball. In her free time, she works as a lead instructor at Robotics Club USA and volunteers at the local animal shelter. Next year she will be attending Texas A&M University and plans to major in biomedical engineering.

Lance Kahl – Is the Chief Financial Officer and responsible for the team's finances. Mr. Kahl is a freshman at TMI Episcopal and has extensive experience with robotics over the last six years. He also participates in football, basketball, lacrosse, and Boy Scouts and he is currently completing the rank of Eagle Scout and intends to pursue a degree in mathematics.

Jake Love – Is the Chief Safety Officer and is responsible for corporate safety. Mr. Love enforces safety during manufacturing and fabrication, as well as product demonstrations. Currently, Mr. Love is in the 11th grade at Lee High School STEM program. He has a keen interest in engineering and robotics with extensive experience over the last seven years, where he has participated in US First FLL and TCEA where he was the team captain. Outside of robotics, he is actively involved in and as a varsity athlete on the Lee High School cross country team. His goal is to attend Cornell University to obtain a degree in chemical engineering.

Jason Love – Is a Technical Engineer and helps complete any task needed. Mr. Love is a freshman at the International School of the Americas LEE and is in the orchestra. He also is on the manufacturing team of the STEM competition robotics team.

Reese Traylor - Is the Chief Electrical Officer and assists with the manufacturing of the electronic system and ensures that everything runs seamlessly. Mr. Traylor is a senior at TMI Episcopal and participates in varsity swimming. In his free time, he plays the piano and enjoys leisure reading. He will be attending UC Santa Cruz and plans to major in astrophysics.