









2014 MATE ROV Competition: Technical Report V1.0

Company: **Project Kraken (Explorer Class)**
School: **Garrett College**
Location: **Mc Henry, MD. USA**

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|  | <p>Kendrick Bender Role: Software. Sophomore</p> <p>Likes all forms of programming. Really wanted to use Python but couldn't.</p> |  | <p>Derrick Maust Role: Pilot / PR. Sophomore</p> <p>Cool under pressure and always networking.</p> |
|  | <p>Aaron Lantz Role: Mechanical. (Frame) Sophomore</p> <p>Came up with the Squid design. Then made it real.</p> |  | <p>Levi Lantz Role: CEO & Mechanical. (Assembly) Freshman</p> <p>Just likes to build stuff and go fast.</p> |
|  | <p>Kevin Haentfling Role: Mechanical. (3D Design) Sophomore</p> <p>A wiz with "inventor" and always busy at the 3D printer.</p> |  | <p>Shawnre Leon Role: Electrical. Freshman</p> <p>Seaperch graduate. Likes soldering, wants to learn software control.</p> |


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|  | <p>Phil Malone Role: Coach / Mentor</p> <p>Loves to inspire kids to be innovators.</p> | <p>Qing Yuan Role: Staff – Funding, Administration</p> <p>Kevin Bass Role: Staff – Support, Travel</p> |
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Abstract

Project Kraken is an elite team of six students from a small community college in the mountains of Western Maryland. Although the team only holds its members for a couple of years, most of them join the company with several years of land-based robot competition experience under their belts. Project Kraken provides them the unique opportunity to apply that experience to underwater robotics.

The unique environment presented by the Thunder Bay Marine Sanctuary presents the team members with a host of new challenges, including: exploring shipwrecks, underwater science and marine conservation.

This year, rather than designing a utilitarian ROV with the sole purpose of satisfying the mission requirements, the team has endeavored to be innovative with a creative and elegant solution suited to a wider set of challenges.

By forgoing a typical boxy design, the team has created an ROV styled after their namesake, the mythical Kraken. Its large head and multiple tentacles form the structure and manipulators of the ROV. A single streamlined neutrally-buoyant tether, and strategically placed thrusters allows the ROV to manoeuver with squid-like grace. Vectored vertical thrusters and a small metacentric height enable dynamic pitch control for more natural-looking vertical transitions.

The eight thrusters use waterproof DC motors, and the custom control logic continually adapts the applied power to the constantly changing downside tether voltage. Custom 3D-printed motor mounts provide safety and utility. Video and data is streamed to the surface via an Ethernet Network, and presented on a graphics screen with integrated video.

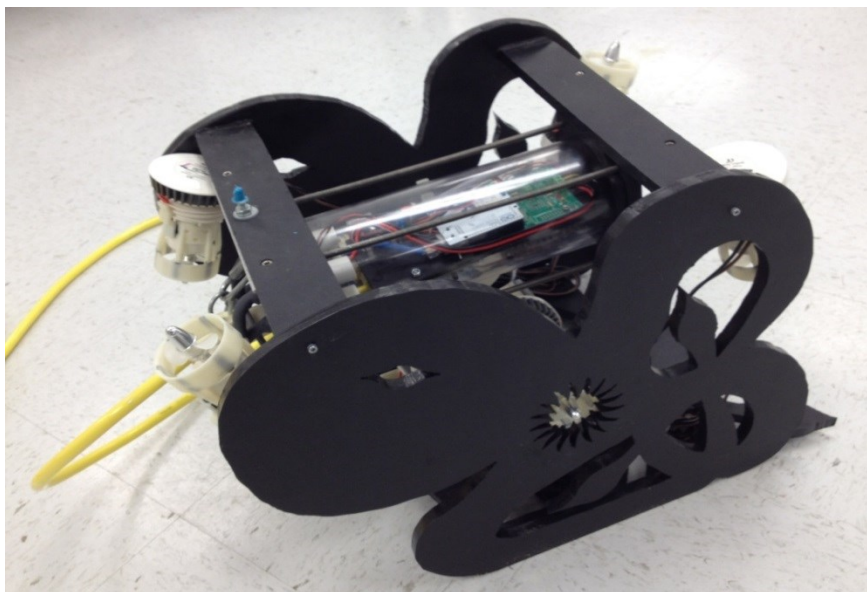


Figure 1: Project Kraken ROV



Design Rationale

This year's ROV was designed from scratch, so the design & build process involved much more than just answering the question: "what tools should we create?" Several key factors had to be decided, including:

- What type of frame structure should we use?
- What form should the tether take?
- How will we protect the electronics from the wet environment?
- What type of motors can we use, and how will they be controlled?
- What type of processor will we use in the ROV to receive telemetry?
- How many, and what type of camera(s) should we use?
- Which missions do we want to pursue?
- What type of mission-specific tools will we need?
- How can we make the ROV as save as possible?

Since each company member had specific skills they brought to the team, the specific design elements were divided among the members.

Frame (an original design)

Aaron and **Levi** worked on the frame design. Having built several PVC frames before, they decided that they wanted a more unique design. After discussing several options, including an aluminum frame, and a torpedo style ROV, it was decided that the frame would be constructed from High Density Polypropylene (HDPE) sheet, and it would be cut in the shape of a Kraken (or Giant Squid) to represent the team. Aaron took responsibility of the actual shape design, and **Levi** started researching different construction methods for HDPE.

Aaron produced a hand sketch, and then traced it into Autodesk Inventor so he could scale it and experiment with different component positions. Once everyone had agreed on the basic design, **Aaron** produced a mockup from plywood. The final ROV can be compared with the original design in figure 2 below.

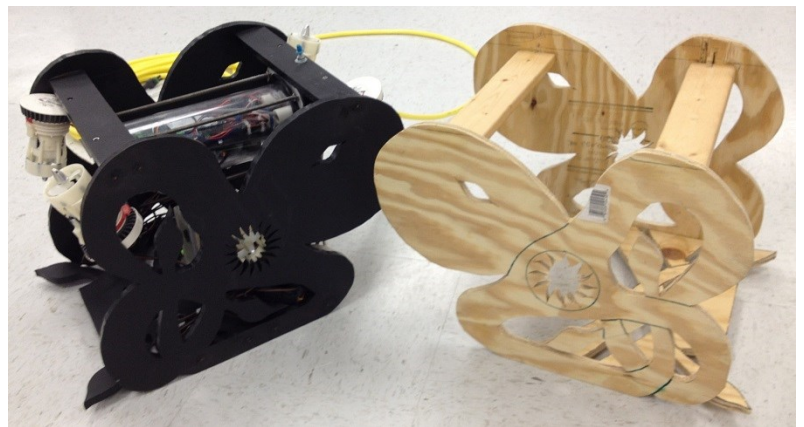


Figure 2: Final ROV shown with the original design mockup.

Tether (an original design)

Since this was the team's first time competing at the Explorer level, they were unfamiliar with using the higher power-supply Voltage (48 V), and the possibilities of using a Neutrally Buoyant (**NB**) tether. The company had previously purchased a length of NB tether from VideoRay, so **Shawnre** researched the possibility of using this single tether on our new ROV for power and data.

Our design criterion was based on a 20 m tether and a maximum power draw of 300 W (six 24 V motors running at 2 A each). We determined that if we used all the heavier gauge conductors in the tether for power, we would only see a 7 V Voltage drop at the ROV. Since it we had decided that a drop of up to 12 V would be acceptable, it was determined that we could use a single NB tether for the ROV (see sidebar calculation.)

VideoRay NB tether specs:

2 Pair 20 AWG (PWR)

1 Pair 24 AWG (PWR)

2 Pair 26 AWG (Ethernet)

Combine 20 & 24 AWG wires for power. Total down & back resistance = 0.54 Ω

300 W @ 24 V = 12.5 A draw.

12.5 A @ 0.54 Ω = 6.8 V drop

This left us with two 26 AWG twisted pairs, which could be used for an Ethernet LAN.

Shawnre spliced the various cables to each end of the tether and potted the terminations. See the details in Figure 3.

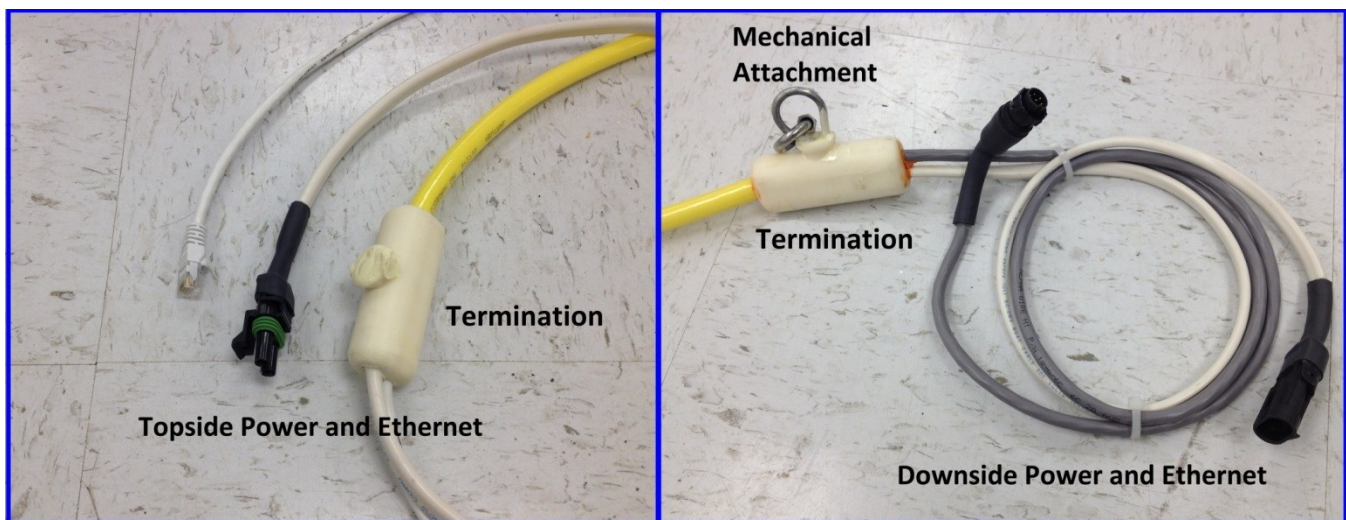


Figure 3: Tether showing topside and downside terminations.

Electronics Housing (an original design)

In past years, the company has used a commercial waterproof box (Otter, Plano etc) to house the electronics. Wire penetrations were drilled into the boxes and back potted to prevent water intrusion. This year, *Levi* and *Kevin* decided to follow a more typical “industry” approach and fabricate a cylindrical electronics vessel with attached end-plates. A survey of the required electronics was performed and it was determined that a 27 cm long, 10 cm diameter, clear polycarbonate tube could easily fit the required components. See Figure 3 for the final results.

Flat end plates were designed to seal the ends of the cylinder, and these are attached using 30 cm long, stainless steel, 4-40 threaded rods and nuts. Butyl rubber gaskets were hand cut to produce a water-tight seal. A single 1.25 cm thick HDPE plate is used at the front of the housing. At the rear-end, an aluminum plate is used to attach the four waterproof connectors. This end-plate is further reinforced by a 1.25 cm HDPE backer plate. See figure 4 for details.

Although the Switchcraft connectors we use are designed for a marine environment, they are not fully pressure tight, so the back side of the bulkhead connector is potted with epoxy resin to prevent any water intrusion. The mating connector is filled with silicon sealer before its boot is attached and then two-part heat-shrink is used to provide a strong mechanical termination.

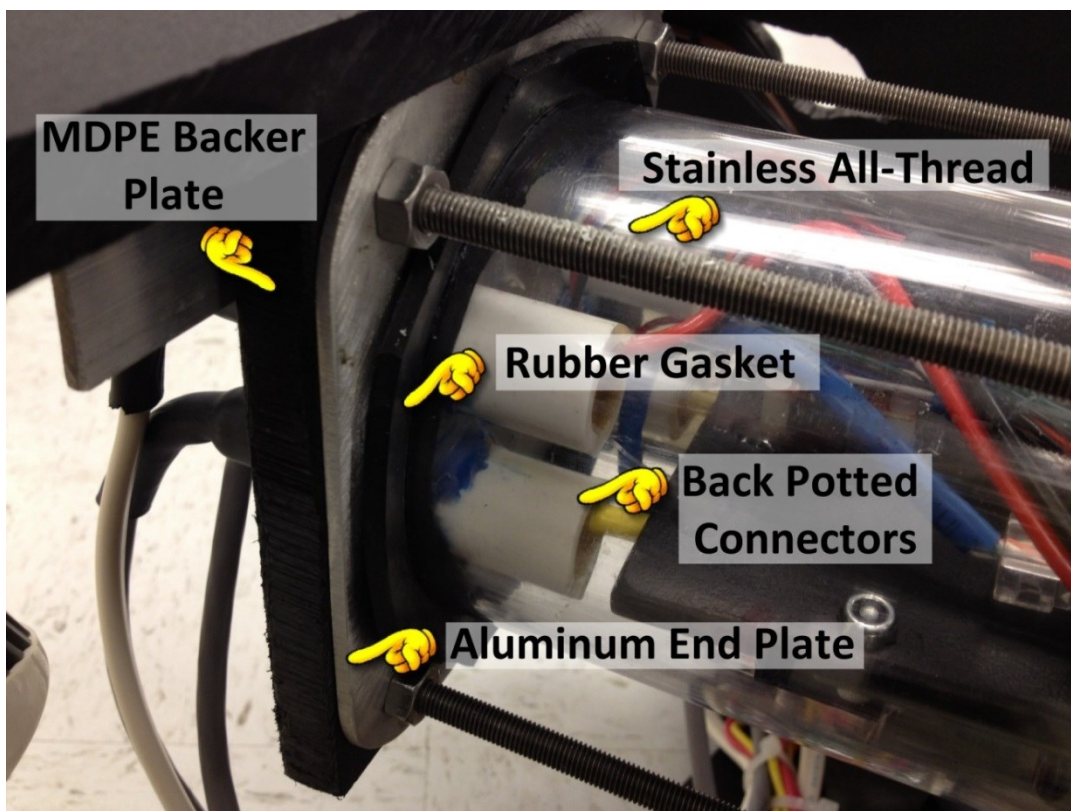


Figure 4: Final construction of Electronics Housing

Thruster Housings (an original design)

The company researched low-cost waterproof motors, and found a small variety of sealed bilge pump motors. One model from Johnson Pumps used a 24 V supply, so these were chosen to minimize the amount of voltage reduction, and drive current, required at the ROV. Since the motor cartridges were designed to fit in a water pump, a new housing and mount was needed.

Kevin created a three-part design that could be economically printed using the college's uPrint rapid prototyping machine from Stratasys Systems Inc. Two of the parts form a housing/shroud assembly, and the third part is a removable mounting flange. The propeller shroud was included as a primary safety feature to prevent any accidental human contact with the props during deployment and recovery.

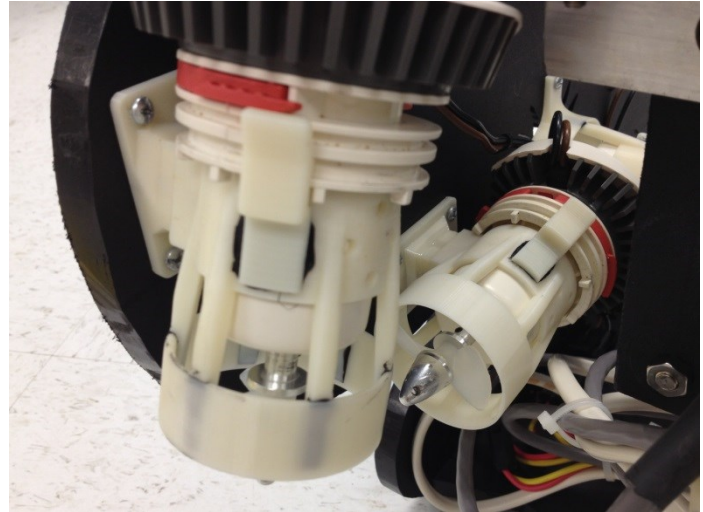


Figure 5: 3D Printed Thruster housings

The final design for the thruster control utilized a PCB designed by the Project Phenix team, so this is considered a loaned part. The motor controller is powered directly from the 48 V Tether supply, but it regulates the motor power using Pulse Width Modulation to reduce the “apparent” voltage to always be less than 24 V. The controller receives its PWM commands from the Arduino processor located in the electronics housing.

ROV Computer Processing (an original design)

Since the decision was made to only pass power and data down the tether, this required us to use a computer in the ROV as well as on the surface. These two computers would communicate with each other using an Ethernet telemetry system. **Kendrick** decided to re-use its existing laptop PC for the surface control and display, and implement a new “brain” for the ROV, using an Arduino Ether microprocessor.

The Arduino Ether combines a standard Arduino Uno with an Ethernet shield on a single board PCB, and it provides a convenient platform to develop code. It is also supported by a community of code libraries. This board is mounted onto a new custom carrier board which provides convenient screw terminals, as well as circuitry to measure the tether voltage and detect internal leaks. See Figure 6.

Kendrick wrote custom software for the Arduino board to communicate with the topside LabVIEW code, the motor controller and compass located in the ROV. This code was written in the Arduino C++ variant.

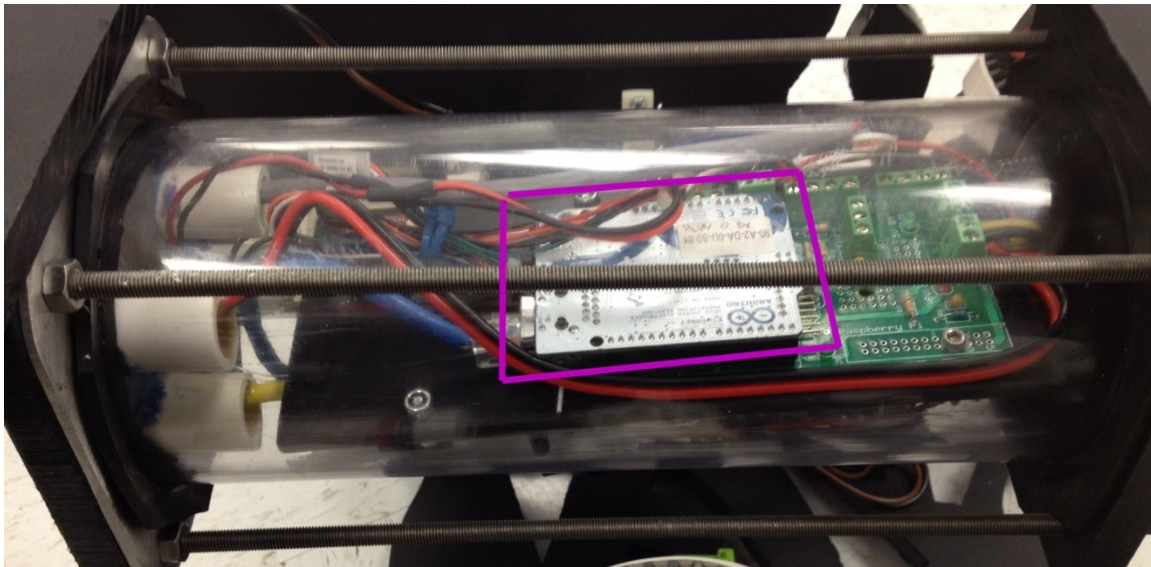


Figure 6: Electronics Enclosure with Arduino Ether highlighted

Camera Housing (an original design)

The refractive index of water causes the viewing angle of any camera to be reduced when used underwater. The company's prior ROV used two IP (Internet Protocol) cameras mounted inside the electronics housing to view in front of, and below, the robot. But the already small field of view (67° FOV) was reduced to the point where even two cameras were insufficient to fly with.

This year the company purchased a high-definition camera with a wider viewing angle (84° FOV), and placed it in its own waterproof housing. **Kevin** designed the housing and created it with the 3D printer. The porous 3D printed material was made watertight by dipping it in acetone. The clear face plate was cut from 6.35 mm polycarbonate and epoxied in place. The final assembly was given a coating of waterproof sealer



Figure 7: Camera in waterproof case

By mounting the camera in a more central location, and making the ROV more agile in pitch, we hope to be able to gain greater visibility without incurring the added complexity of multiple camera housings and cabling.

Mission Selection and Tools.

Given that the company is designing an entire new ROV this year, we were reluctant to take on the task of designing an entire suite of mission tools as well. Consequently the team has decided to focus on selective missions where the ROV's agility can serve the greatest advantage.

Identifying the sunken ship has been made a priority, so a simple manipulator was created capable of opening the cargo crate, lifting the mast to permit entry into the ship, and replacing the sensor string. This compound tool (shown in Figure 8) uses a wedge shaped slot to quickly grab the Sensor string cable, and two uprights at the ends of the tool to turn the lever on the cargo container, and hook the mast rope.

A second tool will be created to grab the plate from the ship.

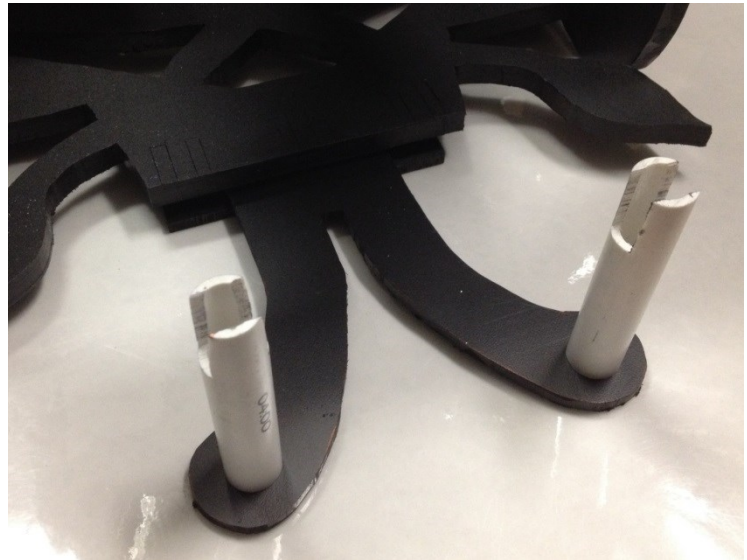


Figure 8: Prototype 3-in-1 manipulator.

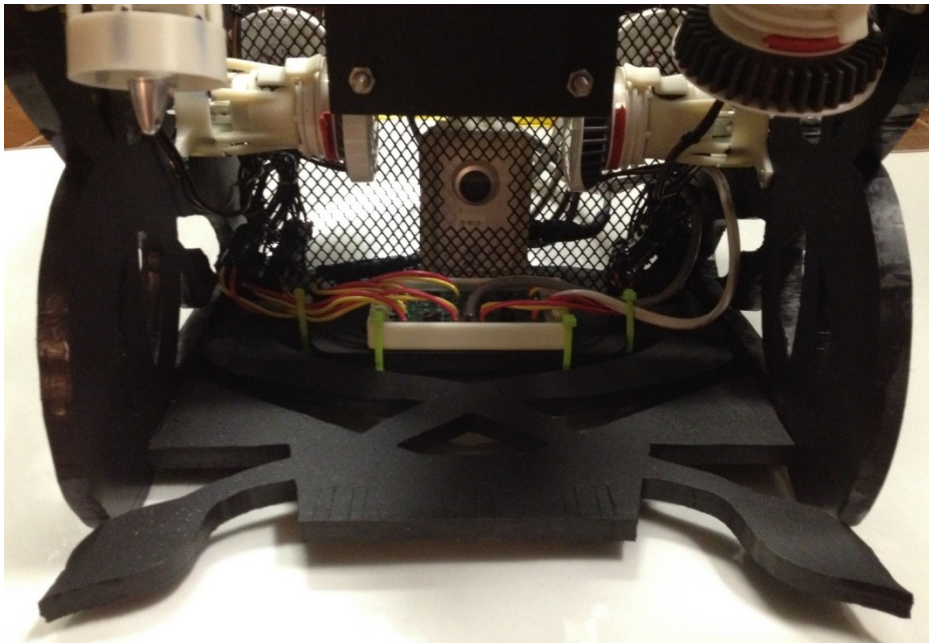


Figure 9: ROV Interior with mesh backing.

For the conservation missions, the ROV will use a scooping action to entrap the debris in an internal basket structure made from lightweight rigid mesh. Figure 9 shows the empty frame cavity with mesh backing.



Safety Features

The Project Kraken team takes human and robot safety VERY seriously and a range of safety features were designed into the ROV system from the outset. These include:

- The ROV's single power feed is protected by a 25 Amp Marine Circuit breaker, AND **Derrick** added a *full bridge rectifier* to eliminate catastrophic failures caused by accidentally reversing the power supply polarity.
- The company has a Safety Checklist that the Pilots and ROV handlers use every time the ROV is deployed and recovered (see Appendix A). Team members have specific task allocations to eliminate any confusion.
- **Kendrick** added a thruster-enable switch on the pilot joystick which keeps all the props motionless after power-up until the pilot pulls the trigger to enable flight mode.
- **Kendrick** also added an automatic thruster-shutdown in the event that telemetry goes down. If the ROV stops receiving commands from the surface, all the thrusters are shut down within a second.
- A leak detector is mounted at the lowest point inside the Electronics Housing. At the first signs of any moisture, the pilot is alerted on-screen so they can shut down power and recover the vehicle.
- **Shawnre** created a hard-mount termination block for the ROV end of the tether. This provides a solid mounting point, and prevents any possibility of the tether separating from the ROV.
- All thrusters are mounted within the protection of the frame, and **Kevin** designed an integrated propeller shroud.

System Integration Diagram (SID)

The final System Integration Diagram (SID) is shown in Figure 10 below. It illustrates the simple tether structure and the location of the 25 A Primary circuit breaker. *Note: No fluid power is used in the ROV.*

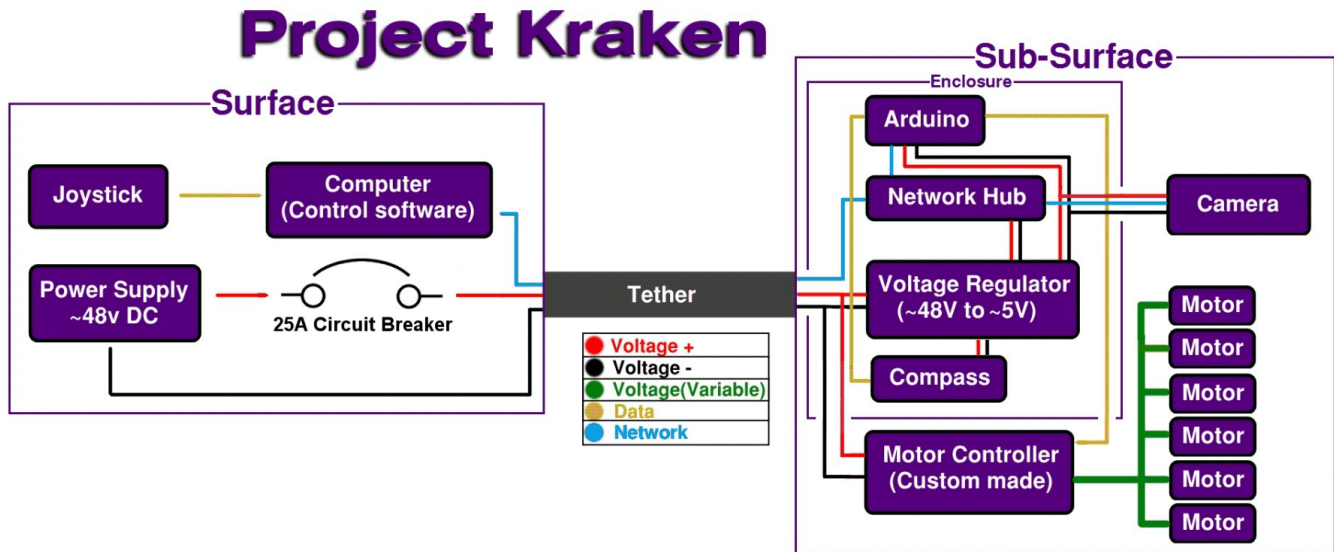


Figure 10: System Integration Diagram

Power Distribution Diagram (PDD)

The ROV's Power Distribution is shown in figure 11. Although similar to the SID, this diagram highlights a key electrical feature, not evident from the SID. The main 48 V power feed from the surface enters the Motor Controller first, and then passes into the electronics housing. This path is chosen to provide the minimum number of connections between the power source and the heaviest power load (the thrusters).

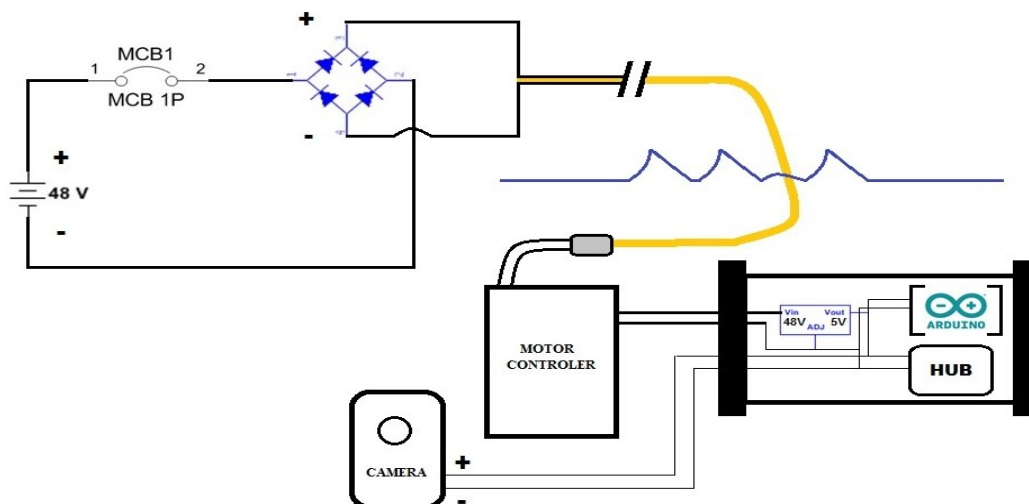


Figure 11: Power Distribution Diagram



System Software Overview

The Project Kraken ROV has three main software subsystems; two on the surface to create the Graphical User Interface (GUI) perform data processing, and one subsurface to control the ROV system hardware. See figure 12 for details

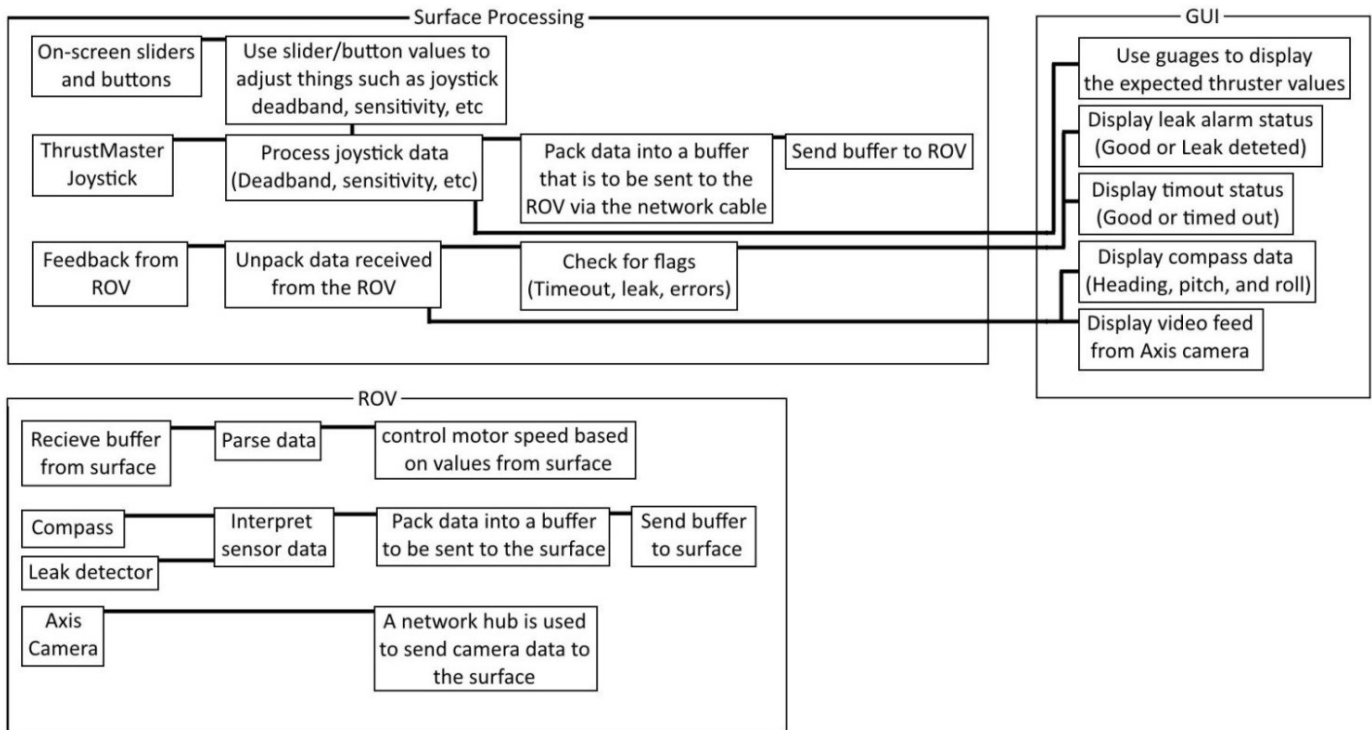


Figure 12: Software functional diagram and data flows.

Surface Processing and GUI (an original design)

The surface GUI is created using the LabVIEW programming environment. The company has experience using LabVIEW for other remotely operated robots. LabVIEW enables us to combine graphical instrumentation and live camera feeds on a single display. LabVIEW also enables us to capture video frames and save them on the surface computer's hard-drive. Figure 13 shows a sample of the topside GUI display. The small video window (right) is a frame-grab, captured from the main video stream (left). Also on the right are dials showing the thruster power values that are being sent to the ROV, and feedback showing the downside tether voltage

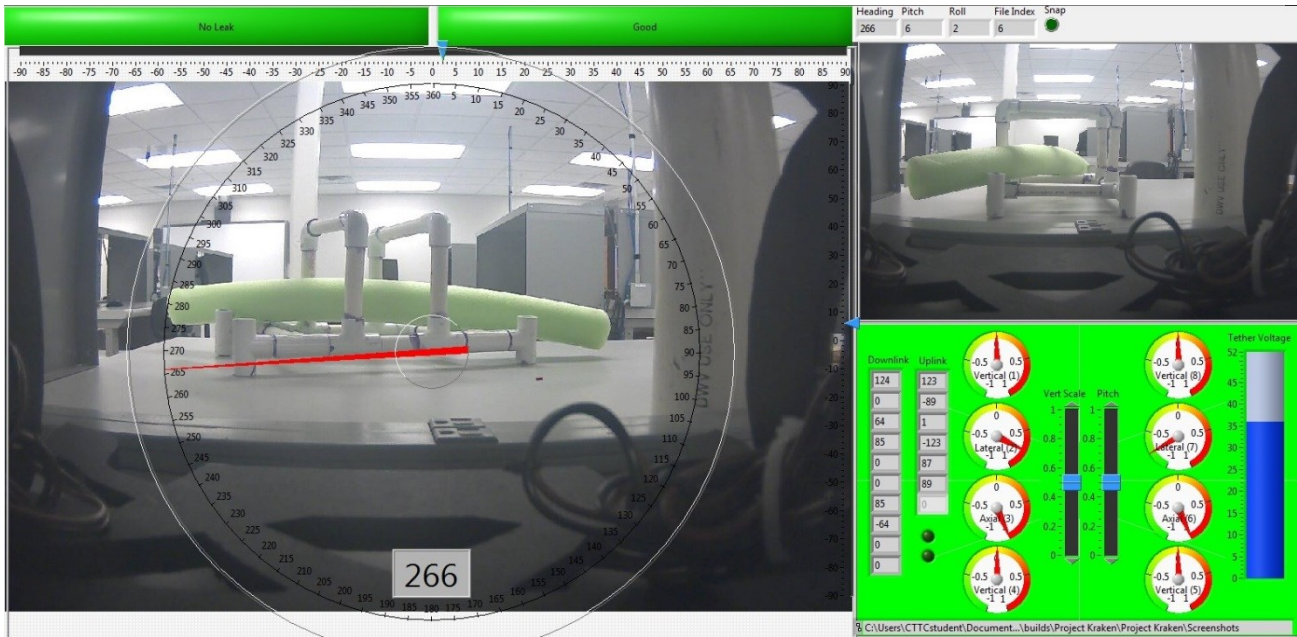


Figure 13: Project Kraken's Graphical User Interface.

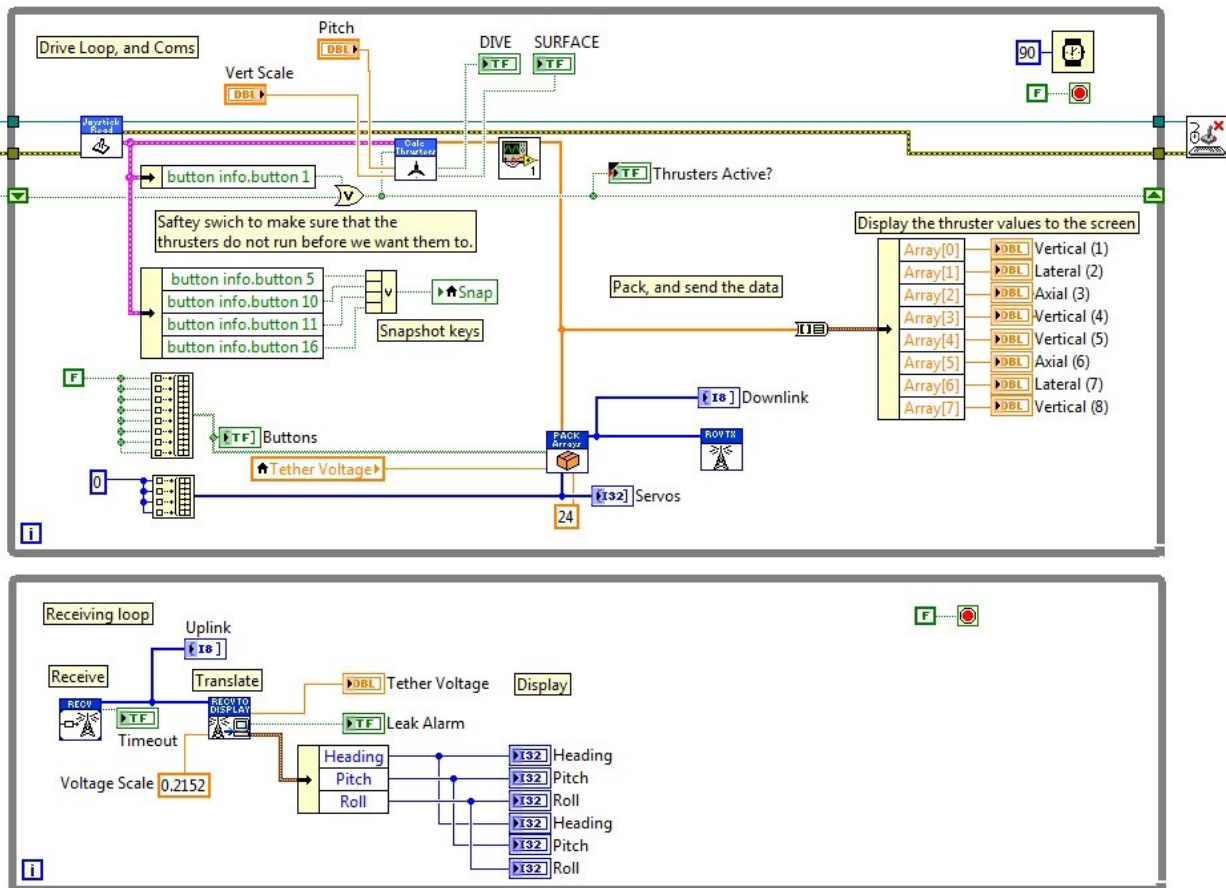


Figure 14: Sample LabVIEW program that performs the "Surface Processing" function.



Figure 14 shows a sample of the topside LabVIEW software. The code shown here performs the “Surface Processing” function from Figure 12. Two loops run in parallel, one to generate the downlink, and one to process the uplink. The data being sent and received is also displayed here.

Input is gathered from the Thrustmaster™ joystick, and the on-screen sliders and buttons. The input from the Thrustmaster™ joystick is processed into a double precision number for each axis that ranges from -1 to 1. We also apply a deadband, and adjust the sensitivity of the joystick based on sliders that are on-screen. This makes the ROV much easier to fly for the pilots. The joystick data is then packed into a buffer and sent to the ROV over a UDP based connection. These values are also displayed on the screen to allow the pilot to see what the expected thuster speeds are.

Feedback is also received from the ROV. We un-pack and interpret this data and then check for any flags. We then display the value of these flags on the screen. This allows us to debug problems with the ROV. In the data that is received there is also compass, pitch & roll values, which we display as guages and sliders on the screen so that our pilot knows which direction he is facing.

Finally, video feed is received from the Axis™ IP cameras through the network hub. We are able to display both the video feed and a “snapshot” or “still image” of the video feed on the screen. With the click of a button the pilot or co-pilot are able to take a snapshot of the video feed and display it on the screen. The pilot is then able to continue flying the ROV while the co-pilot can observe the snapshot.

ROV Software (an original design)

The ROV control software is written in C++ and run on an Arduino™ Ether microprocessor. A standard library is used to receive and send UDP packets. Packets arrive at 10 times a second, and replies are generated 4 times per second. The downlink runs faster than the uplink because a fast downlink is required for a responsive robot, whereas uplink data only needs to be sent at a reasonable display rate.

Much of our sensor processing is done on the ROV using the Arduino™ processor. The Arduino™ takes in raw serial data from our compass sensor and then “translates” it into usable data. We are able to read heading, pitch, roll, and temperature from the OS-5000t compass. We also gather information about the status of the leak detector. We then pack the compass data, and the leak detector data into a buffer and send the buffer to the surface using a UDP based connection. The Arduino™ also parses and the send thruster data to our custom-built motor controller. The motor controller then takes the data from the Arduino™ and controls the amount of power that goes to each thruster based on the data that it gets.

System and Sub-System testing

Wherever possible, ROV subsystems were tested individually before being integrated onto the ROV. Once integration was complete, the overall ROV was tested in a controlled environment (Large tub) before being tested in the Garrett College pool.

One example of subsystem testing was the new electronics enclosure. Several prototypes were build, and then taken to the College pool to be leak tested. The first two design concepts relied on a threaded end cap, and these failed the leak test. Then a clamp-on end cap was created which used a butyl rubber gasket. This design has passed all leak tests. A protocol has been created to ensure equal tightening of the bolts, and a positive seal.

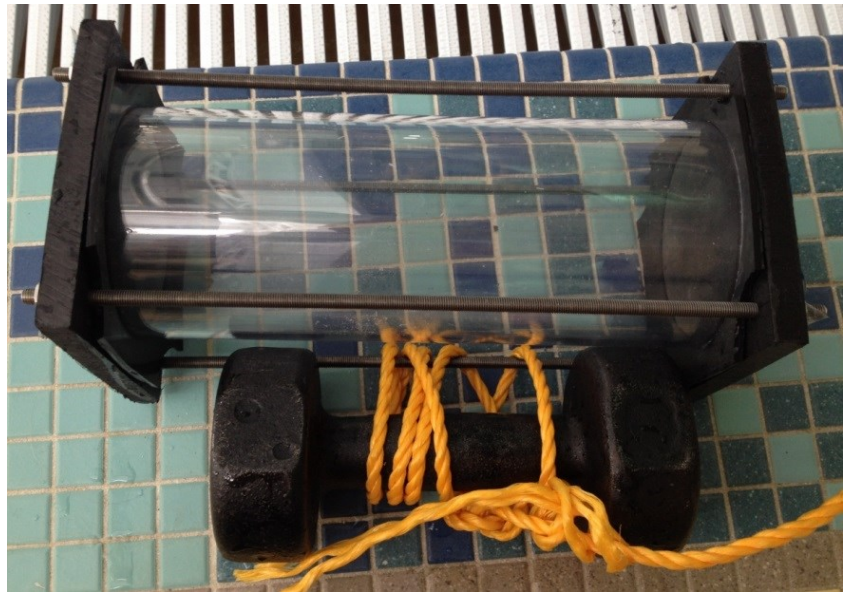


Figure 15: Subsystem testing: Electronics Enclosure.

Figure 15 shows the simple test that was used to verify that the enclosure did not leak. A weight was attached to the enclosure and it was lowered to the deepest end of the pool. It was held there for 10 minutes, recovered and then checked for internal water.

Resolving Challenges

When we encounter an unexpected problem, our company uses the following troubleshooting techniques:

- (1) Identify the problem,
- (2) Hypothesize the cause,
- (3) Test the hypothesis,
- (4) Propose a solution,
- (5) Implement solution,
- (6) Verify that the problem is resolved.

One significant challenge that required this technique to solve was exhibited during the System Demonstration at the PA Regional competition. During the demonstration, the thrusters locked up and would not stop running until power was removed from the ROV. This issue had not occurred before (despite significant in-pool testing at home), but it happened twice during the demonstration.



On returning to MD, we attempted to recreate the issue. **Derrick** (the pilot) commented that both times it had happened; he was doing a hard dive and also maneuvering aggressively. The flight team recreated these conditions in the test tank, and was able to cause the problem to re-occur on demand. The symptom that we discovered was that when the error occurred, the telemetry link between the ROV and surface timed out at the surface, but the Arduino did not seem to be able to recover.

The LAN was still functioning correctly as the live video was still being transmitted.

Levi proposed that the high thruster load was causing an excess voltage drop on the tether, and this was causing the ROV computer system to reset. To test this theory, we removed one of the four 12 V batteries from our battery pack and re-tried the experiment. We monitored the downside voltage, and even though it was now 12 Volts lower, we could not get the error to occur. So this disproved Levi's hypothesis: it was NOT a voltage drop problem.

Since we now knew that the error only occurred with a fully charged battery pack, it was proposed that high current spikes resulting from a very high tether voltage were causing problems with the communications between the Motor Controller and the Arduino. Plus, whatever the problem was, once it occurred, the processor could not recover.

The next suggestion was that there could be an issue with the Arduino Software Library performing the I2C communications between the Arduino and Motor controller, and that when a glitch occurred; the software was left in a loop, waiting for an event that did not happen.

To test the hypothesis, a review of the software was performed and it was discovered that there were no timeout failsafe's in place to prevent such a lock-up from occurring.

The proposed solution was for **Kendrick** to update the software library to include a variable timeout on all communication loops, and to re-initialize the communications whenever a timeout occurred.

The changes were made, and Code was also added to the main program to flash an LED whenever a timeout occurred. In this way we could verify if our hypothesis was correct.

The ROV was returned to the tank and it was quickly verified that the timeout was occurring, and after several adjustments to the code the program was able to successfully detect and correct the error condition.

To further reduce the likelihood of the error occurring, power limits were put in place for the propulsion system. Under normal operations it's not possible to fully drive all of the thrusters simultaneously. However an override button was put in place for emergency situations.

Computer Aided Design

The use of CAD to design mechanical components is a standard practice within Project Kraken. The team has access to two 3D Printers, and the majority of team members are able to create designs using Autodesk Inventor. Even if the final part is not appropriate for 3D printing, we will experiment with prototype concepts using the printer.

The team's custom designed Camera Housing was shown in Figure 7. This is one of many items that were designed using CAD, and fabricated on a 3D printer. Figures 16 (right) and 17 (below), show the CAD drawing and rendering of the final version of this housing.



Figure 16: 3D Part Rendering

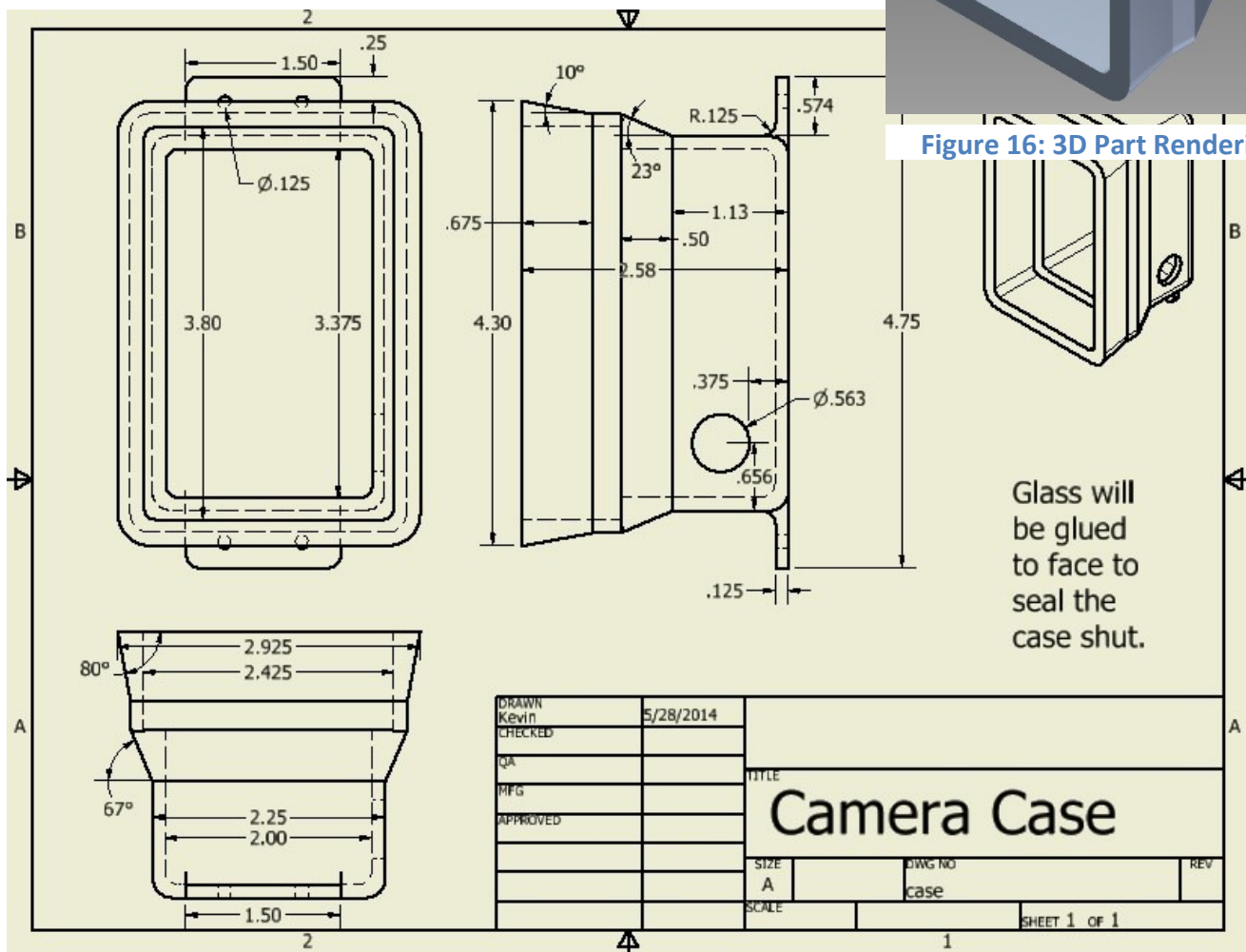


Figure 17: Mechanical drawing for Camera Housing.



Future Improvements

Improved Compass Location

Although the company included a tilt compensated compass on this year's ROV, it did not prove particularly useful as the readings were grossly affected by the magnetics of the ROV. In hindsight, its location next to the main power feed was a poor choice since the fields generated by the conductors seem to be more significant than the earth's field.

In the future we should consider placing it at the connector less end of the enclosure, or in a completely separate housing.

Depth Gauge

One component that we didn't include in this year's robot design was a pressure gauge since it was not necessary for this year's challenge or for navigating in a swimming pool. But for future challenges or for navigating in local lakes and ponds a pressure gauge would be just as helpful as a compass. Unlike our compass that is fully contained in the Electronics Enclosure, a pressure sensor needs to be exposed to the pressure of the water. The dilemma that we then run into is how to expose the sensor to the water pressure but still keep the sensor waterproof. We will design a sensor to be waterproof so we can feed the output to the Comms Board. This will give us a more accurate and faster depth/pressure reading.

A cool advantage of having a depth sensor is that the software could perform a "hover" control algorithm.

Lessons Learned

Derrick: To pay attention to everything around the piece you are heat-treating. How you use a bridge rectifier for safety. That everything should be processed on the ROV and not the surface, so that we can use a much smaller tether and there is much less equipment that needs to be brought poolside

Aaron: This year I took on the task of designing the frame for the ROV. We decided early on that we wanted it to look as good as it worked. I made a prototype out of plywood from sketches, and then I drew up the design in Autodesk Inventor. The next step was to use the drawings to cut the pieces out of .5" HDPE and then finally to attach them together. I learned how to use Autodesk Inventor to generate the drawings for the frame and how to work with the HDPE, as we had never constructed a frame out of it before. The skills I learned from this will come in handy in the future. Also seeing this project through from the concept to the final finished product taught me a great deal.

Kendrick: I have been able to extend my knowledge of c based programming as well as code-based programming in general. I have learned much about using networks to transmit and receive data. These newly acquired skills are certain to assist me in my pursuit of a career in computer science.



Levi: While helping with making the frame of the robot out of HDP I learned a lot about how different materials have different properties. I learned this by using the plastic welder, epoxy, and the torch to try to bond the HDP together to form the frame. By conducting numerous tests we decided the HDPE bonds the best when it is heated, melted, and then bonded. I know this will give me some knowledge in the future when I go through my mechanical engineering courses.

Kevin: I learned you can use acetone to waterproof a 3D printed item.

Reflections

Aaron: Since I was in charge of constructing a frame for the ROV I learned a great deal about management. I had to come up with an idea and construct a prototype, and then I had to get our coaches approval along with the rest of the teams before we could start on the actual frame. I had to manage my time along with the frame construction project to be able to complete it in time with the tools and materials I had to work with. This hands-on experience comes to use every day when managing my time to complete different projects in my personal life and for work.

Kendrick: It has been a wonderful experience to be able to “re-connect” with a team of which I was a part of in the past. The abilities that many of the team members possess are astounding.

Levi: This college MATE team brought new skills to my plate and helped advance existing skills. I have learned how to be able to have somebody depend on me, and that I will need to get that part done in a certain time constraint. I have advanced my communication skills and I have enjoyed advancing all of my life skills through all the opportunities I have had through this MATE team.

Kevin: In the future I hope to build robotics that operates outdoors in all weather. Mate has helped with this by teaching me ways to waterproof electronics, cable, and connections.



Acknowledgements

We would like to acknowledge the efforts of several people/groups:

- The MATE Center and personnel for making this competition possible.
- Our Mentor Mr. Phil, for starting this team and guiding us through the process. Instead of settling for a simple ROV that would just perform the mission, he pushed us to create a more capable ROV that we can use to explore real lakes and ponds.
- Garrett College for sponsoring the team, and providing us with a space to construct our ROV, and access to an excellent pool for practicing our missions.
- Our College liaison Ms. Qing for coordinating with the College and ensuring that resources were made available for the team.
- Our Mentor Ms. Arlene for coordinating travel, ensuring that we all attended our meetings, and encouraging us to be the best that we can be.
- Garrett Engineering and Robotics Society, for being the secondary support organization for the team, and providing resources in the way of tools, materials, and an excellent test tank.

References

- Underwater Robotics: Science, Design & Fabrication
Authors: Moore, Bohm & Jenson



Appendix A: Safety Checklist.

Project Kraken Checklist

- 1. Ensure that the breaker is in the off position**
2. Ensure that all cables on the battery are connected securely
3. Connect tether to ROV
4. Connect breaker to the battery and tether
5. Switch the breaker to the on position
- 6. Check for light on the main control board and motor controller**
7. Connect Ethernet cable and joystick to the computer
8. Wait for camera light to change to green, then run the program on the computer.
9. Enable thrusters, and check that all are operational
 - a. Vertical
 - b. Axial
 - c. Lateral
10. Place robot in pool
- 11. Signal the judge that team is ready to begin.**
12. Get R' done!



Appendix B: Budget sheet and ROV cost.

The following spreadsheet details the costs of the three main ROV system components: Tether, ROV and Topside control. The topside control hardware has been reused from last year (since it represents a major purchase), but the software has been re-written from scratch. A completely new Tether and ROV have been created. The only component in these that have been reused is the 25A Circuit Breaker.

| Tether | Source | Cost | Quantity | Extended |
|--|----------|-----------|----------|--------------------|
| 25A Bussman Marine Circuit Breaker | Reused | \$ 35.00 | 1 | \$ 35.00 |
| VideoRay Neutrally Bouyant cable (per ft) | Purchase | \$ 1.00 | 60 | \$ 60.00 |
| Waterproof Cable Connectors Male/Female Pairs | Purchase | \$ 4.00 | 2 | \$ 8.00 |
| Switchcrafte waterproof bulkhead connector Pairs | Purchase | \$ 14.00 | 5 | \$ 70.00 |
| #12 tinned coppwr wire twin conductor (per ft) | Purchase | \$ 1.00 | 60 | \$ 60.00 |
| Termination molds (3D Printed) | Donated | \$ 10.00 | 2 | \$ 20.00 |
| Potting material | Purchase | \$ 6.00 | 2 | \$ 12.00 |
| Metal rigging hardware | Purchase | \$ 5.00 | 1 | \$ 5.00 |
| | | | | \$ 270.00 |
| | | | | |
| ROV | Source | Cost | Quantity | Extended |
| Polycarbonate Tube | Donated | \$ 25.00 | 1 | \$ 25.00 |
| HDPE Sheet (60x60x1.25cm) | Donated | \$ 45.00 | 2 | \$ 90.00 |
| Stainless Steel Threaded Rod (30 cm) with hardware | Purchase | \$ 11.00 | 4 | \$ 44.00 |
| Butyle Rubber sheet (30 x 30 cm) | Purchase | \$ 10.00 | 1 | \$ 10.00 |
| Johnson bilge pump motors (24 V) | Purchase | \$ 12.00 | 8 | \$ 96.00 |
| Waterproof Cable Connectors Male/Female Pairs | Purchase | \$ 4.00 | 10 | \$ 40.00 |
| Axis IP Camera 1054 | Purchase | \$ 250.00 | 1 | \$ 250.00 |
| DC-DC converter (48-5V) | Purchase | \$ 15.00 | 1 | \$ 15.00 |
| Arduino Ether CPU | Purchase | \$ 65.00 | 1 | \$ 65.00 |
| Ethernet Hub (5 port) | Purchase | \$ 15.00 | 1 | \$ 15.00 |
| Custom motherboard for Arduino (design build) | Purchase | \$ 60.00 | 1 | \$ 60.00 |
| Octobox Motor Controller | Borrowed | \$ 150.00 | 1 | \$ 150.00 |
| Thruster Housings (3D Printed) | Donated | \$ 10.00 | 8 | \$ 80.00 |
| Camera Housing (3D Printed) | Donated | \$ 16.00 | 1 | \$ 16.00 |
| | | | | \$ 956.00 |
| | | | | |
| Topside | Source | Cost | Quantity | Extended |
| Laptop Computer | Reused | \$ 900.00 | 1 | \$ 900.00 |
| Thrustmaster Joystick | Reused | \$ 35.00 | 1 | \$ 35.00 |
| Option Network hub/router | Reused | \$ 100.00 | 1 | \$ 100.00 |
| | | | | \$ 1,035.00 |

Figure 18: ROV Cost Sheet



The overall budget for the 2014 Competition was as follows:

| MATE Budget 2014. | |
|--------------------------------------|--------------------|
| Income | |
| Garrett College Equipment Support | \$ 1,000.00 |
| Garrett College Travel Support | \$ 2,000.00 |
| GEARS Inc Donations. | \$ 500.00 |
| | \$ 3,500.00 |
| Expenses | |
| Robot Parts | \$ 1,400.00 |
| Travel for Regional Demonstration | \$ 200.00 |
| Travel for International Competition | \$ 500.00 |
| Hotels for International Competiton | \$ 1,300.00 |
| | \$ 3,400.00 |

Appendix C: Water Proof Connectors

A critical part of designing a modern ROV is deciding how to handle electrical connections underwater. A commercial ROV will deal with this problem by utilizing very expensive purpose-built connectors that cost anything from \$40 to \$140 each. This is just not practical for a youth built ROV where several such connectors are required for motors and accessories.

Project Kraken has solved this problem by utilizing two different water-resistant connectors, which can then be augmented to produce a water-proof connection.

The first connector is used for attaching the Thrusters to the Motor Controller. This is a commercially available connector used in the extreme motor sports arena. Although not suitable to act as a water pressure block, the connector is great for in-line connections. It uses three rubber seals for each conductor. This prevents current from passing between the connectors at a moderate voltage. A picture of the waterproofing elements is shown below in figure 19. Note the grey rubber seals that fit over the wires, and which seal the entry point into each side of the connector. Also note the green rubber bellow that gets compressed into the mated connector to seal water out of the inner section. The final layer of 2-part heat shrink is mainly used as a strain relief, although it does act to seal the outer sheath of the white cable from water intrusion.

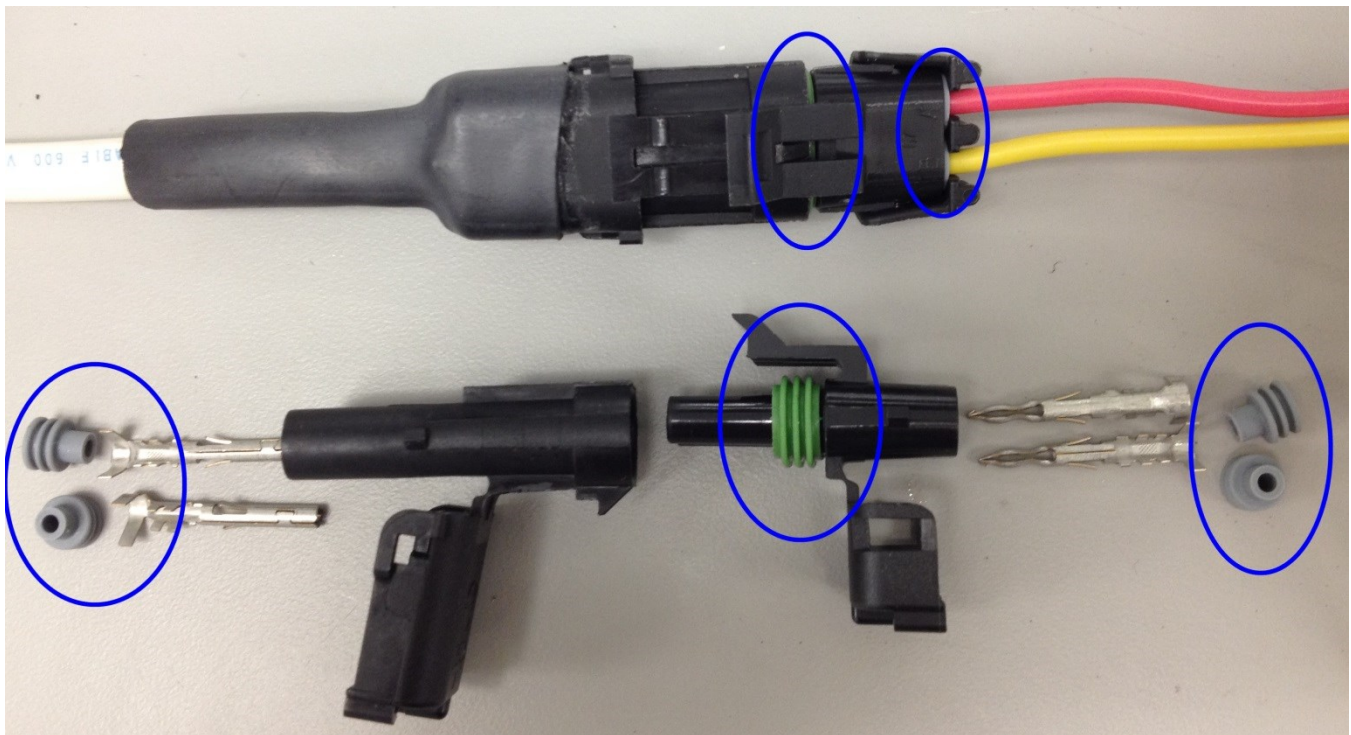


Figure 19: In-line connector waterproofing.

The other connector used on the Kraken ROV is one produced by Switchcraft. It is a water tight connector which conforms to Coast Guard code CFR 46. We use it when we need to pass wires into a water-proof housing. Although this connector is watertight at atmospheric pressure, it cannot resist pressure due to water depth, so for this reason, we mount the bulkhead connector on the outside of the pressure barrier, and then pot the inside of the connector (dry side) with epoxy resin. This structure is shown in figures 4 and 6.

As a final precaution, we fill the “wet” side of the plug housing with silicone caulk before fitting the rear “boot”, and then we apply a final layer of 2-part heat-shrink. A completed connector of this type is shown in figure 20.



Figure 20: Switchcraft connect with cable attached.

A sample from the connector datasheet is shown below in Figure 21.

| SWITCHCRAFT CABLE CONNECTOR ASSEMBLY INSTRUCTIONS | | SPECIFICATIONS | |
|---|--|---|--|
| <p>STEP 1 FEED THE END OF THE CABLE THROUGH THE BOOT AND CABLE CLAMP HOUSING IN THE ORDER AND POSITION SHOWN.</p> | | <p>MECHANICAL: SHOCK: MIL-STD 202 METHOD 213B, COND. K. VIBRATION: MIL-STD 202 METHOD 201 LIFE: 300 INSERTION/WITHDRAWAL CYCLES (MINIMUM)</p> | |
| <p>STEP 2 STRIP CABLE AS SHOWN AND BEGIN SOLDERING CONDUCTORS TO PINS. STARTING WITH CONTACT NO. 1 NEXT TO THE "NOTCH" AND FOLLOW WITH THE REMAINING CONDUCTORS CLOCKWISE WITH NO. 6 OR NO. 8 CONDUCTOR IN THE CENTER.</p> | | <p>ELECTRICAL: DIELECTRIC WITHSTANDING VOLTAGE: 1,000 VAC INSULATION RESISTANCE: 100 MEGOHMS (MIN) AT 77°F CONTACT RESISTANCE: 5.0 MILLIOHMS MAX. CURRENT RATING: 7.5 AMPS (#20 CONTACT) 6.5 AMPS (7 & 8 PIN #20 CONTACT) 13.0 AMPS (#16 CONTACT)</p> | |
| <p>STEP 3 PUSH THE CABLE CLAMP HOUSING FORWARD UNTIL IT LOCKS INTO THE CONNECTOR BODY AND SNAP THE TWO CLAMPS INTO IT'S COMPARTMENTS.</p> | | <p>ENVIRONMENTAL: TEMPERATURE LIMITS: -40°C TO +65°C (NON-OPERATING) MOISTURE RESISTANCE: MIL-STD 202 METHOD 106F INSULATION RESISTANCE: MIL-STD 202 METHOD 302, COND. B THERMAL SHOCK: MIL-STD 202 METHOD 107G SALT SPRAY: MIL-STD 202 METHOD 101D, COND. B WATER TIGHTNESS TEST: U.S. COAST GUARD CFR 46 PART 110.20</p> | |
| <p>STEP 4 PUSH THE BOOT ALL THE WAY FORWARD TO SEAT TIGHTLY ONTO THE CABLE CLAMP HOUSING.</p> | | | |

Figure 21: Switchcraft spec sheet showing environmental data.