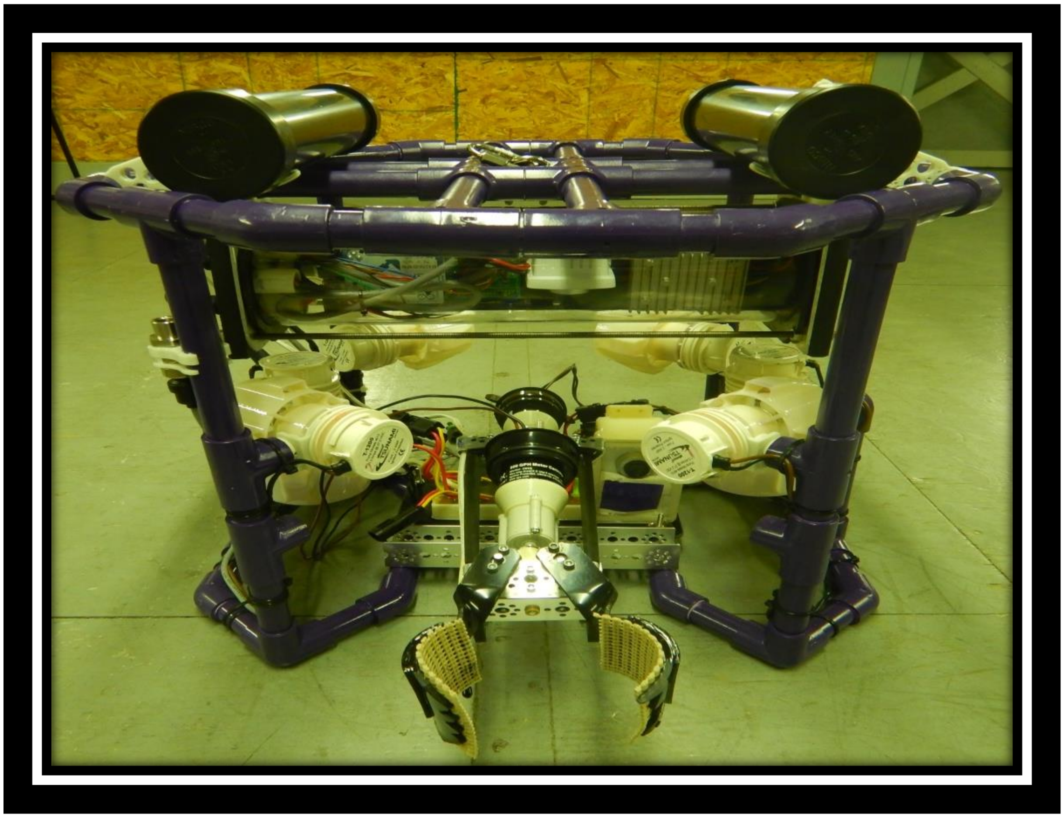
# Project Kraken



## TECHNICAL REPORT 2016

**Garrett College**
**McHenry, MD**

**Team Members:**
Kevin Maust (CEO/CAD Designer) **Safety and Inspections**
Herschel Allen (Chief Mechanical Engineer) **MIA**
Jonathan Oester (Mechanical Engineer/Research) **Co-Pilot**
Scott Brenneman (Electrical Engineer) **Tetherman**
Timothy Gostch (Software/Programming) **Pilot**
Dallas Brenneman (Technical Writer) **Tetherman**

**Mentors:**
Phil Malone (Team Coach)
Kendrick Bender (Software/Programming Mentor)

**Administrator:**
Qing Yuan (Funding)

## Table of Contents

# Abstract

Project Kraken is a company of six students from a small community college in western Maryland, dedicated to producing a Remotely Operated Vehicle (ROV) to fulfill the needs of our potential client, MATE International. MATE's requests for exploration, documentation, and restoration of aquatic environments will be granted with the help of our 2016 ROV, "The Kraken."

The Kraken was designed to be compact and light-weight, making it easy to handle. It is relatively inexpensive and has excellent maneuvering and grappling abilities. The framework of the Kraken is comprised of ½ inch PVC pipe assembled in an octagonal design. The PVC frame adds buoyancy, while reducing the overall weight of the ROV. Six, shrouded, 24 V thrusters provide smooth, responsive maneuverability in any direction. A grasping manipulator arm was integrated by using a waterproof DC motor with a gear reduction assembly to drive the arm and gripper. Pressure and temperature sensors were integrated into the ROV design to obtain various water temperatures and depth readings. The sub-surface electronics and one Ethernet camera are housed in a clear 4" polycarbonate cylinder; the cylinder is sealed with rubber gaskets and aluminum flat plates at each end. The control system utilizes the C++ programming language for the sub-surface electronics and C# for the surface control panel. A joy stick controls the directional movements of the ROV and the grasping manipulator arm. All data and video is streamed to the surface via an Ethernet Network, which is presented on a laptop computer graphics screen.

Figure 1: Project Kraken Team

## System Interconnection Diagram (SID)

The SID diagram in figure 10 illustrates the basic electrical system, from surface to sub-surface, for Project Kraken.

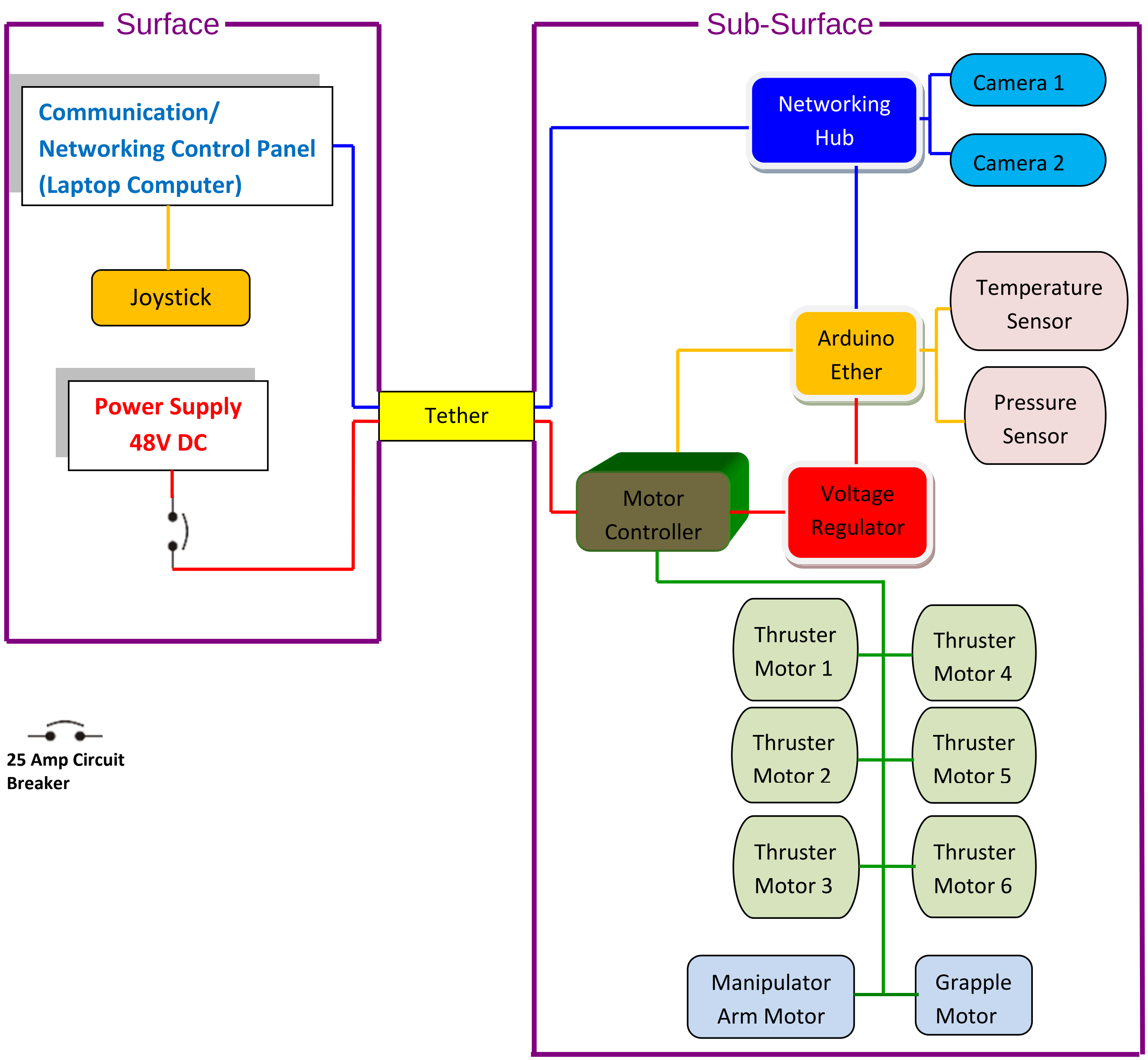



Figure 2: SID Diagram

# Kraken Safety

The Project Kraken team realizes that safety is the key to making any project a success, so safety protocols were practiced from the beginning. Also, safety features were integrated into the design of the ROV for peace of mind while in operation. Thinking ahead to the competition, the team also created a pool-side safety checklist.

**Construction Safety Practices**:

- Using ANSI approved safety glasses when grinding, cutting, drilling, sanding, or hammering
- Using power tools with guards
- Ensuring proper ventilation when using chemicals
- Using proper house cleaning to keep areas free of clutter
- Knowing the locations of fire extinguishers and first-aid kits
- Using clamps and vises to hold down objects being cut or drilled
- NEVER WORK ALONE and ALWAYS THINK AHEAD!

**Design Safety Features:**

- Thrusters are mounted within the protection of the frame to keep them from colliding with outside objects.
- Custom built shrouds are installed on each thruster to keep objects, MAINLY FINGERS, away from propellers.
- Electronics and wiring are waterproofed to ensure failsafe subsurface operations.
- A leak detector is installed within the electronics housing to immediately alert the pilot of any water intrusion.
- A hard-mount termination block is used to connect the tether to the ROV, which prevents any possibility of the tether separating from the ROV during subsurface operations.
- A thruster-enable switch is used to keep the thrusters motionless until the team is ready for operation.
- On the surface, a 25 Amp marine circuit breaker is used to protect the ROV's single power feed. A full bridge rectifier is used to eliminate electrical failures caused by accidentally reversing the power supply polarity.

**Pool-side safety checklist:**

1. Ensure that the breaker is in the off position
2. Ensure that all cables on the battery are connected securely
3. Connect the tether to the ROV
4. Connect the breaker to the battery and tether
5. Switch the breaker to the on position
6. Check for lights on the main control interface and motor controller
7. Connect the Ethernet cable and joystick to the computer
8. Wait for the camera light to turn green, then run the program on the computer
9. Enable thrusters, and check that all are operational (Vertical, Axial, and Lateral)
10. Place ROV in the pool
11. Signal the judge that the team is ready to begin

# Design Rationale

## Introduction

Team Kraken came together in the fall of 2015 with an enthusiasm for designing and building an ROV capable of underwater exploration. Three of the team members have had prior experience with robotics; the other three members are just beginning their journey into the exciting robotics engineering industry. The team's sole purpose of this project is to learn about ROV engineering and improve on their technological skills to better serve future clients. The 2016 MATE International competition provides a host of challenges for our newly formed team to overcome. MATE International challenges teams to design and build light-weight ROVs that can be transported easily at little cost, be capable of withstanding extreme underwater environments, and have the ability to perform multiple subsurface tasks. These tasks include pressure and temperature measurements, video surveillance on mission critical equipment, photography of coral colonies, sea floor oil sample collections, and precise manipulator operations on well heads.

## Design Approach

Team Kraken's ROV design was based on three criteria: the ROV needed to be small and light-weight, rugged and relatively inexpensive, and it had to have excellent functionality and maneuverability to complete the tasks. Our team decided to build around re-used parts from previous years because of their success; these parts include the system controls, electronics, cameras, and thrusters. New to this year's design is the octagonal PVC frame, a longer run of neutrally buoyant tether, a slightly longer electronics housing that supports a second IP camera, a team-built mechanical manipulator, newly designed propeller shrouds, a pressure sensor, and temperature sensor. The decision to re-use previous year's parts and incorporate the new design features not only saved us time and money, but also helped us meet our criteria, and will enabled us to complete the 2016 MATE challenges.

# Structure

## Frame

Team Kraken decided to use 1/2" PVC pipe, assembled in an octagonal design, for the framework. The frame was built using 7 meters (23 linear feet) of pipe and fittings. The over-all dimension of the frame puts our ROV within the 58 cm size measurement (BONUS)!

**Our team decided to use PVC rather than other plastics or metals for several reasons**:

**1)** It is light-weight and has a low density, which gives it positive buoyancy.
**2)** It is non-corrosive, easy to work with, and is a relatively inexpensive material.
**3)** Parts are easy to find at any pipe supply store.
**4)** No special machining tools are needed to construct the frame.
**5)** Its small circular shape allows it to pass through water with little resistance.

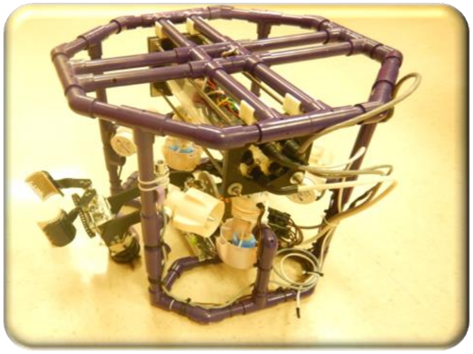


Figure 3: Final Frame Design
(Side View)

The frame design was changed to reduce its overall size and accommodate the new mounting location of the electronics housing and manipulator assembly. The outside dimensions of the final frame design are 55 cm x 55 cm x 43 cm. Holes were drilled into the frame at strategic locations to help correct the "righting" of the ROV and minimize any "free surface effect" caused by air pockets within the frame members.

## Buoyancy

After testing the ROV in the pool, the team realized it was negatively buoyant (it sank). To fix this problem, two floatation cylinders were attached to the top of the ROV to make it neutrally buoyant and give it a strong righting moment. The cylinders were constructed from two pieces of 2" ABS pipe, cut to 31.75 cm lengths; end caps were glued on for a water tight seal. The cylinders provide 1.36 kg of buoyancy, which was enough to give us a neutrally buoyant ROV. ABS pipe was used for the floatation rather than foam because of its low cost and availability, as well as its ease of construction and round shape.

## Electronics Housing

The electronics housing was changed slightly from the previous year, but is still the same basic design. A 35 cm long x 10 cm diameter clear polycarbonate tube is used, rather than the original 27 cm long tube, to accommodate a second IP camera. Flat aluminum end plates, backed by 13 cm x 13 cm x 1.25 cm MDPE plates, and hand cut Butyl rubber gaskets are used to seal each end of the cylinder. The plates are attached using 40 cm long, stainless steel threaded rods and nuts.

Figure 4: Bulkhead Connectors

Six, Switchcraft, waterproof connectors are inserted into the aluminum plate at one end of the housing. Since the connectors are not fully pressure tight, the male ends of the connectors were potted with epoxy resin into the bulkhead to prevent any water intrusion. The terminal end of the connector is filled with silicon sealer before its boot is attached; then, two-part heat shrink is used to provide a strong mechanical termination.

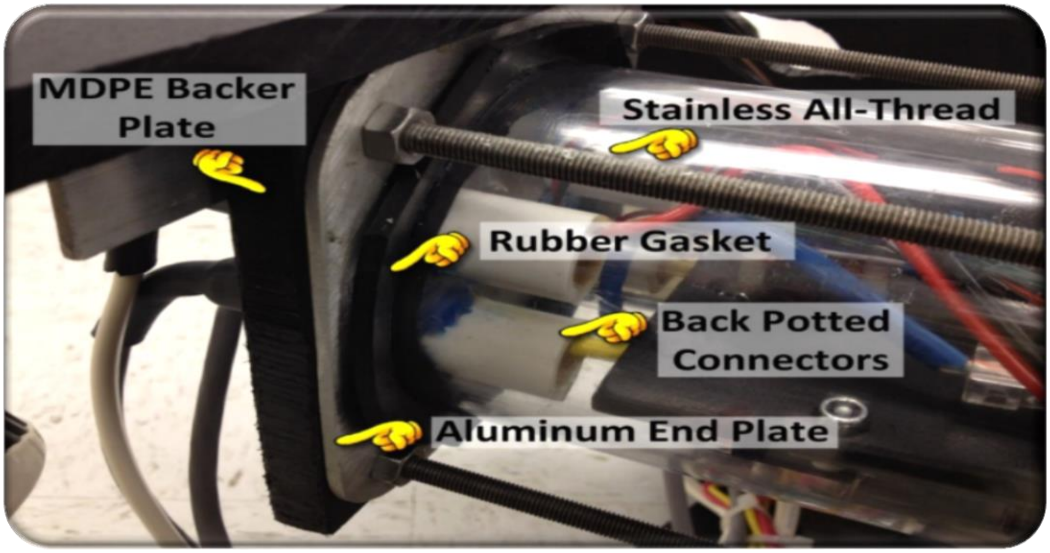



**Figure 5: Housing Construction**

Four, 3-D printed snap-on frame connectors are bolted to the edges of the MDPE plates. The snap-on connectors allow for quick attaching and detaching of the electronics housing to and from the frame. This is a great feature for transportation purposes, as well as emergency situations during operations.

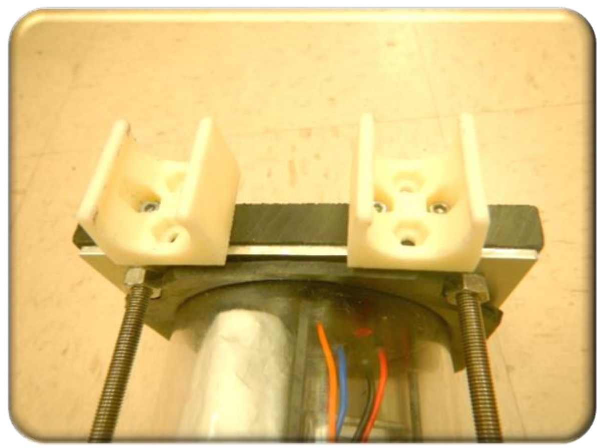


**Figure 6: Snap-on Frame Connectors**

# Propulsion

Our team researched low-cost waterproof motors and found a variety of sealed bilge pump motors from Attwood Marine Products. Our chosen model was the 24 volt T-1200 Tsunami, which is rated for 1.5 amps at a 27.2 V design voltage. This model was chosen to minimize the voltage reduction and drive current at the ROV. The motor cartridge is designed to fit into a water pump housing that would normally surround the propellers and act as a shroud. Since we only needed the motors, our team designed propeller shrouds to fit the new motors using Garrett College's Stratasys 3-D printer.

**Figure 7: Vertical Thruster**

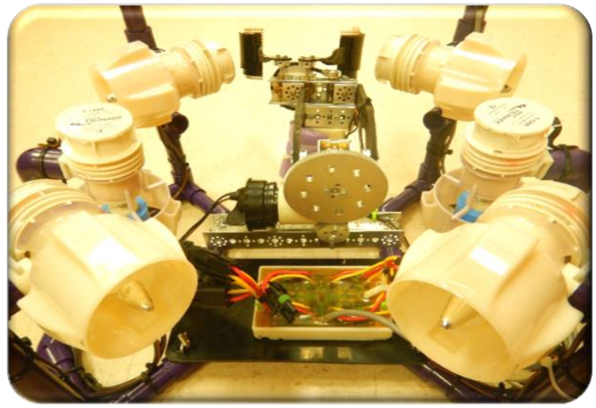


**Figure 8: Thrusters and Shrouds**

Some thruster testing helped us determine which propellers to use for our vertical movements. A medium pitch, straight twin-blade propeller was found to give the most vertical thrust, while minimizing amperage draw. Round twin-blade propellers were found to be the best choice for horizontal movements. Our thruster arrangement hosts two vertical thrusters and four vectored horizontal thrusters, which allows up, down, forward, backward, rotating, and crab-walk movements.

# Payload Tools

## Manipulator

At the beginning of the project, team Kraken decided to build a manipulator capable of grasping small parts of PVC pipe for the “Rigs to Reefs” well head challenge, as well as the “Forensic Fingerprinting” and “Mission-Critical Equipment Recovery” challenges. The mechanical engineers designed the manipulator to receive power from two, 12 volt, Johnson bilge pump motors. One motor raises and lowers the arm, while the other opens and closes the grasping jaw. It was determined that a gear reduction assembly was needed to slow the motor’s RPMs to a reasonable speed for good arm rotation control and a firm grip. A sufficient gear reduction was found using two, Tetrix, 30:1 worm gear sets. One set opens and closes the grasper and the other raises and lowers the arm.

**Figure 9: Manipulator Arm Assembly (Original Design)**

A later manipulator design was chosen to lighten the assembly and make it more compact. The design uses two planetary gear boxes from Tamiya, Inc. which can be adjusted to a 400:1 gear ratio. In the new design, the arm gear box is set to a 400:1 ratio and the grasper is set to a 100:1 ratio. 3-D printed motor housings were made to connect the motor to the gear boxes.

## Sensors

For the "Mission to Europa" challenge, the team installed a Honeywell pressure sensor to the ROV for determining the thickness of ice at the surface, as well as the depth of the ROV during operation. The pressure sensor was mounted 10 cm below the highest point on the ROV, which when calibrated gives the most accurate depth reading for our system. A temperature sensor was installed to determine the temperature of a sub-surface venting fluid. The temperature sensor is mounted on the arm of the manipulator, where it will be in view of a camera; this is so the team will be able to see precisely where they are holding the sensor for the most accurate measurements.

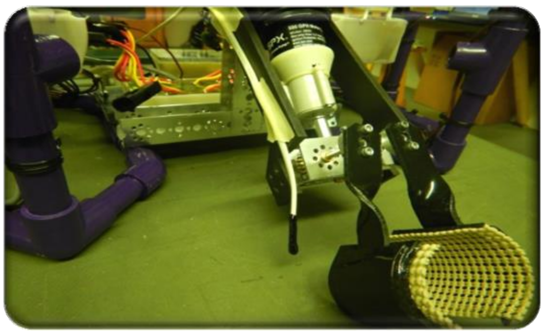


**Figure 10: Temperature Sensor Wire**

**Figure 11: Pressure Sensor**

# Cameras

The refractive index of water causes the viewing angle of any camera to be reduced when used underwater. After researching some IP (Internet Protocol) cameras for our Ether savvy ROV, we found a high-definition Axis IP camera with a wide viewing angle (84° FOV), and placed it in its own waterproof housing. Kevin, our CEO/CAD designer, designed the housing using CAD software and the 3-D printer. The housing was made water tight by coating the outer surface with epoxy resin. The clear face plate was cut from 6.35 mm clear polycarbonate and epoxied in place. This camera is mounted in a central, forward facing location for a good view of manipulator operations. An extra Axis camera is sealed inside the electronics housing with a downward view. The extra camera gives the team a clear view for picking up objects from the sea floor.

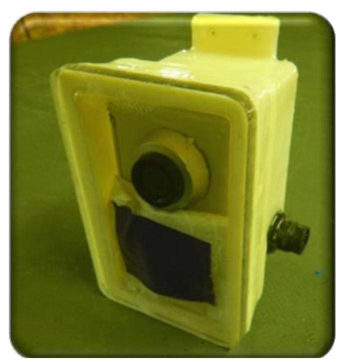


**Figure 12: IP Camera in Waterproof Case**

# Tether

Our team previously purchased a length of neutrally buoyant tether from VideoRay, and it was determined that the tether could be used to stream both power and data. The ROV design was based on a 22.8 meter tether length and a maximum power draw of 300 watts (six 24 V motors running at 2 A each). We determined that if we used the heavier gauge conductors for power, we would only see a 7 V voltage drop at the ROV; a drop of up to 12 V was acceptable. This left us with two 26 AWG twisted pairs, which could be used for an Ethernet LAN. (See Sidebar for 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*

**Figure 13: Tether Calculations**

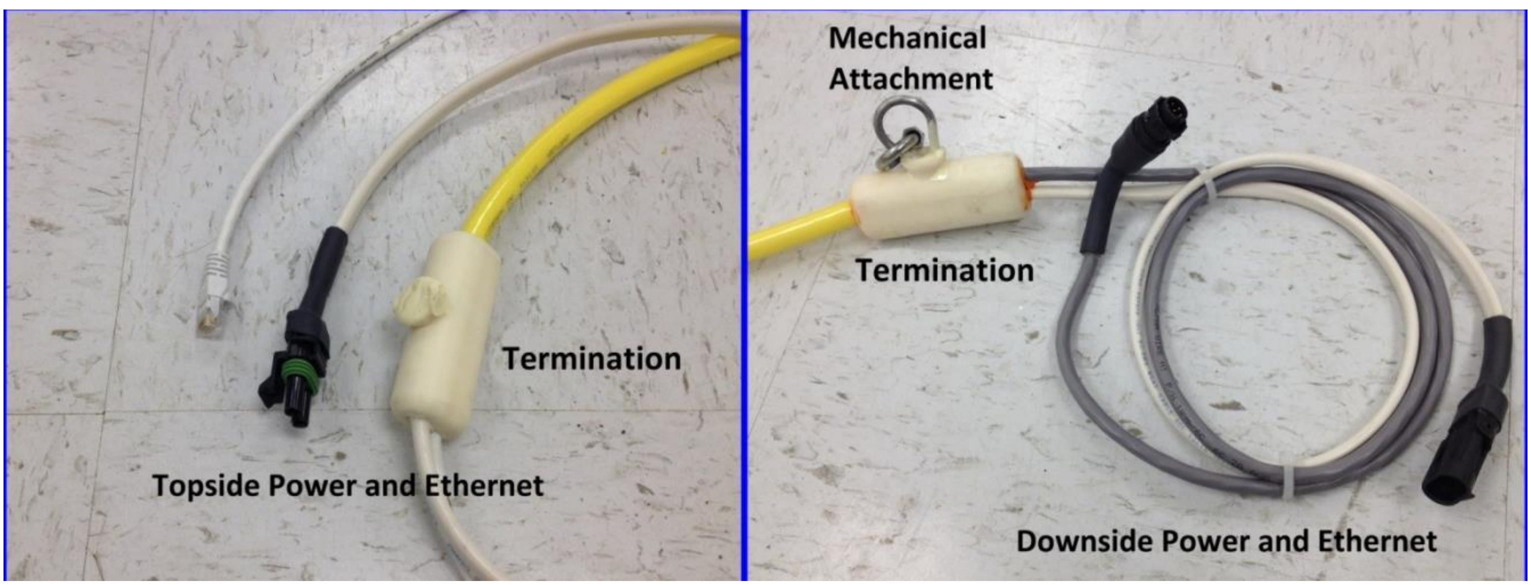



**Figure 14: Tether with Topside and Downside Terminations**

# Electrical Systems

The main 48 volt power feed from the surface enters the motor controller first, and then passes into the electronics housing. This path was chosen to provide the minimum number of connections between the power source and the heaviest power load (the thrusters). The final design for the thruster control utilized a PCB designed by the Project Phenix team; the motor controller is a re-used part. The motor controller is powered directly from the 48 volt tether supply, but it regulates the motor power using Pulse Width Modulation (PWM) to reduce the "apparent" voltage to always be less than 24 volts. The controller receives its PWM commands from the Arduino processor located in the electronics housing. The motor controller was potted with epoxy resin for waterproofing.

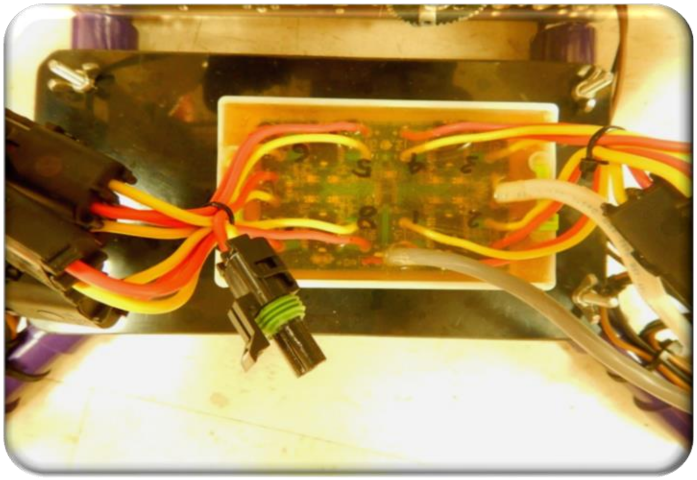


**Figure 15: Potted Motor Controller**

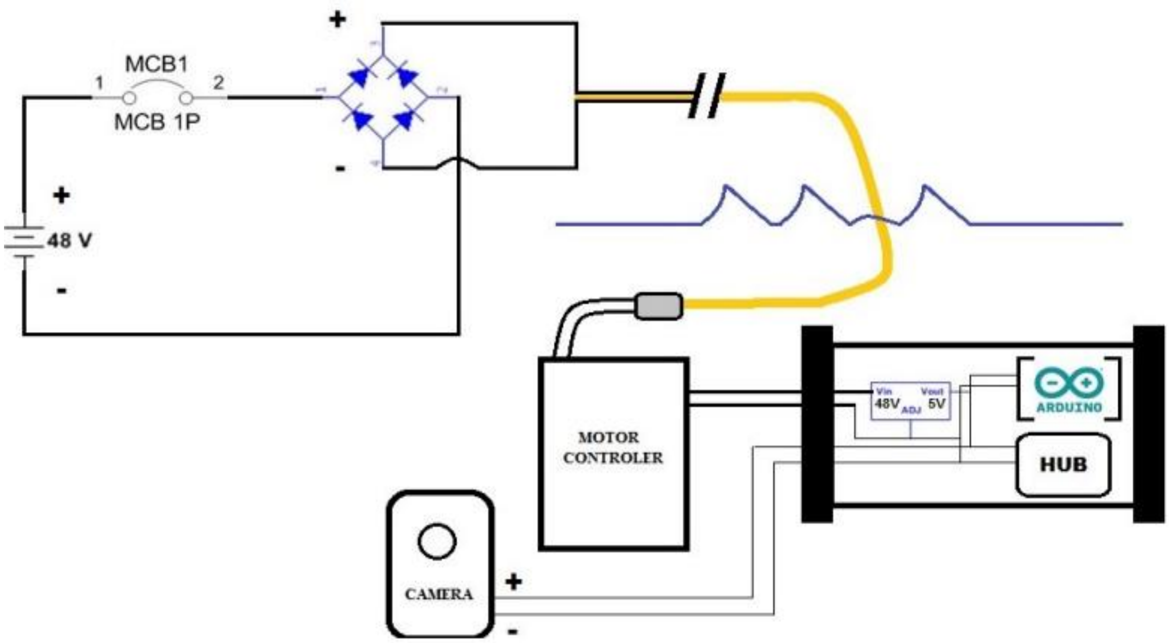



**Figure 16: Power Distribution Diagram**

# Software and Control Systems

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 pressure and temperature sensor and then “translates” it into usable data. We also gather information about the status of the leak detector. We then pack the pressure, temperature, 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. Our team used C# to program the surface side control GUI and telemetry. We used Arduino’s C based language to program the ROV’s functionality. The surface side communication starts by acquiring the raw data of our joystick. These values are run through a method that uses the joystick values to calculate the appropriate thruster values to send to the Arduino. The method also calculates the motor power for our arm and claw motors. These values are then used to populate an array that is sent down to the ROV. The communications processing, as well as the processing for the GUI elements, runs 20 times per second. The surface side computer receives asynchronously from the robot. We chose this method so that the transmission and GUI processing would not get stalled by lost packets from the robot. Whenever the surface side computer receives a packet from the ROV, it converts the numbers sent up the tether into human-readable units. The program then displays important information, such as depth, temperature, leak sensor status, and tether voltage.

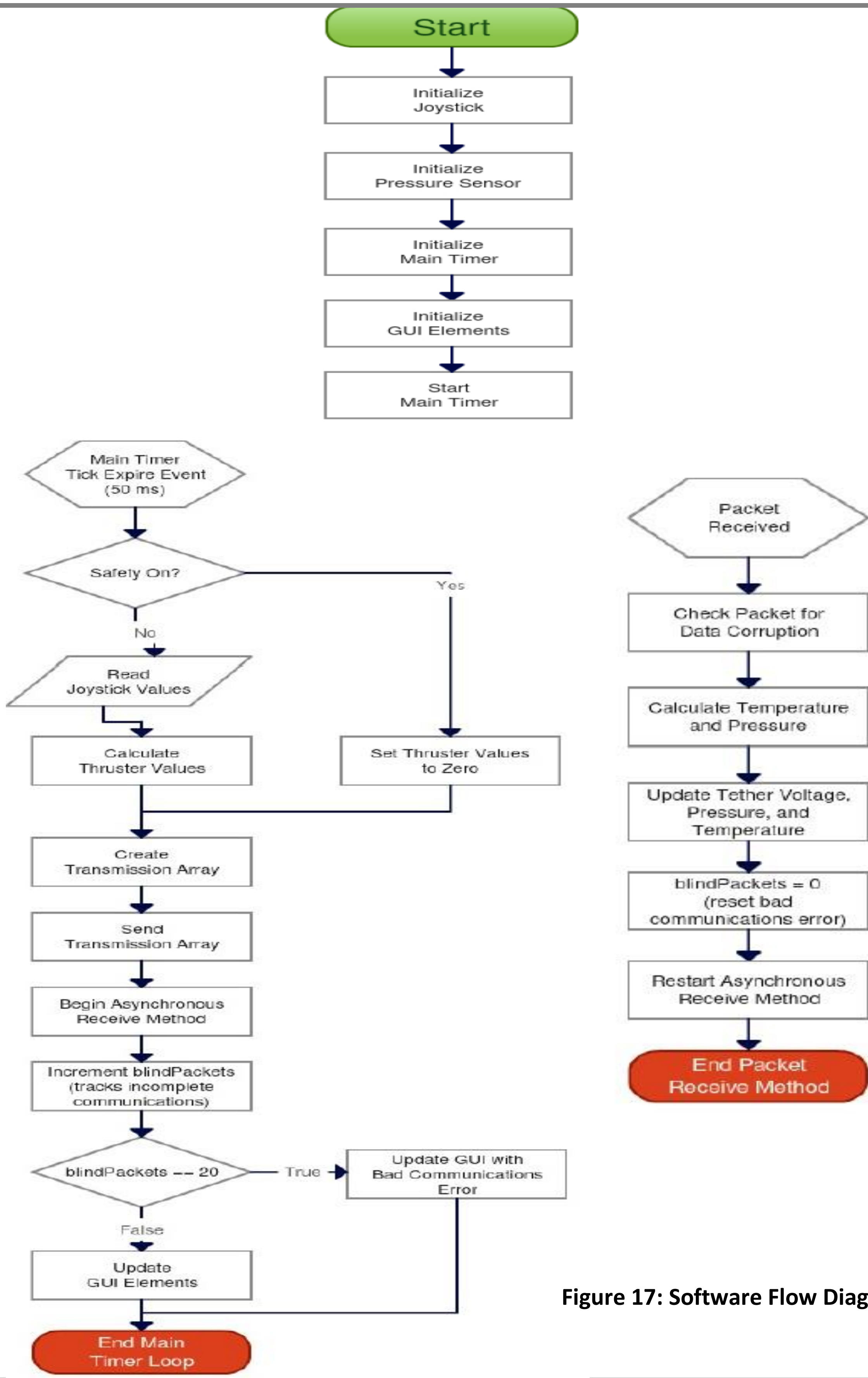



**Figure 17: Software Flow Diagram**

# Company Cost Sheet

| Category/ Item# | Item Description | Source | Qty. | Unit Cost (Market Value) | Total |
|---|---|---|---|---|---|
| **Purchased Items**(company cost) | | | | | |
| Frame & Bouyancy | | | | | |
| 1 | 1/2" PVC Pipe | Lowe's | 20 ft. | $5.52 / 10ft. | $11.04 |
| 2 | 1/2" PVC Cross | Lowe's | 4 | $0.99 | $3.96 |
| 3 | 1/2" PVC Tee | Lowe's | 22 | $0.46 | $10.12 |
| 4 | 1/2" PVC 90° Elbow | Lowe's | 2 | $0.36 | $0.72 |
| 5 | 1/2" PVC 45° Elbow | Lowe's | 16 | $0.51 | $8.16 |
| 6 | 1/2" PVC 90° Elbow/side outlet | Lowe's | 4 | $1.18 | $4.72 |
| 7 | 2" ABS DWV Pipe | Lowe's | 5 ft. | $4.88/ 5ft. | $4.88 |
| 8 | 2" ABS Cap | Lowe's | 4 | $4.48 | $17.92 |
| 9 | Purple spray paint | Lowe's | 1 | $6.99 | $6.99 |
| 10 | Green spray paint | Lowe's | 1 | $6.99 | $6.99 |
| | | | | **Sub-Total:** | **$75.50** |
| Hardware & Waterproofing | | | | | |
| 1 | 30 min. Quick-set Epoxy | | 1 | $18.00 | $18.00 |
| 2 | Urethane Potting compound | Aero Marine | 1 | $38.00 | $38.00 |
| 3 | S.S. All-Thread w/ hardware | | 4 | $15.00 | $60.00 |
| 4 | Tamiya Planetary Gearbox Set | Tamiya, INC. | 2 | $20.00 | $40.00 |
| | | | | **Sub-Total:** | **$156.00** |
| Sensors & Connectors | | | | | |
| 1 | Pressure Sensor | Honeywell | 1 | $240.61 | $240.61 |
| 2 | Temperature Sensor | | 1 | $10.00 | $10.00 |
| 3 | Waterproof connectors | Switchcraft | 2 | $14.00 | $28.00 |
| | | | | **Sub-Total:** | **$278.61** |
| | | **Purchased Items Total:** | | | **$510.11** |

| Category/ Item # | Item Description | Source | Qty. | Unit Cost (Market Value) | Total |
|---|---|---|---|---|---|
| | | **Re-Used Items** | | | |
| Control System & Electronics | | | | | |
| 1 | Octobox Motor Controller | Phenix Technologies | 1 | $150.00 | $150.00 |
| 2 | Custom-built Arduino motherboard | Gears, Inc. | 1 | $60.00 | $60.00 |
| 3 | 5 Port Ethernet Hub | Gears, Inc. | 1 | $15.00 | $15.00 |
| 4 | Arduino Ether CPU | Arduino | 1 | $65.00 | $65.00 |
| 5 | DC voltage regulator (48v-5v) | | 1 | $35.00 | $35.00 |
| 6 | Jumper wires | Switchcraft | 1 ft. | $5.00 | $5.00 |
| 7 | #12 copper wire twin conductor pairs | In-Line | 60 ft. | $1.00/ft | $60.00 |
| 8 | HDPE sheet | Gears, Inc. | 1 | $45.00 | $45.00 |
| 9 | Butyle Rubber sheet | | 1 | $10.00 | $10.00 |
| 10 | Waterproof connectors | SwitchCraft | 6 | $14.00 | $84.00 |
| 11 | Waterproof connectors | | 12 | $4.00 | $48.00 |
| 12 | Samsung laptop computer | Garrett College | 1 | $900.00 | $900.00 |
| 13 | Option Network hub/router | | 1 | $150.00 | $150.00 |
| 14 | Thrustmaster Joystick | | 1 | $50.00 | $50.00 |
| 15 | 25 Amp Bussman Marine circuit breaker | | 1 | $35.00 | $35.00 |
| 16 | Termination molds (3-D printed) | Garrett College | 2 | $10.00 | $20.00 |
| 17 | Metal rigging hardware | Lowe's | 1 | $5.00 | $5.00 |
| | | | | **Sub-Total:** | $1,737.00 |
| Thrusters & Cameras | | | | | |
| 1 | Attwood bilge pump motors | Attwood, Inc. | 6 | $47.00 | $282.00 |
| 2 | Johnson bilge pump motors | Johnson, Inc. | 2 | $32.18 | $64.36 |
| 3 | Axis IP Cameras 1054 | Axis | 2 | $200.00 | $400.00 |
| 4 | Camera Housing (3-D printed) | Garrett College | 1 | $16.00 | $16.00 |
| | | | | **Sub-Total:** | $762.36 |
| | | | | **Re-Used Items Total:** | $2,499.36 |

| Donated Items | | | | | |
|---|---|---|---|---|---|
| 1 | Tether (Neutrally Bouyant) | VideoRay | 75 ft. | $5.00/ft | $375.00 |
| 2 | Clear Acrylic electronics housing tube | Gears, Inc. | 2 ft. | $15.00/ft | $30.00 |
| 3 | Custom built thruster shrouds (3-D printed) | Gears, Inc. | 6 | $10.00 | $60.00 |
| 4 | Manipulator arm & grasper parts | Gears, Inc. | 1 | $250.00 | $250.00 |
| | | | **Donated Items Total:** | | **$715.00** |
| Cash Donations | | | | | |
| 1 | | Garrett College | | | $6,000.00 |
| | | | **Total Donations:** | | **$6,715.00** |

# Budget

| Kraken Budget | |
|---|---|
| **Category** | **Estimated Cost** |
| Framework | $75.50 |
| Propulsion | $0 |
| Electrical/Electronics | $0 |
| Sensors | $278.61 |
| Cameras | $0 |
| Manipulator/Grasper | $40.00 |
| Waterproofing | $56.00 |
| Hardware | $60.00 |
| Software/Networking and Controls | $0 |
| **Total Company Cost:** | **$510.11** |
| **Parts Donations** | **$715.00** |
| **Cash Donations** | **$6,000.00** |
| **Re-Used Items** (Market Value) | **$2,499.36** |
| **Total Projected Cost:** | **$9,724.47** |

# Challenges

## Technical

Team Kraken ran into some problems during the in-pool testing. When the ROV performed multiple maneuvering functions simultaneously, the thruster motors locked up causing an error in telemetry (bad comms) to occur on the surface controls. After checking all wiring connections, one of the Switchcraft connectors, attached to the sub-surface electronics housing, was found to be taking on water and possibly caused a short. The problem was fixed by attaching a new connector and filling it with Di-electric grease to help seal out any water. This fixed the problem.

## Interpersonal

Three members of Team Kraken have just been introduced to underwater robotics this year. Also, due to the team's schedule differences, they had a minimal amount of time (one day per week) when all members could meet to work on the project together. The inexperience and short meeting times proved to be a challenge for our team, as deadlines approached for technical documentation and a finished ROV. These challenges caused some irritation between team members, but we overcame them by focusing our energies toward completing the goal of building an ROV for our potential clients MATE International. The new members worked hard to learn about and build the finished product by the deadline, as the more experienced members tried to help.

# Lessons Learned

**Dallas:** Throughout this project, I have learned how extremely important it is to organize and document ALL information obtained during the research, design, testing, and construction phases of an engineering project. I've also realized that taking lots of quality pictures during each phase is crucial for creating a good report. The more data that is collected during the design and building process, the easier it will be to improve future projects.

**Kevin:** I learned a lot this year by being the CEO. I did not realize the amount of responsibility that was involved with being the CEO. I learned that getting a time that works for a group of people to get together can be very difficult.

# Skills Gained

**Dallas:** In volunteering to be the technical writer of the company, I was involved in just about every part of the design and building process. I feel like I've gained a lot of knowledge and skills in a short amount of time. This should help me with any future management opportunity. These skills involve research and development, data collection, creating spreadsheets, designing diagrams and flow charts, and forming documentation for presentations. I've also gained some mechanical experience by helping to build the manipulator, which required some knowledge of gear reduction and assembly.

**Kevin:** I learned more about how RS-422 and RS-485 work and the differences between them.

# Reflections

Throughout the entire project, the team struggled to get things working perfectly on the ROV, but the process helped each teammate realize the amount of work it takes to complete a task like this. Each member enjoyed learning about the various aspects of building an underwater ROV capable of completing the tasks set before them. These challenges have strengthened each member in the fact that they were able to apply what they learned in the classroom to a real world problem. Working as a team is rarely ever easy since everyone has different ideas that they want to apply to the project, however, our team did very well at taking advice from each other to get the job done. New skills were learned by each member of the team including mechanical, electrical, programming, scheduling, and technical writing. These skills will serve each member well in their future by giving them the ability to perform tasks that an average person may not be able to. The experience was awesome!

# Future Improvements

The goal for Team Kraken is to use science, technology, engineering, and mathematics to design a line of state-of-the-art ROVs to suit the needs for potential future clients. Some future improvements that we would incorporate into the design of our ROV would be smaller cameras and a smaller electronics housing. The Axis IP cameras are bulky, so finding smaller high-definition cameras would be a great area to improve on. These new cameras could be located anywhere on the ROV to allow multiple viewing angles at a fraction of the weight. The electronics housing is also bulky, so reducing the size would allow for a smaller overall frame dimension, making the ROV even more compact, easily maneuverable in tight spaces, easier to handle, and more cost effective during transport.

# Acknowledgements

We would like to acknowledge several people/groups for their help in making this experience possible for us:

- The MATE Center and personnel for setting up an awesome facility for the teams to compete in.
- Our mentors Mr. Phil, and Kendrick for giving us guidance through the process of learning about underwater robotics and applying what we learned to the project.
- Garrett College for sponsoring our team, and providing us with some of the tools and space necessary for constructing our ROV. Also, special thanks to the CARC center for allowing us access to the college's pool to test and practice with our ROV.
- Our college Financial Advisor/liaison Mrs. Qing Yuan for coordinating our travel itinerary and for helping fund our traveling expenses. Thanks Qing!
- Garrett Engineering and Robotics Society (Gears), for supporting the team with donations and access to tools and materials for building the Kraken.
- Our parents for allowing us to be out late to get it built.
- Our instructors for supporting us and giving us valuable information that we will need for future endeavors.

# References

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

# Appendix A: Thruster shroud Design

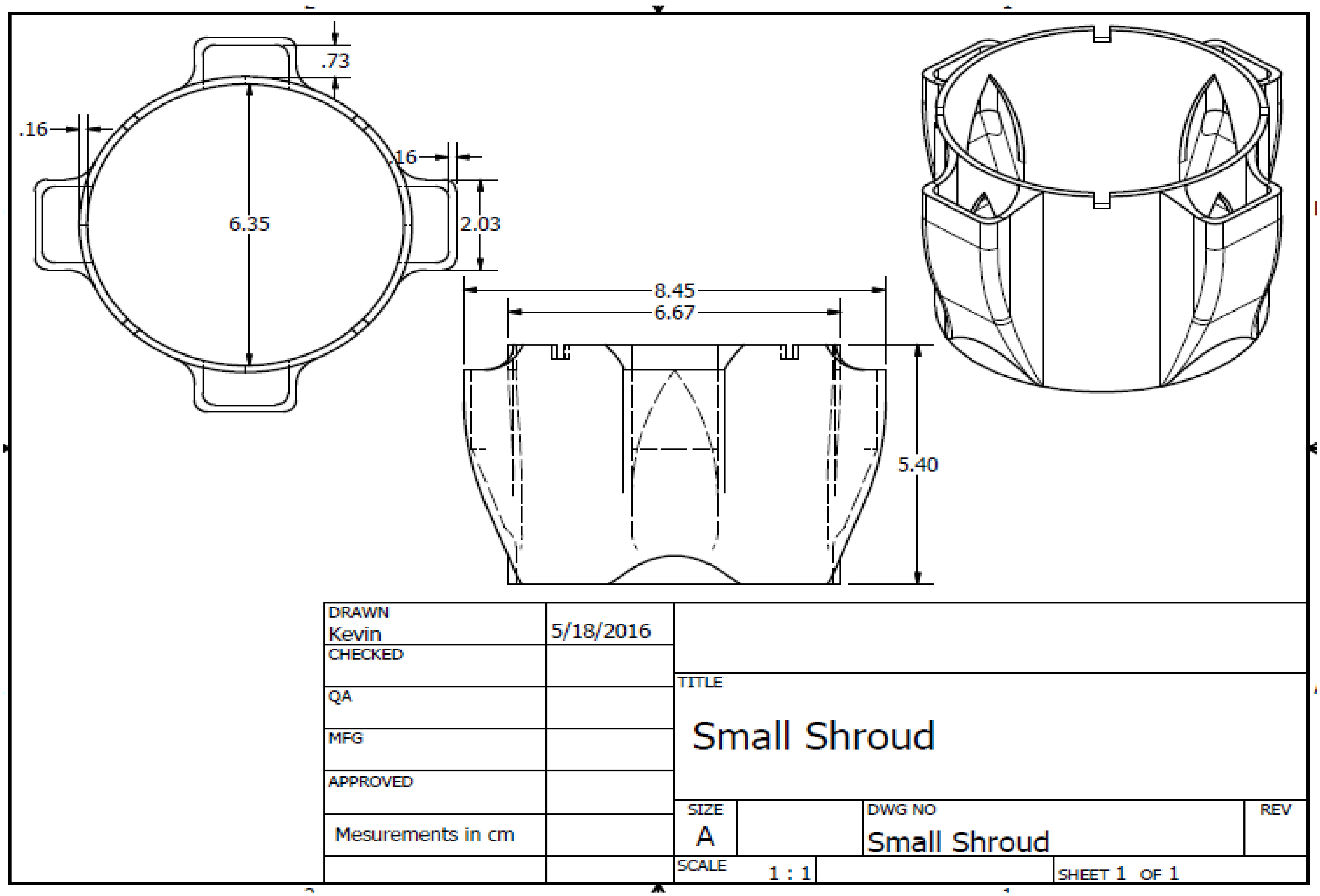



**Figure 18: Thruster Shroud**

# Appendix B: Camera Housing Design

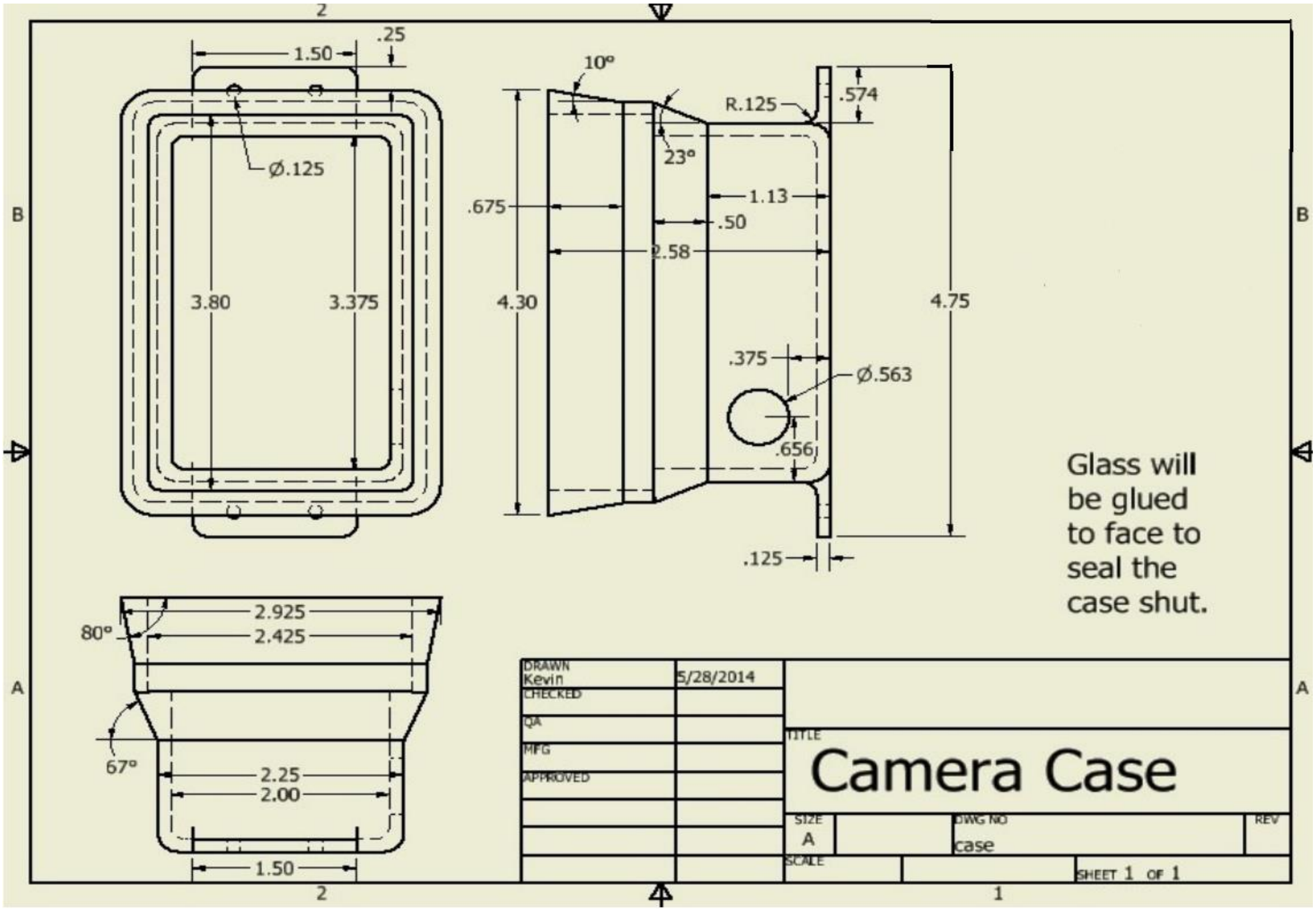



**Figure 19: Camera Housing**

# Appendix C: Job Safety Analysis

## *JOB SAFETY ANALYSIS WORKSHEET*

| | | |
|---|---|---|
| **Department:** Project Kraken | **Job Analyzed:** Pool-Side Operations | **Date Completed:** |
| | **Task Completed By:** Tethermen | **Supervisor:** Kevin Maust |
| **Location:** MATE International NBL Houston, Texas | **Analysis By:** Dallas Brenneman | **Reviewed By:** Kevin Maust |
| | **Approved By:** Kevin Maust | |
| **Required Personal Protective and Emergency Equipment** Safety Glasses, Closed-Toed Shoes, Life Jackets, First Aid Kit | | |

| SEQUENCE OF JOB STEPS | POTENTIAL HAZARDS | CONTROLS/ PREVENTION MEASURES |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |