Project Kraken

McHenry, MD, USA
Garrett College

2017 MATE INTERNATIONAL ROV COMPETITION
Port Cities of the Future: Commerce, Entertainment, Health, and Safety
(Long Beach, California)

Garrett Owens (Mission Controls & Pilot) – Freshman, electrical engineering
Scott Brenneman (Mission Electrical & Co-Pilot) – Sophomore, general studies
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Mentors: Phillip Malone (GEARS, Inc.)
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1. ABSTRACT

Accidents and pollution caused by the busyness of commercial ship traffic has negatively impacted marine life in ports around the world. Project Kraken, an Explorer class company comprised of three Engineering students, has developed the Kraken III ROV to keep the Port of Long Beach, California safe and operational for years to come. Kraken III, a highly versatile submersible ROV was designed to provide underwater surveillance, locate and identify sunken hazardous cargo containers from commercial ships, collect contaminated sediment samples for the remediation of marine life, and aid in the installation and maintenance of underwater mechanical systems.

Kraken III features custom-designed fully epoxied Brushless DC (BLDC) motors that power the ROV's five thrusters, and the rotational and grasping manipulators for mechanical operations. A Logitech gamepad controller is used to control the directional movements of the ROV, the manipulators, and a front-mount tilt-able camera. Low-light analog video cameras are used to survey the ocean floor and allow for crisp visual images of maintenance operations. An HC-05 Bluetooth receiver module, along with a 3 watt LED is used to activate and receive RFID numbers on sunken sea containers. Fathom-S and Fathom-X interfaces were installed to provide camera and Ethernet signal transmission. Subsurface electronics are housed in a clear cast acrylic tube rated for 100 meter depths. All data and video from the ROV are streamlined to the surface through a 16 meter neutrally buoyant tether, and are presented on two TFT color monitors. A Raspberry Pi touchscreen enables the topside programming features.

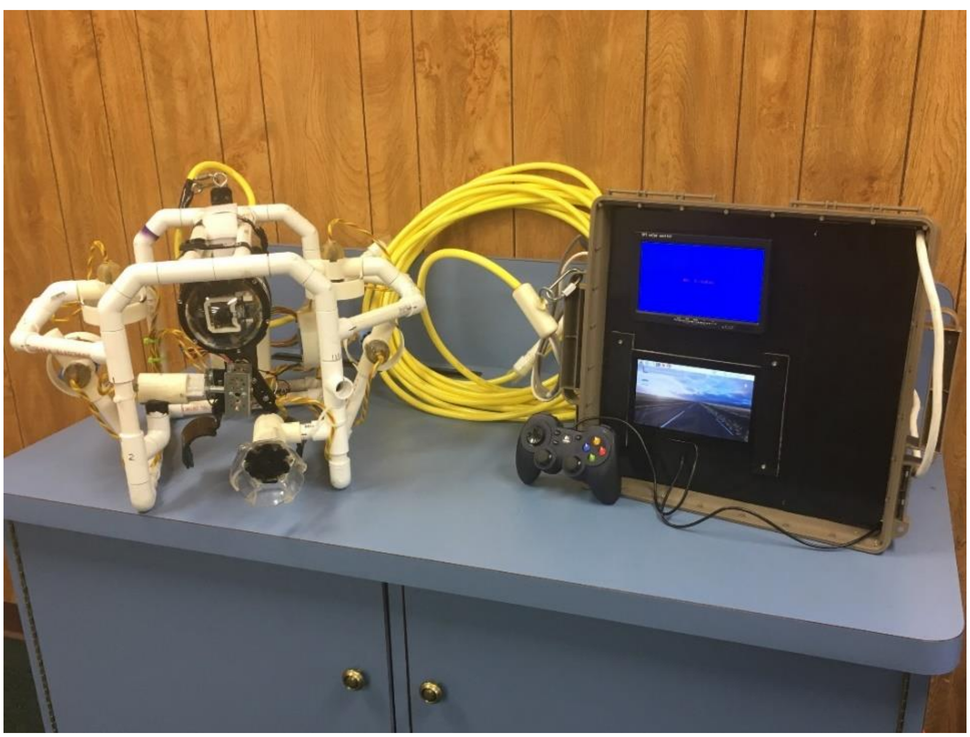


Figure 1: Kraken III ROV System

2. COMPANY SPECS

Company Name: Project Kraken

Location: McHenry, MD, USA

Company History: Fourth year in operation. Current participants include two prior year members and one new member. Company placed 12th in the 2016 Explorer class at NASA's neutral buoyancy facility.

Garrett Owens (SW), Scott Brenneman (EE), Dallas Brenneman (CEO, ME)

Company Member Information

Garrett Owens – Programmer/Software Engineer, Mission Pilot (Freshman) NEW MEMBER
Scott Brenneman – Electrical Engineer, Mission Co-Pilot (Sophomore) RETURNING
Dallas Brenneman – Mechanical Engineer, Mission Tether Control (Sophomore) RETURNING

3. SAFETY

Safety practices are extremely important, not only in a work environment, but also in the design of a product. Kraken III has many built-in safety features to ensure the safety of all personnel (company members and bystanders) and to prevent its sensitive parts from being damaged. These safety features include caution labels for all moving parts, strain relief at both ends of the tether, a 20 amp in-line fuse located 13 cm from the power supply attachment point, a 25 amp manual circuit breaker switch on the control station, shrouded thrusters, waterproofed BLDC motors resistance tested to >200 MΩ at 500 volts, no sharp edges on the ROV that can cause injuries or damage, thrusters that are mounted within the protection of the frame, a subsurface electronics housing pressure rated for 100 meter depths, and potted electrical connections.

Workplace Construction Safety Practices:

1. Use of proper personal protective equipment (PPE) for each task: eg. ANSI approved safety glasses, closed-toed shoes, gloves, and earplugs
2. Use of power tools with guards: eg. grinders, table saws, and band saws
3. Ensure proper ventilation when using chemicals and soldering: eg. epoxies, glues, primers, and acetone
4. House cleaning to keep workplace free of clutter
5. Use of clamps and vises to support objects being cut or drilled
6. Know the location of fire extinguishers and first aid kits in case of an emergency
7. Never work alone and always think ahead!

*Before the mission start-up procedure, each company member verifies they are in cooperation with MATE's PPE requirements (wearing safety glasses and closed toed shoes).

ROV start-up and mission safety checklist:

1. The team makes sure the AC power bar and circuit breaker switches are in the "OFF" position to prevent unintended damage or injuries during power-up.
2. The pilot and co-pilot verify that a 20-amp fuse is inserted in-line with the 48-volt power source.
3. The pilot and tether man verify that the strain relief at both ends of the tether are securely attached. Then, the pilot plugs the main Anderson power connectors as well as the tether's data and power lines into the control station.
4. The tether manager checks all penetrators on the electronics housing, including the pressure release screw, to verify they are in and tight.
5. The Pilot alerts all company members that "POWER IS COMING ON".
6. The Pilot turns on the main circuit breaker switch and AC power bar.
7. The Pilot initializes the ROV program and asks the tether man to verify ROV connection.
8. Once connection is verified, the tether man asks the pilot for a thruster and manipulator function test to verify all motors and mechanisms are functioning properly before flight.
9. After the team verifies that the ROV is fully functional, they are ready to begin the mission tasks.

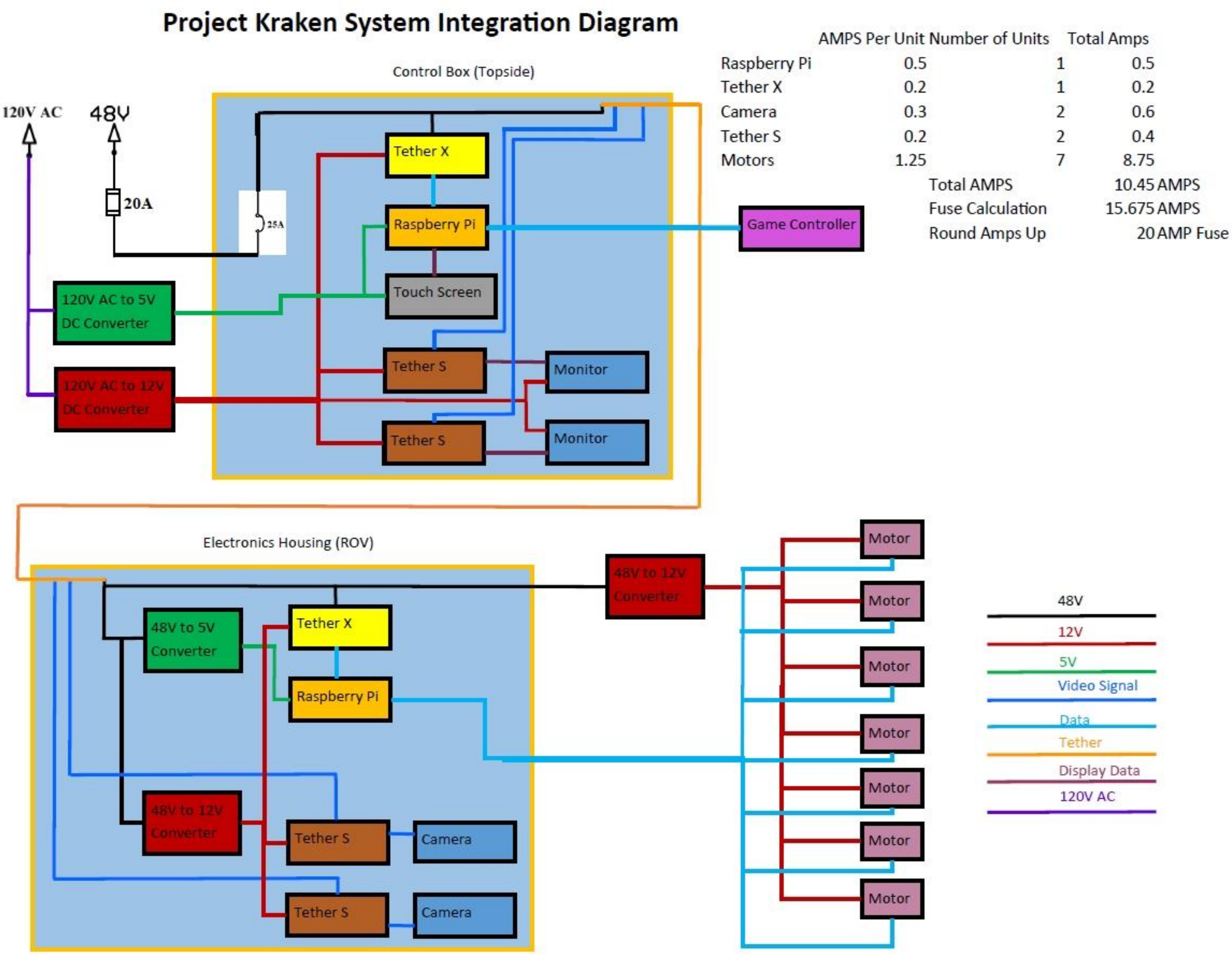
Figure 2: Proper PPE (safety glasses) is worn during construction

Figure 3: Warning sign posted during resistance testing

Figure 5: Life Guards for Pool-Side Safety

Figure 4: Getting the Youth Involved

4. SYSTEM INTERCONNECTION DIAGRAM (SID)



	AMPS Per Unit	Number of Units	Total Amps
Raspberry Pi	0.5	1	0.5
Tether X	0.2	1	0.2
Camera	0.3	2	0.6
Tether S	0.2	2	0.4
Motors	1.25	7	8.75
	Total AMPS		10.45 AMPS
	Fuse Calculation		15.675 AMPS
	Round Amps Up		20 AMP Fuse

Figure 6: System Interconnection Diagram (SID)

5. DESIGN RATIONALE

Our company designed an ROV capable of performing various underwater tasks related to the remediation of marine life and maintenance operations for sea ports around the world. Due to the congestion of vessel traffic, ports can often become confined and very difficult to maneuver in, especially for underwater vessels that must contend with the currents created by the propellers of large ships.

There were five main criteria that our company considered during the design phase of our ROV:

1. The size and weight of the ROV needed to be minimized for transportation and handling,
2. Thruster power needed to be enough to propel the ROV through the congested waters without being too overpowering to perform intricate mechanical operations,
3. Multiple viewing angles were needed for the pilot to have multiple perspectives of mission tasks,
4. The ROV needed to meet our budget requirements,
5. The ROV needed be extremely reliable with minimal chance for malfunction.

These design criteria were met in the choice of our frame structure, thruster and payload tooling configurations, cameras, electronics, tether, and control station.

5.1 Frame and Buoyancy

The frame was constructed using ½ inch schedule 40 PVC pipe. PVC pipe has several beneficial properties making it well suited for the frame structure. PVC is light-weight and rigid, and due to its round shape, very hydrodynamic. No machining of parts is required for frame construction, and it can be easily disassembled. Due to its hollow shape, ballast and floatation can be added inside the frame members, which reduces overall outside dimensions. The frame features a custom made rotational tether connection which provides strain relief and keeps the tether in an upright position during operations.

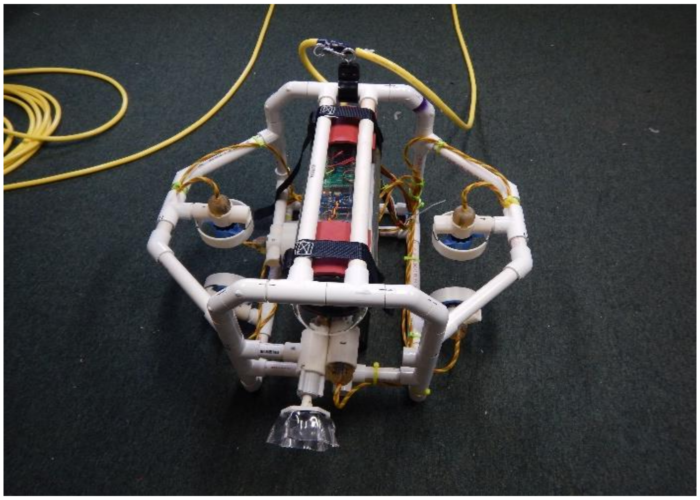


Figure 7: Original PVC Frame Structure

The outside dimensions of the ROV's frame are 55cm x 53cm x 35cm. The ROV is neutrally buoyant. To attain neutral buoyancy and horizontal balance, correct amounts of floatation and ballast were added strategically inside the front and rear frame members. Equilibrium was found through empirical testing methods.

When handling mission pieces, the ROV buoyancy will change. To compensate, we have added a software "trim" to enable the pilot to re-establish a neutral buoyancy.

5.2 Thrusters

The ROV has five thrusters (two vertical, two axial, and one lateral). The thrusters, as well as the payload tools, are powered using 750 KV brushless DC (BLDC) motors. All motors are controlled with commercial electronic speed controllers (ESCs). They have been flash programmed using BL Heli Suite firmware to suit our needs for bi-directional motor rotation.

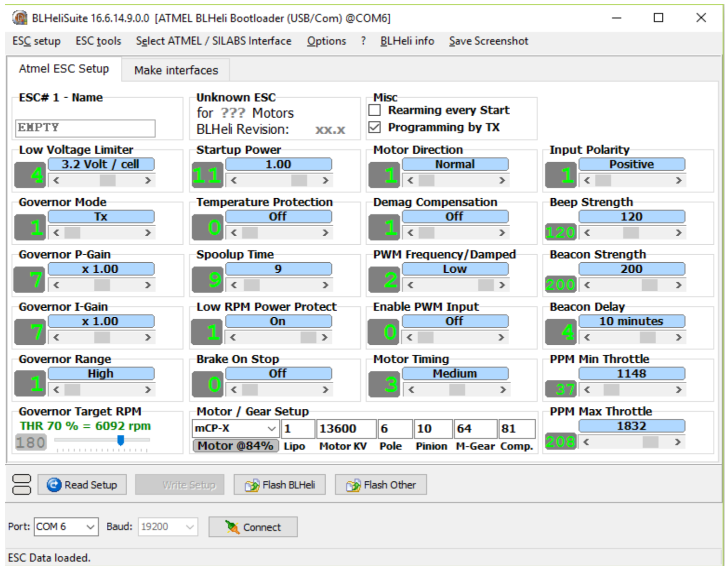


Figure 8: BL-Heli Suite Boot-loader

The motors and ESCs have been potted as a single unit with marine grade epoxy resin. These specially designed motor assemblies helped us meet our requirement of having a light weight vehicle. The new motors have a combined weight savings of more than 1 kg over last year's bilge pump motors. By potting the motors and ESCs as a single unit, it eliminates the need to install the ESCs inside the electronics housing, which saves space for other crucial electronics.

Figure 10: Custom Motor Before and After Potting

Waterproofing of the motors was accomplished by creating a positive silicon mold of the motor/ESC assembly, inserting the motor/ESC assembly into the mold, pouring in the epoxy, and vacuuming it in a pressure chamber. This process provides complete coverage of the motor windings and leads. After full cure of the epoxy, the motors were submerged in tap water for 24 hours and insulation tested for conductivity to resistances at or greater than 10 MΩ at 500V. In addition, the motors were also pressure tested to 30 PSI with no negative effects on electrical insulation or performance.

Figure 9: Waterproofing the Motors

The thruster housings are CAD designed and 3-D printed to fit the ½ inch PVC frame structure and provide a tapered fit for the motors. After testing various propellers, the Blue Robotics T100 propellers were found to be the best match for the motors. The combination provides 1-1.2kg of thrust at 12VDC and maximum current draw of 5 amps. The propellers are fitted on the motor using 3-D printed mounting plates.

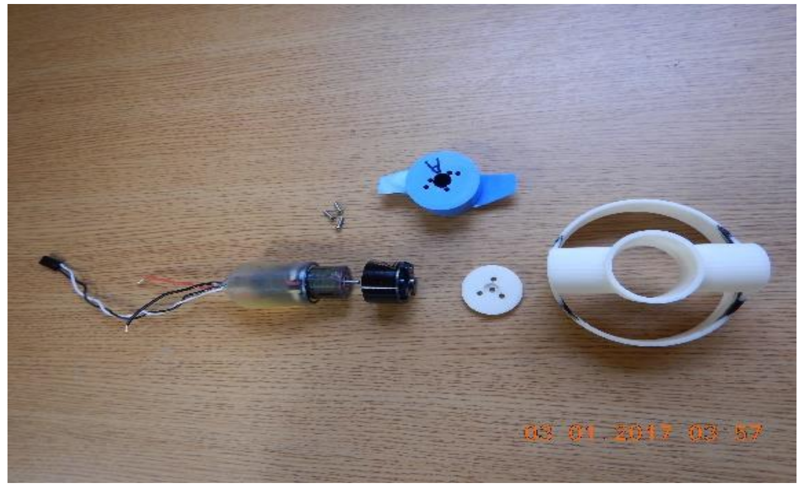


Figure 11: Thruster Components

5.3 Payload Tooling

To perform the various mechanical operations required for each task, the ROV relies on two manipulator tools; a rotational tool that provides continuous 360° of freedom, and a grasping tool that provides 90° of freedom. Both tools are driven using the team's custom potted BLDC motors for power and a Tamiya planetary gear box for gear reduction.

The rotational tool is comprised of three main parts:

1. a clear plastic valve nut,
2. three neodymium magnets,
3. a 3-D printed gear box-to-valve nut hub.

Figure 12: Rotational Tool

The valve nut was heat formed to fit the specific size of a ½- inch brass gate valve. The valve nut was then adhered to the 3-D printed hub, which is then connected to the gear box.

The hub was designed to accept three neodymium magnets. The magnets were integrated after some pool testing revealed difficulties in holding the ROV perfectly on the ½-inch valve.

The magnets help lock the ROV onto the valve, reducing the need for perfect pilot maneuvering during task 2.

The grasping tool is comprised of three main parts:

1. a 30:1 Tetrix gear reduction assembly,
2. two adjustable grabbing arms,
3. non-slip rubber gripping material.

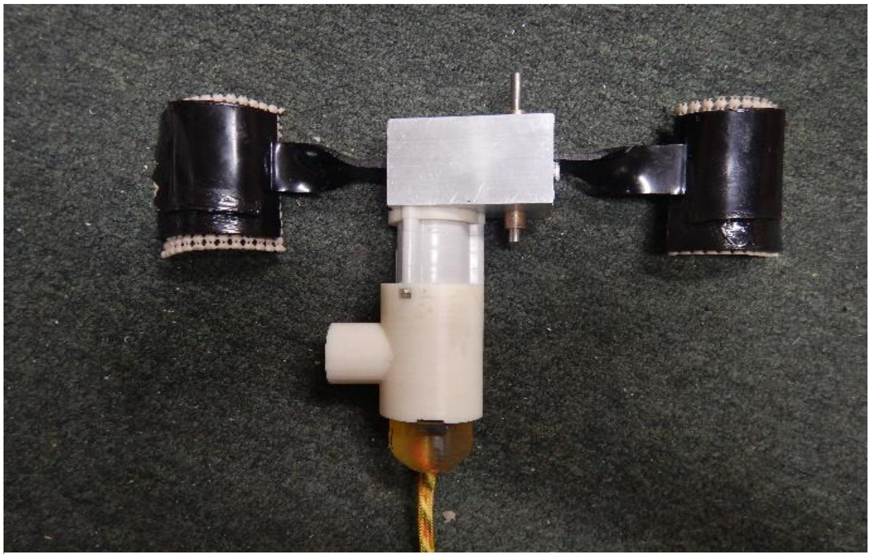


Figure 13: Grasping Tool

The grasping tool can be used for procedures that require horizontal and vertical lifting of objects. The arms have been heat formed to fit the specific diameter of the 1 ½-inch power cable connector in task 2, but the tool can lift a variety of objects due to its design.

The non-slip rubber gripping material was adhered to the arms to provide a firm, non-slip grip on objects. If needed, the speed at which both tools function can be changed in the software.

The ROV also features an onboard Bluetooth RFID receiver to help identify the contents within sunken sea containers. A 3-watt smart LED is used to activate transmitters on the sea containers, as well as produce lighting for the low-light conditions of underwater operations. Both the LED and Bluetooth module have been installed in the electronics housing.

5.4 Electronics Housing

A Blue Robotics Cast Acrylic Tube with a 10.16 cm inner diameter and wall thickness of 6.3 mm houses the onboard electronics. A flat aluminum end cap with O-Rings is used to seal the rear of the housing, while a clear dome end cap is used to seal the front end of the housing. Tether and data cables enter and exit the rear end cap through potted penetrators. The rear end cap features a depressurization vent screw that is used to release pressure as the enclosure is being sealed. The housing is pressure rated to a maximum depth of 100 meters.

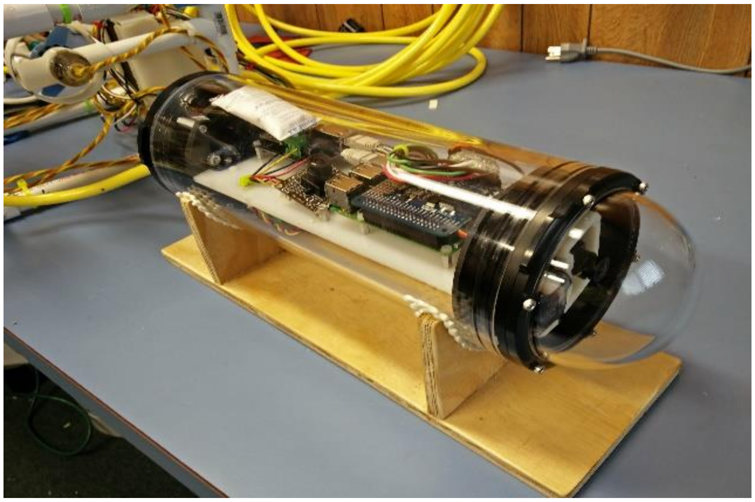


Figure 14: Electronics Housing

5.5 Cameras

Two high definition (700TVL), wide angle (128°), low-light analog video cameras are installed in the electronics housing to provide multiple perspectives of tooling operations and ROV location. One of the cameras is mounted on a tilt mechanism, located in the front dome section of the electronics housing. This camera provides adjustable viewing for maneuvering in confined spaces. The other camera is centrally located in the electronics housing for a downward view of the grasping tool and anything beneath the ROV.

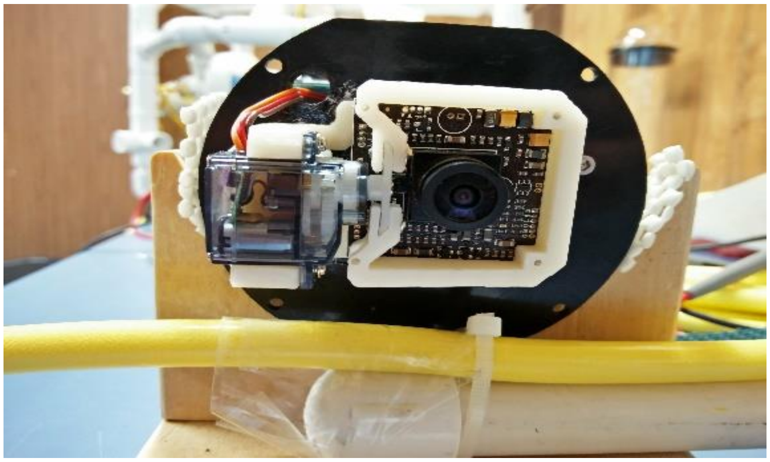


Figure 15: Tiltable Camera

5.6 Control System

5.6.1 Hardware

After considering the control system, our company decided that fine control over the ROV would best suit our needs. We also wanted the ability to use a game pad controller that would give us analog (proportional) signals.

Due to its processing speed and versatility we decided to use Raspberry Pi3 Single-Board Computers (SBCs) to read and process our data.

Kraken III hosts two Raspberry Pi SBCs to operate the control system, one on the topside control box and one on the ROV.

The Raspberry Pi SBCs along with two Fathom-X interface boards allow transmission of data through the tether to the ROV. The data is then converted to a Pulse Width Modulation (PWM) signal, which is then sent to the Electronic Speed Controllers (ESCs) to power the brushless DC motors.

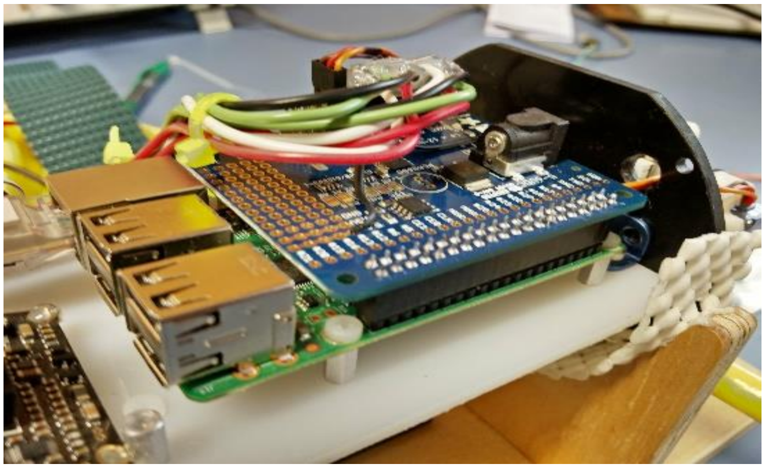


Figure 16: ROV Raspberry Pi

5.6.2 Telemetry

At the beginning of the build process, our company decided to use a Kevlar protected, neutrally buoyant tether from Video Ray. The tether has two pairs of 20 AWG for power, one pair of 24 AWG for data, and two pairs of 26 AWG for data.

This tether is very light weight and durable, allowing for easy transportation. One limiting factor in designing an ROV is getting enough power to the robot; because of this, we wanted to dedicate as many conductors for power as we possibly could.

This led us to finding and using the Fathom X tether interface to transmit data back and forth on the ROV. The Fathom X works by using the same conductors that carry power to transmit data. This happens when the Fathom X sends a superimposed high frequency signal over the conductors that is decoded each end.

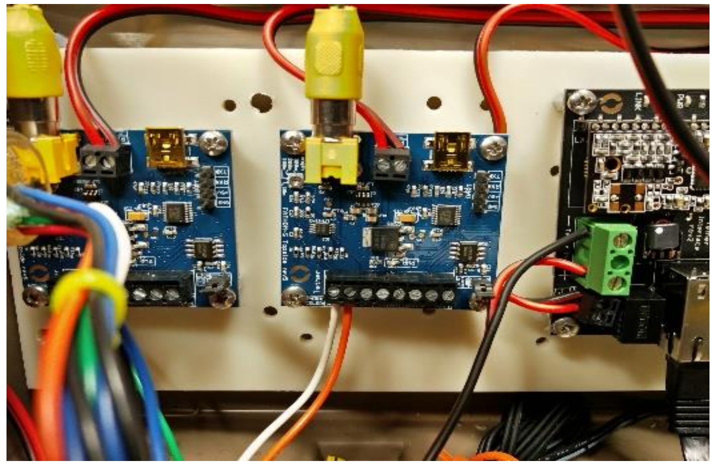


Figure 17: Top-Side Fathom-S and Fathom-X Boards

Our company used IP cameras on previous ROV designs. This allowed us to have high quality video, but there was a very noticeable latency, making flying difficult. Project Kraken began to look for a new way to send video to the topside. We decided to use the Fathom-S tether interface to transmit video, because it allows us to send analog video to the surface with almost no latency or loss of quality. The Fathom-S only needs two small conductors to transmit video. Kraken III hosts two analog cameras, which requires two Fathom-S interface boards. A total of four conductor wires are dedicated to video and the rest can be used for power and data transmission.

5.6.3 Software

The software for both the control box and the ROV is written in python 3 and run on the two Raspberry pi 3s, one in the control box and one on the ROV. The "pygame" library is used to create the topside Graphical User Interface (GUI). A socket library is used to connect the two raspberry Pis using a TCP connection. The connection status is displayed on the control box screen in a window created by the pygame libraries. If the ROV connection is broken, the status turns red, otherwise it's green.

The ROV is controlled by a game controller plugged into the raspberry pi in the control box. The pygame module reads the controller data. The controller data is run through a process to change it into thruster motor power levels. These power levels are displayed on the control screen. That data is then sent to the ROV, in an array format, which then gets changed into PWM signals using an Adafruit servo HAT and downloaded libraries for the HAT. Those generated signals are sent out to their assigned motors, based on their placement in the array, to control their speed and direction. As a *safety feature*, if thruster command message stop at any time, all thrusters and tools are brought back to an idle (stopped) state to prevent injury to personnel or the ROV

ROV status and Bluetooth Beacon information are sent back to the console as part of the reply to the thruster message. Figure 19 shows a basic block diagram/data-flow for the system. Figures 20 and 21 show the program flowcharts for the topside controller and ROV respectively.

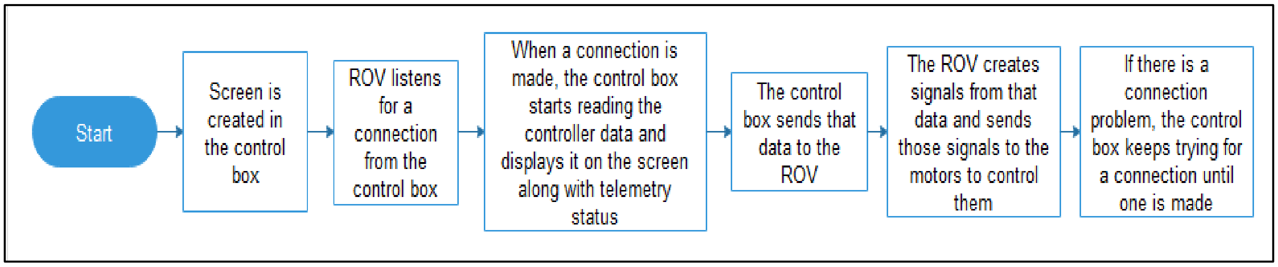


Figure 18: Software Block Diagram

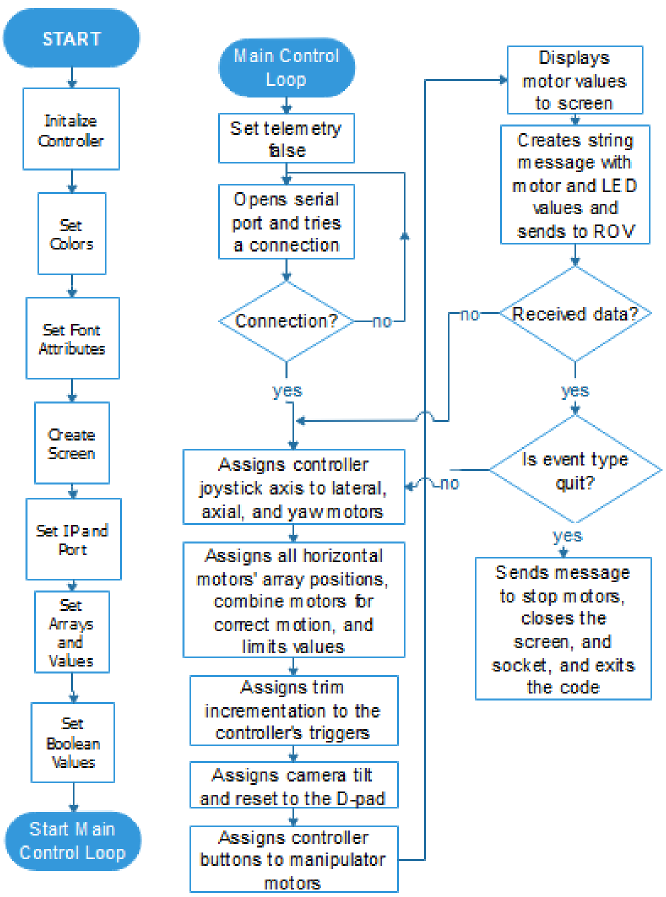


Figure 20: Topside Flowchart

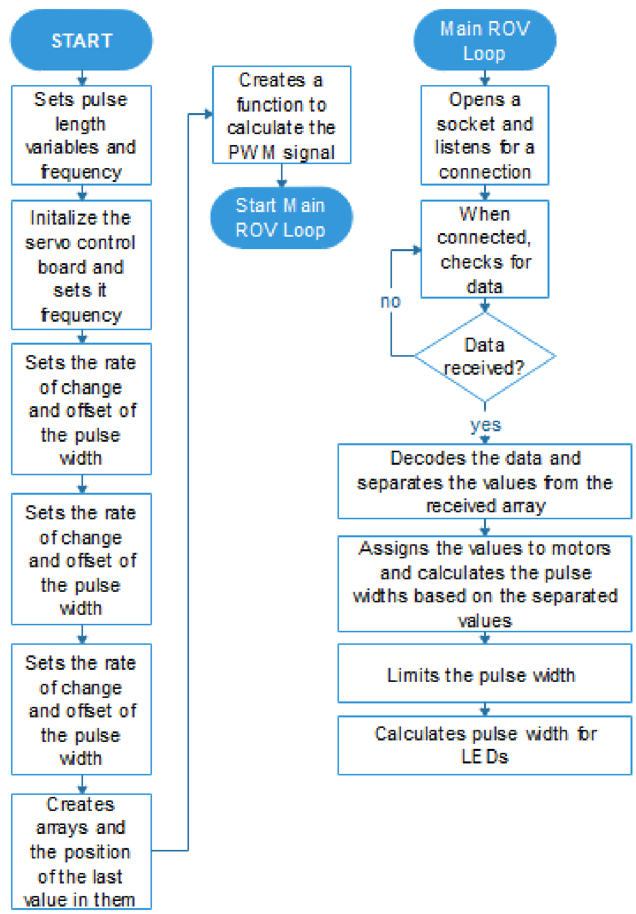


Figure 21: ROV Flowchart

6. BUDGET AND PROJECT COSTS

Our total budget for this year's competition was $6,500.00 including travel expenses.

Last year's expenditures drained all our assets, so our team did some fundraising to get a budget started for this year. We ended up raising $5,300.00 through this year's fundraising efforts.

Garrett College also supplied us with additional funding we needed to reach our budget goal.

The total funding we received gave us enough to build the ROV and travel to this year's competition in Long Beach, California. Travel expenses totaled $4,100.00, and ROV expenses totaled $2,220.50, giving a grand total of $6,320.50 in expenditures.

We met our budget goal for this year leaving $179.50 in unused funds.

Topside Console		Quant	Each	Total
Pilot Station Case	Plastic Ammo Case	1	$40.00	$40.00
Display (Video)	7" Flat Screen	1	$24.00	$24.00
Raspberry Pi	Rev 3	1	$35.00	$35.00
Raspberry Pi Screen	7" Touch Screen	1	$60.00	$60.00
Game Controller	Logitech Rumble Pad	1	$25.00	$25.00
Misc. cabling.	Cable and connectors	1	$35.00	$35.00
DC Power Supplies	12V and 5V	2	$10.00	$20.00
		Topside TOTAL		**$239.00**

ROV		Quant	Each	Total
Mechanical				
Clear Pressure Housing	Watertight Enclosure for ROV/AUV (4″ Series)	1	$200.00	$200.00
Penetrators	Misc. Blanc, 6 & 8 mm	5	$5.00	$25.00
Planetary Gearbox	Tamiya	2	$20.00	$40.00
Props	T100 Propeller set (pair)	3	$9.00	$27.00
ROV Frame	Assorted PVC Pipe and fittings (est)	1	$50.00	$50.00
3D Printed Parts	Thruster Housings, Motor Mounts, etc. (/cu inch)	10	$4.00	$40.00
Epoxy	Marine Epoxy (Tube)	2	$9.00	$18.00
Manipulators	Misc. metal and plastic raw materials	1	$35.00	$35.00
Electrical				

Data Interface	Fathom-X Tether Interface Board Set	1	$160.00	$160.00
Video Interface	Fathom-S Tether Interface Board Set	2	$85.00	$170.00
Raspberry Pi	Rev 3	1	$35.00	$35.00
PWM Module	16 Channel Adafruit PI Hat	1	$16.00	$16.00
BLDC Motor ESC	EMAX BLHeli Series 15A ESC	7	$9.50	$66.50
BLDC Motor	Propdrive 750 KV brushless motors	7	$14.00	$98.00
Analog Camera	Low-Light Analog Camera 128 FOV	2	$32.00	$64.00
Raspberry Pi Camera	Raspberry Pi Camera Module v2 w/ Wide Angle Lens 110 FOV	1	$50.00	$50.00
48-12V Reg	2.5A	1	$35.00	$35.00
48-5V Reg	3A	1	$30.00	$30.00
Voltage Regulator	DC 48V Step-down to 12V 30A 360W Waterproof DC Converter Regulator	1	$35.00	$35.00
Bluetooth Slave		1	$10.00	$10.00
Camera Tilt Servo	Micro Servo	1	$12.00	$12.00
Misc cabling.	Cable and connectors	1	$35.00	$35.00
Potting Box	Polycase enclosure	1	$10.00	$10.00
Tether	10Videoray Tether per M.	15	$35.00	$525.00
Materials for motor fabrication				
Silicon Casting Resin		1	$75.00	$75.00
Silicon Mold Rubber		1	$120.00	$120.00
			ROV Total	**$1,981.50**

TOTAL SYSTEM COST: $2,220.50

7. LESSONS LEARNED

One of this year's goals was to move away from the large brushed bilge pump motors that were used in last year's design and move toward brushless motors for their reliability and reduced size.

Since most off-the-shelf brushless motors are not designed to be submerged under water due to electrolysis of the motor leads, they needed to be sealed with epoxy. Our team decided to learn the "state of the art" of encapsulating motors so we could develop our own "standardized" motor insert.

To facilitate the process, our team purchased a 5-gallon pressure paint tank, which was used to vacuum de-gas the motors. Vacuum sealing brushless motors was a newly learned technique for our team this year. This led to some initial problems when trying to 'pot the motors. After trying to seal the first motor, we determined that the epoxy we were using did not provide enough time for a complete release of air before it cured (the epoxy had a work life of only 15 minutes). Because of this, air pockets formed all through the epoxy as it cured, ultimately causing the first motor to fail the resistance test.

To remedy this problem, we found another marine grade epoxy with a work life of 60 minutes. This provided us with sufficient time to fully degas the epoxy and give complete coverage of the motor windings and leads. After a 10-minute vacuum, the epoxied motors were placed under a heat lamp to help lower the viscosity of the epoxy. This allowed any remaining air to escape. This procedure worked very well, giving us resistances of >200MΩ at 500 volts with our "mega".

8. FUTURE IMPROVEMENTS

There are three areas in the design of our ROV that we would like to improve on:

1. Electronics,
2. Thruster shrouds and propellers,
3. Frame structure.

This year, our company chose to purchase tether interface boards from Blue Robotics to suit our needs for video and data transmission. Although they work well for us, we do not use all aspects of the boards. We could minimize the electronics footprint by designing our own custom tether interface boards based on Blue Robotics' design. This would allow for a smaller electronics housing or extra space to install other electrical instrumentation.

The thruster housings and shrouds are a one-piece design, which is a step up from last year's design, but they could be more ergonomic by using Rice nozzle principles to maximize thrust efficiency. Also, we would like to be able to 3-D print or mold our own propellers to perfectly couple with our motors.

Lastly, the frame structure that we have been using consists of ½-inch PVC pipe. By choosing a different material for our frame structure, we may gain insight in how to design a more rugged and user friendly ROV.

9. ACKNOWLEDGEMENTS

There are several people and organizations that we would like to thank for their support:

1. All MATE personnel (Matt Gardner, Jill Zande, etc.) for orchestrating the MATE ROV competition, addressing our questions and concerns.
2. Garrett College for supporting the Project Kraken team and providing space and equipment for the construction of our ROV.
3. Garrett College Foundation for providing funding.
4. Our Garrett College liaison Qing Yuan for managing our fundraising, and travel.
5. Our mentor Phil Malone (GEARS, Inc.).
6. The CARC center for allowing access to their pool to test our ROV.
7. All our college instructors.

10. REFERENCES

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Authors: Moore, Bohm & Jenson