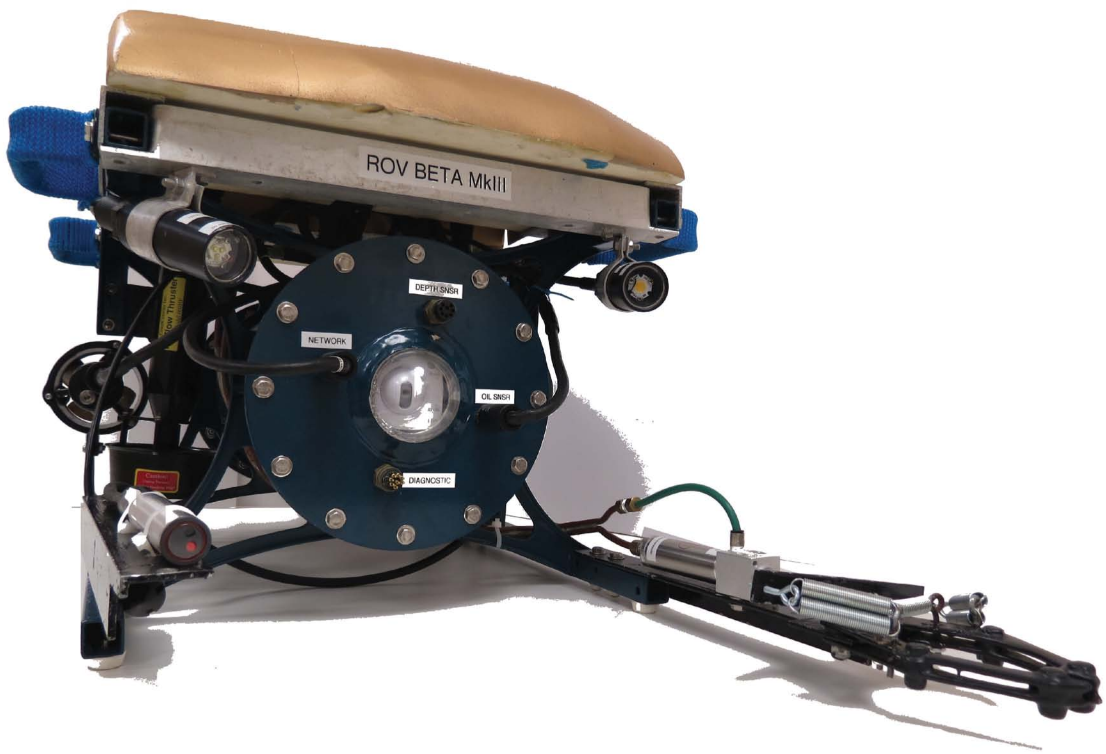
Georgia Tech Savannah Robotics



Remotely Operated Vehicle Beta MkIII

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Savannah, Georgia

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Message from the CEO

For the past four years, Georgia Tech Savannah Robotics has developed platforms tailored specifically to our clients' needs. In keeping with our tradition of customer satisfaction, Georgia Tech Savannah Robotics (GTSR) strives to always bring the best to our customers. As the new CEO of Georgia Tech Savannah Robotics - ROV Division, I am pleased to announce the debut of our revamped ROV, Beta MkIII.

The newest features on Beta MkIII include low maintenance manipulators, improved remote telemetry, and a more intuitive interface. Also updated on Beta MkIII include a new software architecture, TCP/IP communication, and improved deployment time. As always, our products continue to be built with quality components from National Instruments, Texas Instruments, Sea Con, and CrustCrawler.

I promise to continually bring you the best in underwater technology and earn your trust. As always, Georgia Tech Savannah Robotics and all of the employees here wish you the very best with our new ROV Beta MkIII.

Evelyn Kim
Chief Executive Officer
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As the foremost underwater robotics venture in the southeastern United States, Georgia Tech Savannah Robotics is located in Savannah, Georgia. With easy access to oceanic fronts and other testing facilities, our products undergo constant testing and improvement in order to bring you the pinnacle of underwater robotic technology.

Photo on cover:
Image of ROV Beta MkIII during development.

Abstract

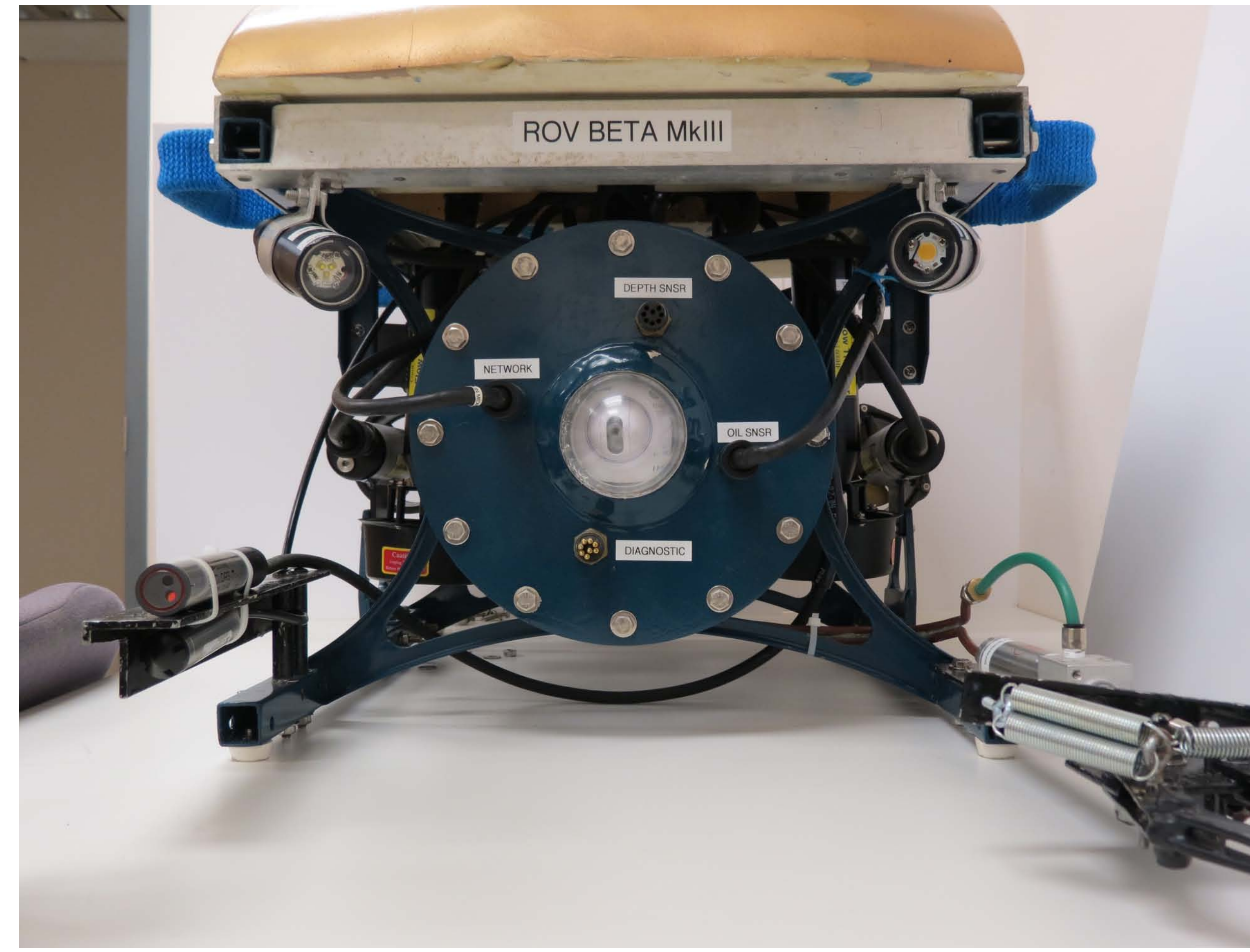

Figure 1. ROV Beta Mk III during initial test phases after refurbishment.

ROV Beta MkIII was developed as a response to the Marine Advanced Technology Education Center's (MATE) call for a remotely operated underwater vehicle to survey the WWII shipwreck, SS Gardner, and to facilitate environmental conservation through the removal of toxic materials.

After three years of development, ROV Beta MkIII inherits the cylindrical steel hull, four high power CrustCrawler thrusters, and a pan and tilt camera. To meet the demands of the mission, several systems were augmented, including: a more versatile clawed manipulator, new sensors, and faster, more reliable software architecture. Hardware improvements include enhanced reliability and more efficient high voltage speed controllers.

To meet the MATE center's call to action, Georgia Tech Savannah Robotics proposes ROV Beta MkIII as a new, highly versatile platform for underwater survey and repair.

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Introduction

GTSR was founded in January 2009 by a group of undergraduate engineering students at the Georgia Institute of Technology - Savannah campus. Since then, GTSR has excelled in the field of underwater robotics, while also expanding into autonomous surface vehicles. GTSR's team is comprised of a small, but specialized group of undergraduate engineering students with graduate mentors and faculty support. For the development of ROV Beta MkIII, GTSR - ROV Division consists of six undergraduate engineers.

Keeping in mind the experiences of previous years, ROV Beta MkIII improves on the reliability and versatility of ROV Beta MkII. Aside from base improvements in reliability and efficiency, new specialized subsystems have been created to meet market demands while also facilitating cross market applications such as a planned mission to survey a Civil War era shipwreck off the coast of Virginia.

Figure 2. Georgia Tech Savannah Campus.

Design Rationale

ROV Beta MkIII is completely modular in design, allowing seamless subsystem integrations to satisfy individual client needs. For this year's MATE International ROV Competition, it was decided to develop payloads that were mission oriented, yet flexible enough to be used for other scenarios, such as tasks for real world applications. The ROV has a standard payload which is included every year as it serves the most important and basic functions, such as providing illumination, eyes, movement, and buoyancy. This year's mission calls for a survey and assessment of the situation of a shipwreck that contains oil which must be extracted. For the purpose of this and other missions, a two-pincered claw manipulator was created. This design allows the ROV to carry out all of the tasks, without the need of a specialized, mission specific manipulator that only has one use.

ROV Beta Specifications

Mechanical

The ROV shown in Figure 1 has dimensions of 57.15 x 92.58 x 46.36 cm (W x L x H), weighs 56.7 kg, displaces 39 kg of water, and is comprised of the pressure vessel, mounting rack, propulsion system, buoyancy system, and manipulator. The majority of the body is comprised of aluminum and carbon steel. Nite Tide Rustoleum paint is used to protect the carbon steel from corrosion.

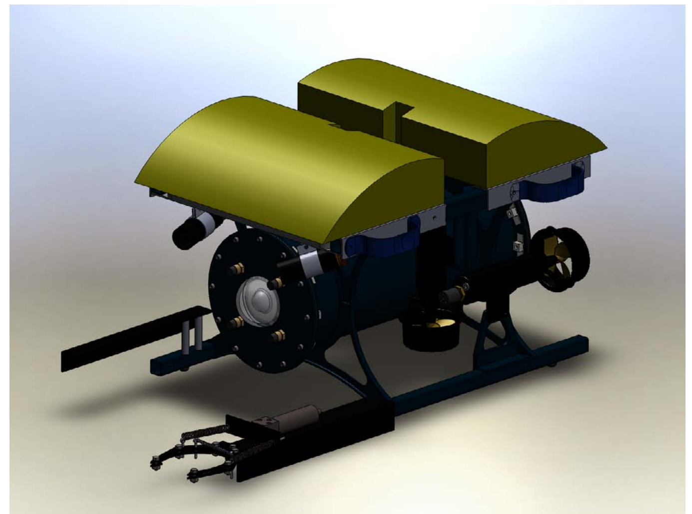

Figure 3. ROV Beta Mk III Solidworks Model.

Pressure Vessel and End Cap

The pressure vessel, as shown in Figure 4, is 406.4 cubic cm in volume and is rated for 152.4 m of depth. The pressure vessel is cylindrical with two removable end caps mounted on the forward and aft ends of the cylinder.

The caps are sealed with rubber gaskets and secured to the vehicle using twelve bolts on each end. Each cap houses waterproof SEA CON connectors used for through-hull electrical connections. The forward cap is equipped with a transparent acrylic dome for the primary camera.

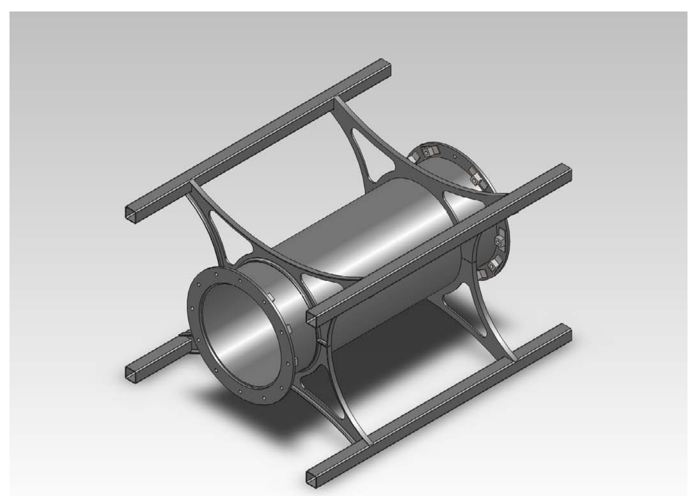

Figure 4. ROV Beta MkIII Pressure vessel with mounting rack.

Mounting Rack

The mounting rack is made from Carbon steel and is welded directly to the pressure vessel. All mechanical subsystems are mounted to the ROV via the rack. Each rail on the mounting rack is 50.8 cm in length.

Propulsion

Propulsion is handled by four, 600 watt CrustCrawler thrusters, each capable of producing 111.2 N of thrust. The thrusters are mounted using student designed mounts. The positioning of the thrusters allows for four degrees of freedom for the ROV's motion. All thrusters are oil compensated to improve performance at depth and to increase overall reliability.

Propulsion (continued)

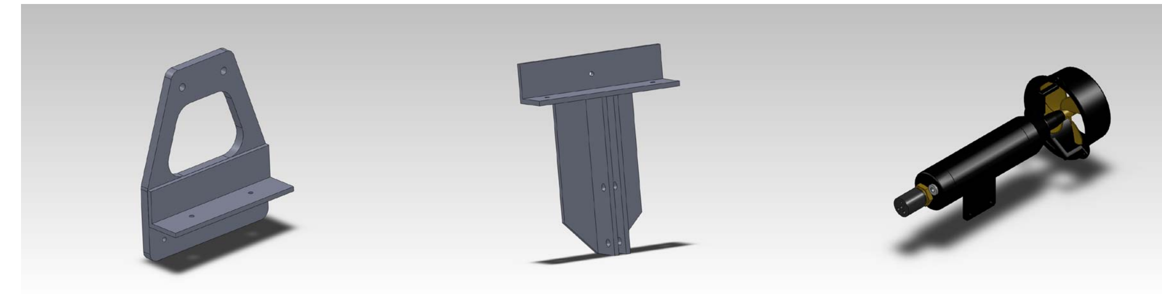

Figure 5. (left to right) Horizontal thruster mount, vertical thruster mount, and CrustCrawler thruster

Buoyancy

The negative buoyancy of the ROV is offset by positively buoyant syntactic foam. The syntactic foam is mounted using four pieces of aluminum angle that are bolted straight to the top of the Mounting Rack. The syntactic foam is then bonded to the aluminum angle with epoxy. The foam is mounted in such a way that it places the center of buoyancy above the center of gravity, allowing the ROV to be more stable.

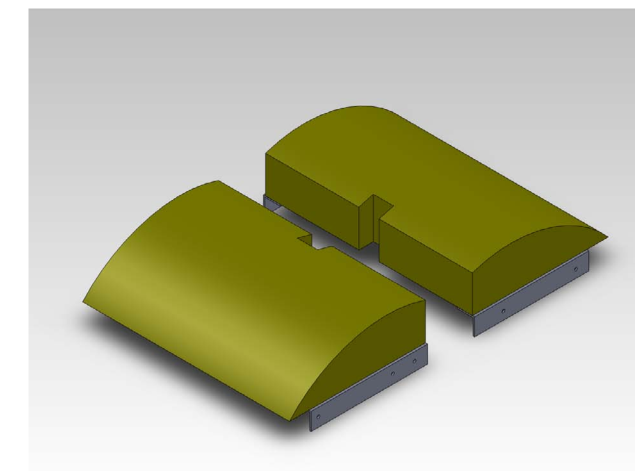

Figure 6. Syntactic foam with aluminium mounts.

Manipulator

The Mark 3 pneumatic manipulator as seen in Figure 5 is constructed from aluminum. The manipulator is designed for collecting objects no wider than 7.62 cm. It has one degree of freedom and is powered by three steel springs and a pneumatic actuator operating at 65 psi. The springs increase the holding strength, allowing it to tightly grip objects. A second effect of the springs is the quicker reaction times while closing. At the bearing joints, nylon washers are used to reduce friction. The entire manipulator is painted with black rustoleum paint to prevent corrosion.

Figure 7. Above. Solidworks model of manipulator.
Figure 8. Left. actual manipulator.

Pneumatics

Mechanical power, used to drive the manipulator and sampling subsystems, is stored and transmitted using fluids. The compressed air is stored in an 41.6 L tank with a max pressure rating of 689.5 kPa. The vacuum is stored in a 19 L, 13.6 kg tank with a max pressure rating of 2.76 MPa. The tanks are filled using a 12 Vdc reciprocating pump. All tanks are DOT rated.

The pneumatics are routed around the body of the ROV by copper piping. The rigidity of the copper piping helps hold the lines to the body and reduce the chance that an airline will get damaged by a thruster.

Tether

The tether is 94.5 m in length and weighs approximately 90.7 kg in air. It is comprised of three polyethylene lines, rated for 1.03 MPa maximum as well as vacuum rated, one Cat5e line, and 10 awg 4 conductor wires for power.

Electrical Systems

Power system

The ROV Beta MkIII is powered by four marine deep cycle lead acid batteries connected in series. On board the ROV, the 48 volts is converted to 24 and 9 volts to power the subsystems on board. The 9V regulator is designed and manufactured by our electronics department to ensure it fits the needs of our systems perfectly. The 9V regulator has a minimum voltage of 6V and a maximum of 14V, and has up to 90 seconds of reserve power. The compact RIO (cRIO) is behind a capacitor bank to ensure systems will stay operational during voltage drops due to thruster action. All systems shut off after five seconds of full power loss.
All systems are protected on board by a marine fuse block and the main power supply is behind two 40 amp breakers. An easy access emergency cut-off switch is located at the control station.

Communication System

The communication link is conducted through a gel-filled direct burial cat5e cable. The system can transmit data at a rate of up to 100 Mb/s
On the shore side, the communication is routed by an Asus RT-N12 router with 802.11n wireless band. The use of a router on shore allows the control computer to wirelessly connect to the point where the tether enters the water. On board the ROV, there is a Trendnet Green Net 5 port Gigabit switch. The switch connects to the cRIO and network camera.

Computation

The ROV uses a HP DM1Z with AMD Fusion processor as the control computer, along with an extra 23" LCD display. The main computer runs on Windows 7. The ROV uses a National Instruments CompactRIO and chassis with a built in Field Programmable Gate Array (FPGA) for on board computation and IO. The FPGA is produced by Xilinx. The cRIO has a 400Mhz processor and 128MB of Ram. The chassis has room for 4 modules produced by National Instruments. Currently in use is an Analog Input module, a Digital Input/output module, and a Solid state relay module.
The thrusters are controlled by four high voltage ESCs developed by CastleCreations. The ESCs operate at 48V and have a maximum current limit of 120 A each.

Sensors

Beta MkIII's sensor payload is comprised of a Keller America Depth Sensor rated to 15.24m, a Panasonic BL-C210A pan and tilt camera mounted inside the pressure vessel with a viewing dome, and a microstrain 3DM-GX1 IMU.

Electrical Schematic

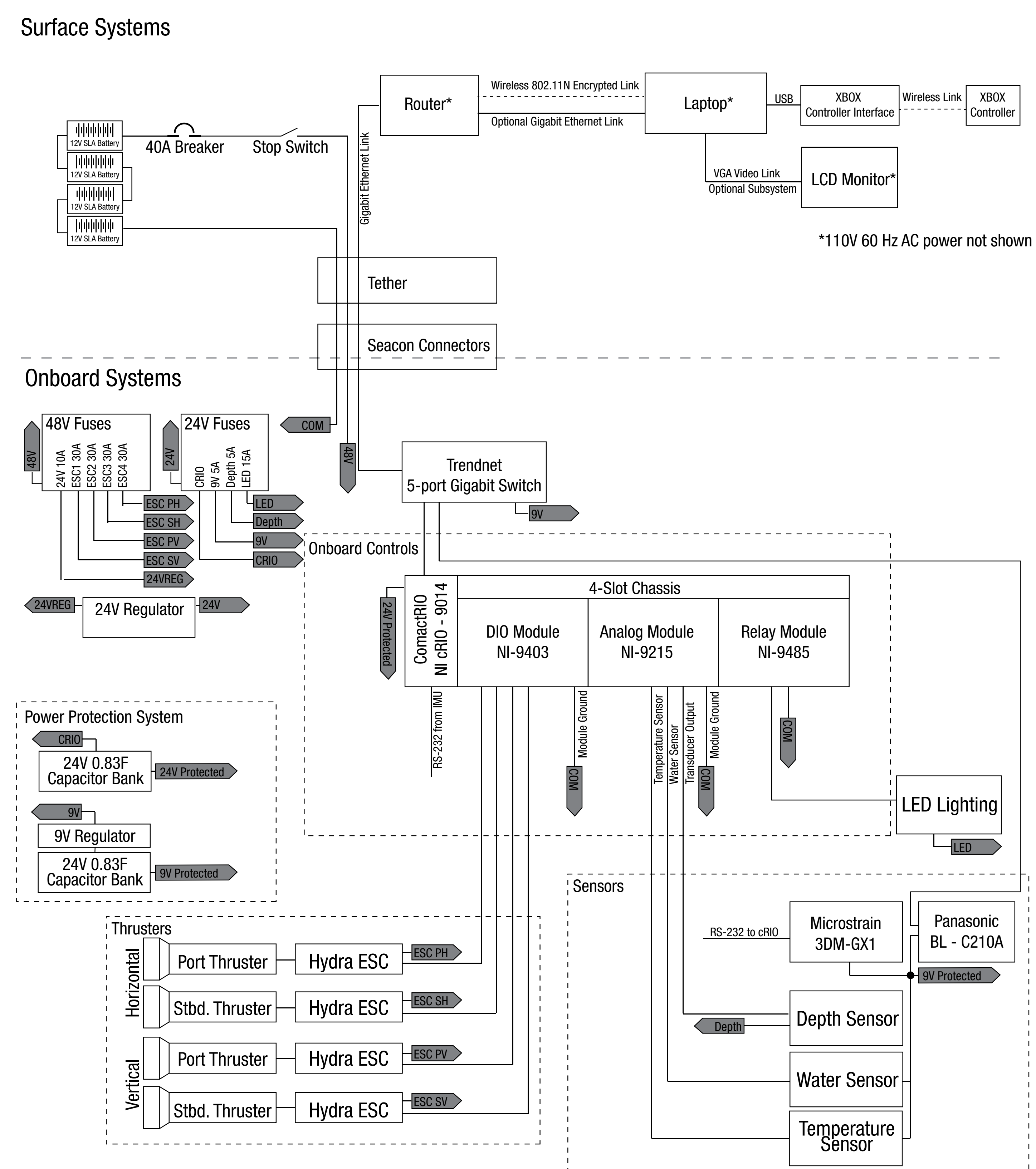

Figure 9. Electrical Schematic for ROV Beta MkIII.

Software

The ROV software is written using National Instruments' LabVIEW graphical programming language. The LabVIEW programming language has its advantages in its ability to quickly prototype new features in code and its built in variable arbitration, making the use of multiple threads easy. Computation is divided between two devices, the shore computer and the cRIO with build in FPGA. Communication between the cRIO and the shore is handled using Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) network protocols. The overall design of the software was made with modularity and expandability in mind.

The code has been broken down into multiple files to facilitate a large team of codes working on the project in the future. The overall design of the state machine,communication, and IO were created with the ability to add autonomous functionality in the coming years without the need for a complete code rewrite.

User Interface

ROV Beta MkIII's user interface was designed in LabVIEW. The interface is broken down into three sections for easy viewing. The first section is the general operation menu. This menu provides indicators for all the sensors currently deployed on the ROV as well as information regarding communication and controller statuses. The second section provides two graphs. The first graph plots depth for the last 4 seconds and when in auto depth mode, shows how the vehicle is matching the set depth. The second graph shows the thruster signal that is being sent out of the FPGA. The last section is the settings menu. The settings allow real time remapping of thruster controls, the ability to change network settings, and the constants that govern the depth controller. All controls are accessed on the Xbox Controller (Figure 10).

Communication

All data sent between the shore computer, cRIO, and network camera is transmitted using either TCP or UDP. TCP is used for sending state change commands to the cRIO and movement commands to the pan and tilt camera. When a command is needed to be sent via TCP, it is added to a queue inside the program. For every iteration of the TCP thread, the program removes the oldest message from the queue and then sends it to the cRIO. This set up allows multiple locations to send commands without needing to know what the other sections of code are doing.

UDP was chosen for the thrusters and sensor data transmission due to the need for rapid updates, minimum bandwidth usage, and missing packets not being an issue.

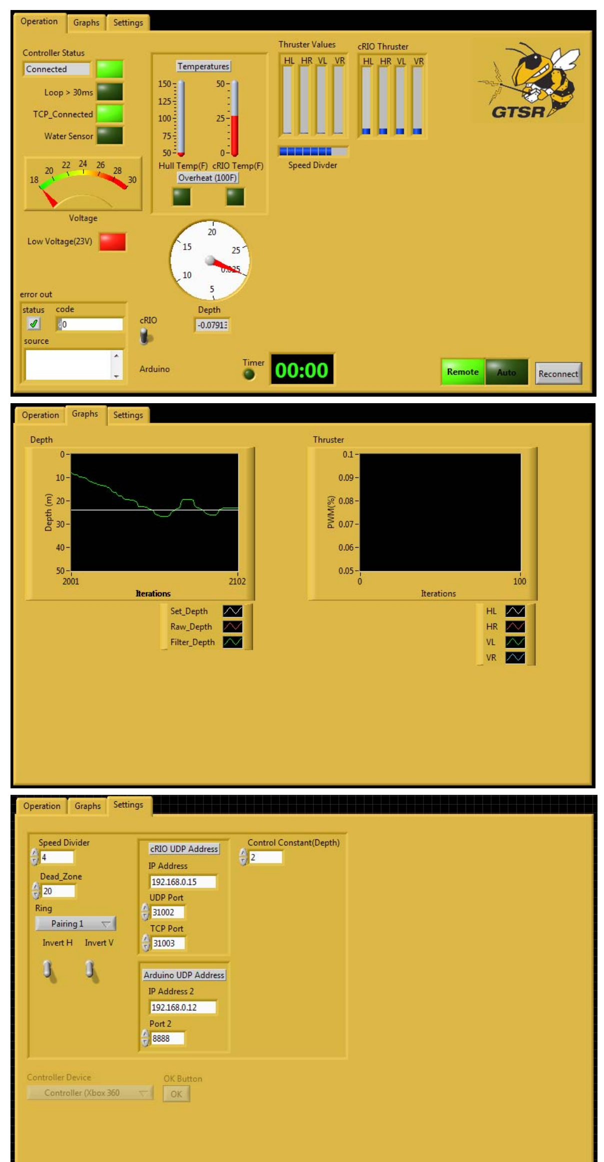

Figure 10. From top to bottom. Main panel, graph panel, and settings panel.

Thruster Control

Thruster Commands are sent via UDP messages every 40ms to the target. The command is in the form of a percentage between -100% and 100%. Once on board the cRIO, the thruster value is converted into a Pulse Width Modulation (PWM) duty cycle value between 0.05 and 0.10 before being sent to the FPGA. The FPGA then smooths out the changes in the thruster signal before it is sent to the speed controllers. This action prevents damage to the thrusters due to large changes in speed.

If at anytime the cRIO stops receiving UDP packets, the FPGA is sent zeros for the PWM signal and shuts down the thrusters. The smoothing filter will also prevent this stop from being too quick, thus protecting the thrusters from potential damage.

Figure 11. Xbox controller and mappings.

Auto Depth Controller

This year we will be implementing a PID controller to regulate the vehicle's depth, allowing the driver to have an easier time focusing on the task at hand. The controller was tuned through data collected from pool testing.

Sensors and Logging

All sensors are read through the FPGA built into the cRIO's chassis. All sensor and thruster data is then logged, along with current state and error codes. The logged data is later used to debug code and improve the overall performance of our ROVs by running it through simulated runs of old and new versions of code.

Figure 12. Above. cRIO, chassis, and modules.
Figure 13. Below. Depth sensor.

Software Flow Diagram

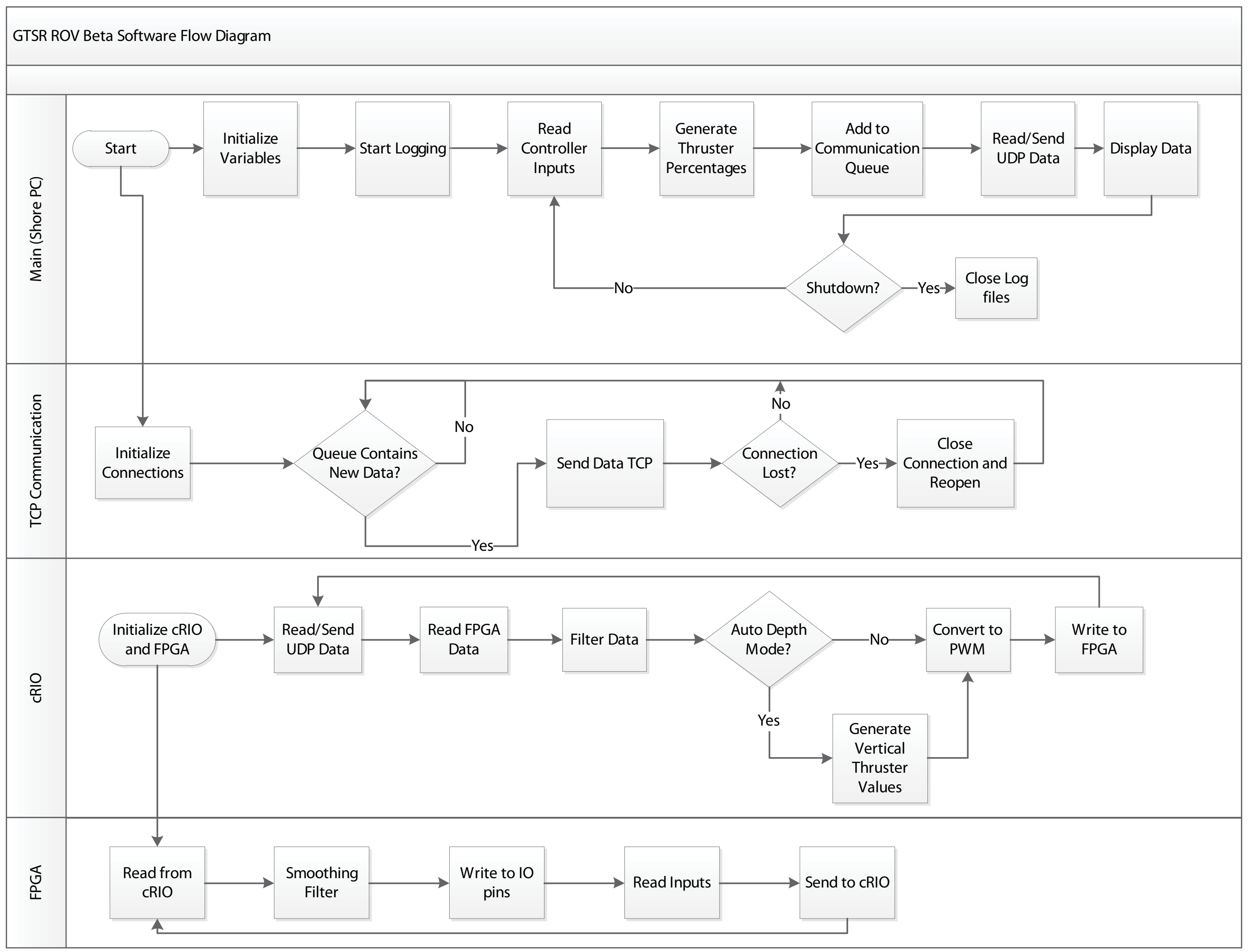

Figure 14. Software flow diagram for ROV Beta MkIII.

Mission Plan

To accomplish the tasks set before us, we have developed adaptations to our general class ROV Beta MkIII model. However, many of the tasks only require our standard payload.

The first thing that needs to be accomplished in the mission is a survey of the wreck site and data collection to ensure a successful extraction of oil. Using a rotary encoder attached to a spindle of string with a hook, we will measure the length of the shipwreck. The rotary encoder will be attached to the spindle, so that as the string unravels, the encoder will measure the rotations. Using a simplified conversion, we can then determine the length from the rotations. The orientation of the ship will be determined with the built in compass of the newly installed Inertial Measurement Unit (IMU). Our vehicle will also be installed with a magnet and hall effect sensor to determine if the debris in the surrounding area is ferrous or not. Using data and camera footage, the co-pilot will be able to construct a map of the wreck site. Then, the newly developed automatic depth control system, combined with the extremely stable design of our ROV, will scan the ship with sonar to portray a better image of the wreck.

After the site has been surveyed, we will proceed to damage control. The task of damage control will be handled by our Mark 3 Manipulator and sampling system. The manipulator will easily transport the lift bag and attach it to the mast. The lift bag will then be inflated by purging air from the sampling system into the bag. With the lift bag inflated, the mast will be lifted off of the seafloor and moved over to a designated area, with guidance from the manipulator. We will then use the manipulator to gently relocate any coral to a safe location. Using our newly installed neutron backscatter and ultrasonic thickness gauges, we will measure the hull's thickness and check for the presence of fuel oil.

In the case of fuel oil being present, we will penetrate the hull and use the sampling system to extract the fuel oil. However, to prevent a dangerous collapse of the ship caused by the negative pressure difference created between the hull and the environment, a second line will pump in seawater simultaneously with the oil extraction. After the operation, the drill hole will be sealed with a magnetic patch put into place by the manipulator.

Safety/Troubleshooting

While developing Beta MkIII, the team, in keeping with our high standard of safety and reliability, added many safety features. Shrouds over thrusters not only vector the thrust, but also prevent accidental contact with the thruster prop. The location of the thrusters also prevent damage being done to them during operation and reduce the likelihood of injury. The many safety labels located at hazardous locations upon the ROV are there to protect individuals who are uninformed about the dangers of this unit. An emergency shut off button is located on the shore side control center in case the need arises to rapidly shut down the unit. On board the ROV, is a fuse block to protect the circuits, as well as breakers at the control station and batteries to prevent harm to the control circuits and anyone around them.

In case of a software glitch, all run time data is logged on board and can be reviewed after the end of operation to find the source of the bug. Also, during operation, all monitoring information is sent to shore to allow the driver to diagnose any potential problems when it happens.

Challenges/ Teamwork

Our greatest challenge was having to repair our ROV after serious damage due to water intrusion that occurred during its last research trip. This required spending a tremendous amount of time on repair instead of focusing on improvement and apparatus design for the upcoming tasks. This was made more difficult by the restructuring of our organization. In the past year, the ROV team started collaborating the ASV team, reducing the available resources that could be allocated to the ROV. All of this was overcome with the dedication of the ROV team. Meetings were held every other week and deadlines were planned to help keep day to day objectives on track.

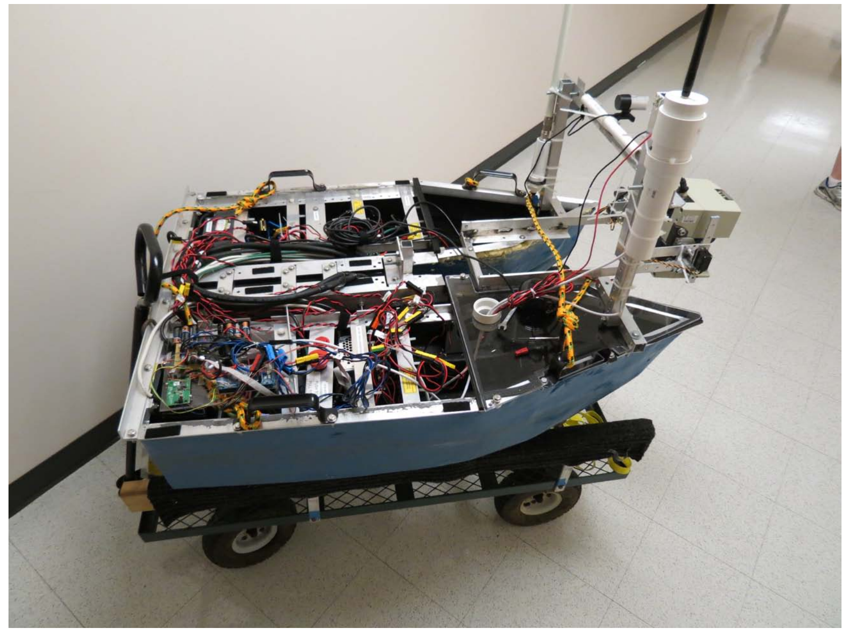

Figure 15. ASV during development.

From a technical standpoint, the failure of our ESCs and the increasing age of our current thrusters lead to the need for new hardware. The ESCs had to be completely replaced with newer, higher voltage, ESCs. The thrusters were not such an easy fix. Due to their price, effort was put towards repairing the once non operational thrusters.

Lessons Learned/ Future Improvements

Lessons learned throughout the process of developing ROV Beta MkIII have given great insight as to how things should be done in the future. First off, a clear separation between the two divisions of the team need to be defined. Due to the limited amount of staff available, misallocation of the resources resulted in a stalled effort in the ROV division while the ASV division got focus. In addition, a regular maintenance and check schedule was developed and is in the process of being refined after a near catastrophic failure when the ROV returned from a deployment with water intrusion and was left to fester for months untouched.

Future improvements to the ROV's mechanical systems include upgrading the pneumatic actuator for the manipulator to an electronic one allowing quicker actuation with more precision. This will be the first step towards developing an electronic manipulator, with multiple degrees of freedom, robust enough to be used for a wider range of tasks. A readjustment of the vertical thrusters with a slight outward angle protrusion would give the ROV an additional degree of freedom in movement, strafing.

Future refinements to the software systems include adding more stability features and automatic piloting routines. Included among these are camera based holding functions, using IMU data to assist in piloting to the site, and using camera data to stabilize the manipulator for more precise control.

Real World Applications

The MATE Center's request for proposal is for an ROV to perform an assessment of the oil tanker *SS Gardner* which was sunk on December 25, 1942 by a German U-Boat. During the month of July, the GTSR team will be conducting a trip to virginia to survey Civil war Shipwrecks as part of a NSF grant. This research will be done alongside researchers from the College of William and Mary of Virginia.

Reflections

"Working with Beta's code has given me a better understanding of the complicated inner workings of computers and how they interface with external hardware."
-Brian Redden

"As a member of team, I have come to be a part of a group and have been given new inspiration for success. I have also learned to appreciate the fine points of group dynamics as a whole and to work with each of the members shortcomings as well as their strengths to the full advantage of the team."
–Michael Tam

"This experience has taught me just how important time management, planning, and goal setting are. These skills are essential for any successful team in both the academic and professional environments."
-Michael Bunch

"Working with this amazing team has taught me a lot about teamwork and dedication. It has shown and taught me much about what passion for engineering really is about."
-Evelyn Kim

"Designing and implementing electrical systems on the ROV off site and delivering all parts through the mail was a unique experience. Without direct access and with remote video chat being the only option for support, pretesting, and proper design became a fascinating, but sometimes frustrating experience."
– Phillip Cheng

Working together as a team, each of us contributing our own skills, and drawing on the strengths of others to fill the valleys of our weaknesses, the experiences and memories of this year will truly be an experience to remember, and will never be replicated. But those of us who can will be returning next year to repeat the frustrations, but also the joys of underwater robotics.
- Georgia Robotics Technologies

Acknowledgements

We would like to thank SeaCon for their discounts on their great watertight connectors. CrustCrawler for their powerful thrusters. MATE for hosting this competition and giving us this great opportunity. Castle Creations for the high voltage electronic speed controllers. Vicor for the high efficiency 48VDC to 24VDC regulators. National Instruments for the expandable compactRIO system. National Science Foundation for the funding to do everything here. The mentors for dedicating the time and effort to provide us with useful advice. Georgia Tech Savannah for the facilities to house and work on the ROV.

Expense Report

Item	Vendor	Qty	Unit	Expense	Donation /Discoun
NI cRIO-9024	National Instruments	1	pcs	$ 2,429.00	$ 1,700.30
NI 9403 DIO Module	National Instruments	1	pcs	$ 3,779.10	$ 2,645.30
NI 9215 Analog Module	National Instruments	1	pcs	$ 514.00	$ 359.80
NI 9485 Relay Module	National Instruments	1	pcs	$ 287.10	$ 200.90
High-Flow Thruster Model 600HF	CrustCrawler	4	pcs	$ 6,396.00	$ 800.00
WET-CON Connectors	SEA CON	8	pcs	$ 2,500.00	$ 1,000.00
UWL-401 Low Voltage LED Light	Outland Technology	2	pcs	$ 2,600.00	$ 2,600.00
Hydra HV-60	Castle Creations	4	pcs	$ 1,116.00	$ 335.00
Steel for Hull	Metals Depot			$ 400.00	
Southwire 10-4 SOOW	Home Depot	100	m	$ 372.00	
Cat5e	Home Depot	100	m	$ 100.00	
Polyethelyne Tubing	Grainger	300	m	$ 78.00	
Depth Sensor	Keller America	1	pcs	$ 300.00	
HP dm1z Notebook	HP	1	pcs	$ 500.00	
Panasonic BL-C210A Camera	Amazon	1	pcs	$ 150.00	
Asus RT-N12 Router	Amazon	1	pcs	$ 40.00	
Dell E2009W 20" LCD	Dell	1	pcs	$ 300.00	
Pneumatic Actuator	Bimba	1	pcs	$ 40.00	
Xbox Controllers	Amazon	2	pcs	$ 80.00	
Pelican 1600 Series Case	Grainger	1	pcs	$ 255.00	
Misc. Hardware	Grainger, Home Depot			$ 200.00	
Misc. Electronics	Digikey, Jameco			$ 200.00	
Misc. Pneumatic Hardware	McMaster Carr			$ 150.00	
	Subtotal			$ 22,786.20	
	Discounts				$ 9,641.30
	Funded Cost			$ 13,144.90	

*Expenses covered by NSF grants obtained by Dr. Fumin Zhang

Design Rationale

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Publication fonts	Photography	Typsetting
Helvetica Neue Lt Std, Minion Pro	Phillip Cheng, Michael Tam	Phillip Cheng