Seawolf IV

Seawolves
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Wesson, MS

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Co-lin S.U.R.E.

I. Abstract

The seas' below-the-surface unknowns have called to humans like a celestial siren since the beginning of time, yet conducting work below-surface has been remotely impossible until the emergence of recent technologies.

Seawolf Underwater Robotics Engineering (S.U.R.E.) serves as an education-based organization focused on the design, engineering, and manufacturing of Remotely Operated Vehicles (ROVs). S.U.R.E.'s company collectively operates in departments including engineering, drafting, electronics, and machining in which advanced technologies are utilized including AutoCAD, SolidWorks, and Computer Numerical Control (CNC) milling to maximize productivity and efficiency.

Seawolf IV is S.U.R.E.'s latest ROV iteration and is purposefully manufactured for service as a refined observational/working class ROV capable of conducting work and research below the Arctic's surface in frigid temperatures. The vision behind the vehicle is one which has taken experience from S.U.R.E.'s past efforts, collective brainstorming, and research over the past several months. In its present state, Seawolf IV is a highly capable underwater vehicle precisely engineered to weather the Arctic environment.

Figure 1: 2015 S.U.R.E. Company

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II. Design Rationale

2.1 Overview

Seawolf IV utilizes a High Density Polyethylene (HDPE) frame held together by stainless steel screws to form a robust housing structure. In all, there are eight separate pieces of HDPE: two vertical sides and six horizontal cross-member bars held together by stainless steel screws. A stainless steel mounting frame is attached between the top of the two vertical sides to seal the acrylic electronics enclosure (ebox) and aluminum lid. Careful consideration was taken into account of how the ebox is designed, and thus a square design was selected to maximize the space for electronic and hydraulic components.

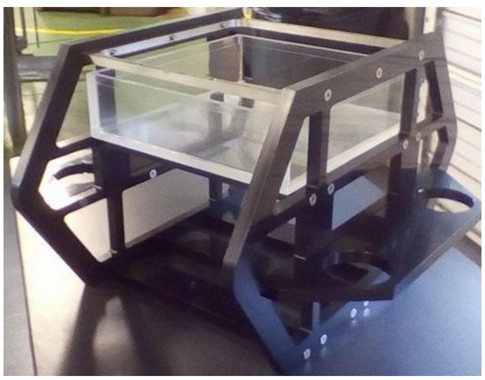


Figure 2a: HDPE frame with acrylic ebox.

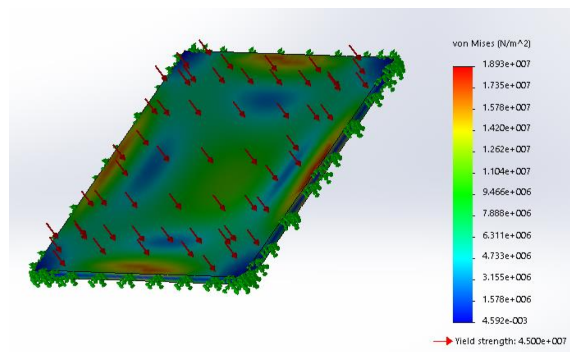
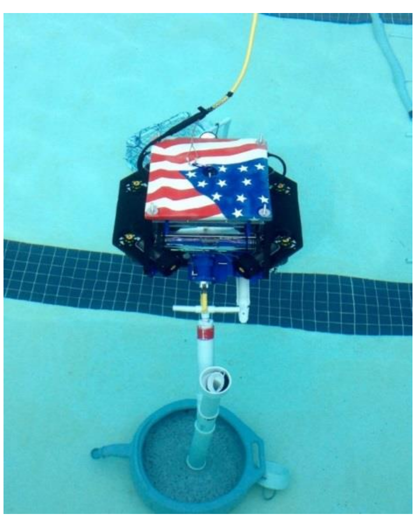


Figure 2b: Stress test in SolidWorks to test the square design of the ebox.



Two thruster wings are mounted on either side of Seawolf IV's frame to protectively place the four vertical thrusters. The four horizontal thrusters are secured by custom 3D printed mounts. To achieve slight positive buoyancy, a syntactic foam block is mounted on top of Seawolf IV. LED lighting adorns Seawolf IV within the ebox and the front and rear camera/laser tubes.

Figure 3: Seawolf IV demonstrating stability by inserting a hot stab into a wellhead.

2.2 Frame

Discussion concerning the material of the frame served as a rudimentary first step in designing Seawolf IV. The company decided upon 12.7 mm High Density Polyethylene (HDPE) because of its ability to operate in extreme temperatures (120°C to ⁻100°C) in terms of expansion, contraction, and brittleness. HDPE's light weight and almost neutrally buoyant characteristic also served as an important factor the Seawolves considered as it reduces stress on the thrusters. Concerning the shape of the frame, the company first discussed using a square, rectangular form because of its popularity in the ROV community. Examination of the physics of the frame and testing in Inventor and SolidWorks 3D CAD (seen in figure 2b) brought S.U.R.E. to its current frame design of a 55° hexagonal figure due to strength and aesthetics advantages a hexagonal frame provides over a square, rectangular frame.

Seawolf IV's frame is tapped and held together with stainless steel screws. Stainless steel hardware was chosen because it is an industry standard for rust-resistance. To achieve desired buoyancy, Seawolf IV is equipped with a fiberglassed syntactic foam block and is trimmed with weights to compensate for its mission-specific tooling.

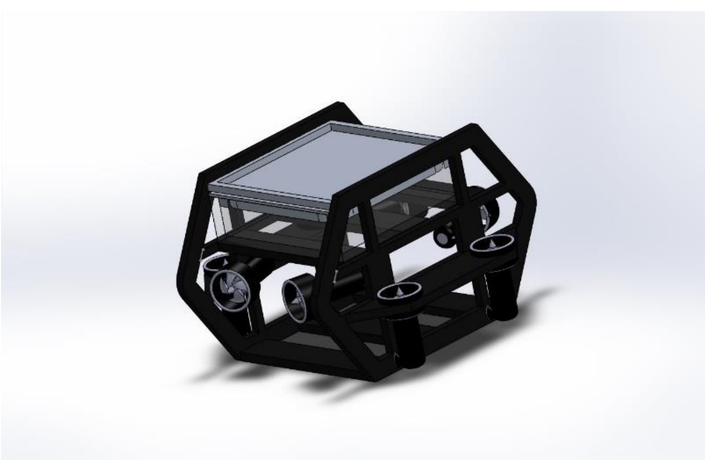


Figure 4: Computer Simulation of Seawolf IV's frame with thrusters and electronics box.

Figure 5: Painted syntactic foam block.

2.3 Electronics

Seawolf IV's acrylic electronics enclosure (ebox) serves as the compartment which contains the electronic boards and hydraulics systems. Mounted within the acrylic bottom are ten bulkhead and hydraulics connectors including: tether connections (eight-pin Ethernet port and three-pin power port) and connections for tooling, lighting, and thrusters. Within the box, the 8 H-bridge thruster controllers mount along an aluminum divider which serves as a heat sync for the electronics systems to dissipate heat through. A pressure release plug is also mounted into the acrylic bottom.

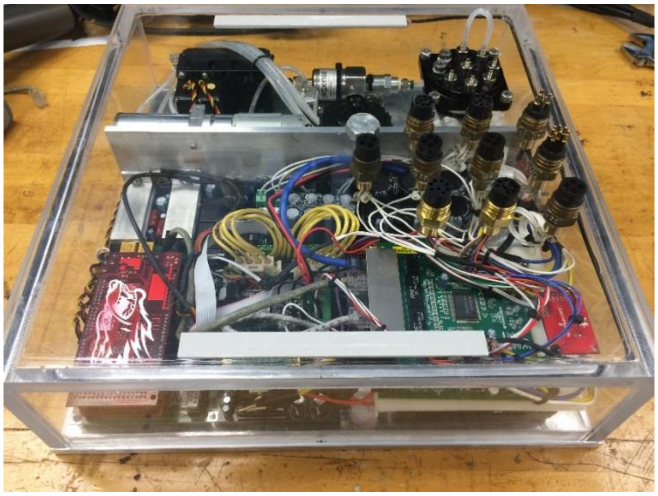


Figure 6: Seawolf IV's ebox system houses electronics and hydraulic control systems (bottom view).

To tightly seal the ebox with its aluminum lid, a nitrile rubber o-ring seal is placed in between the acrylic top and the CNC machined aluminum lid (seen in Figure 7). The nitrile o-ring is rated to –30°C and was chosen for optimal sealing in Arctic conditions. A watertight seal is achieved from tightening bolts in the machined stainless steel frame to compress the ebox's rubber o-ring between the frame and cross sections below the ebox.

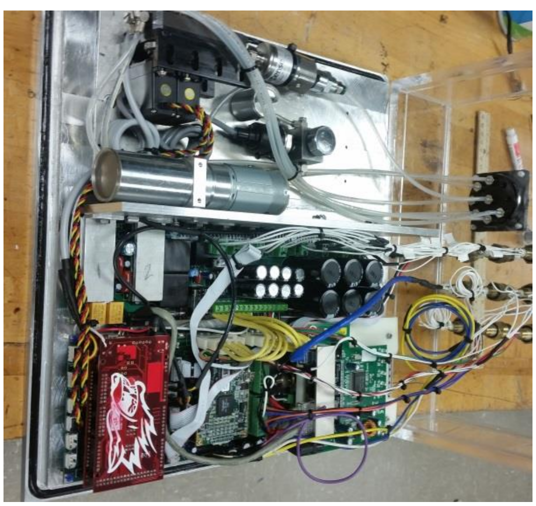


Figure 7: Nitrile rubber o-ring installed in aluminum lid.

Figure 8: Testing the ebox compartment for waterproofing.

Within the ebox is an Ethernet switch that connects the tether to two on-board components: chipKIT Max32 microcontroller (see section 2.4) and an Axis video encoder (see section 2.5). Temperature is monitored within the ebox in three locations including power supply, motor controls and ambient which is displayed in LabVIEW (see section 3) allowing the pilot to monitor the on-board temperature. A Sparkfun 9DOF Razor IMU includes three sensors with nine degrees of inertial movement: an ITG-3200 (MEMS triple-axis gyro), ADXL345 (triple-axis accelerometer), and HMC5883L (triple-axis magnetometer). LabVIEW uses this inertial data to display the ROV's pitch, yaw, and roll.

Seawolf IV utilizes two in-house designed circuit boards created with National Instruments software Ultiboard (see Figure 9a/9b and Figure 10a/10b).

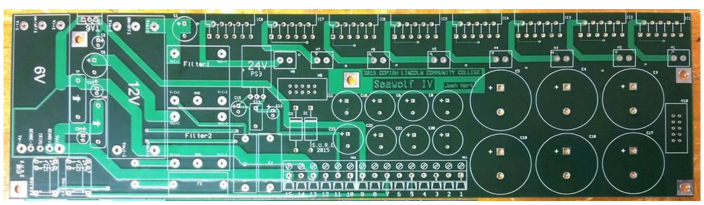


Figure 9a: High Voltage Board before components.

Figure 9b: High Voltage Board with components installed.

The High Voltage Control Board (power supply) converts 48vDC into filtered 24vDC @ 300mA, 12vDC @ 20A, 9vDC @300 mA, and 12vDC @ 20A and accounts for optimum filtered power to each component of Seawolf IV. The power supply utilizes industry standard 1/8 brick DC-DC converters, frequently used in networking equipment. The converters are fused to prevent over current and are tested at 94.5% efficiency with the ability to operate in harsh environments including extreme cold and heat with very little specification derating.

Figure 10a: A top view of the Low Voltage Control Board designed by our Electronics Engineer.

Figure 10b: The Company logo can be seen on the bottom of the board (right).

The low voltage control board includes the Diligent chipKIT Max32 microcontroller with network shield (see section 2.4), video multiplexer (see section 2.5), lights/laser switching, and an ambient temperature sensor.

2.4 Microcontroller

Seawolf IV reuses last year's 80 MHz 32-bit chipKIT Max32 microcontroller. Featuring a 32-bit MIPS processor core performing at 80 MHz, 512K of flash program memory and 128K of SRAM data memory, the microcontroller operates on an in-house customized firmware version of the LINX open source project in which the firmware is designed to accept Ethernet packets from LabVIEW and translate these packets into commands for the ROV hardware components.

Figure 11: Right is the chipKit Max32 microcontroller that is mounted on the Low Voltage Control Board.

2.5 Video/Lighting Systems

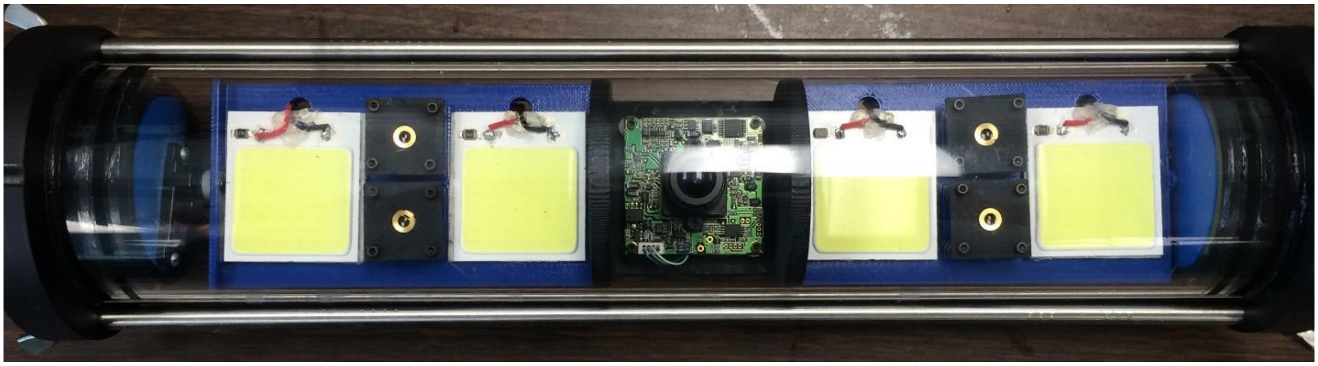


Figure 12: One of two camera tubes equipped on Seawolf IV which houses a camera, four LED modules and four lasers.

A total of three cameras are mounted on Seawolf IV, but on request a fourth waterproof camera is available to be mounted onto the frame for mission specific tasks. On both the front and rear ends of Seawolf IV, camera tubes (at a diameter of 51.75mm) are mounted to allow our ROV to utilize the potential of tooling. A prime example of utilizing both the front and rear cameras is the task of servicing a wellhead. Seawolf IV uses a custom piece of PVC tooling on its rear side to remove and hold the cap from the wellhead while the front manipulator places the gasket inside the wellhead. In this task, Seawolf IV is not required to leave the top of the wellhead because it is equipped with two cameras and can simply hover its front and rear sides to complete the task, switching fields of vision. Within each camera tube's left end cap is a servo motor which rotates the camera mounts for optimal viewing with a range of 180° of tilt. Our blue camera mounts are in-house designed and the mount assembly within each tube is accompanied by a single camera, four LED modules, and four adjustable 5mW lasers. The four LEDs are 12V chip on board (COB) modules, and through LabVIEW the brightness can be adjusted.

Laser utilization allows Seawolf IV to measure distances, such as the keel depth and diameter of icebergs or other objects by surveying four points along the perimeter. Seawolf IV is equipped with eight 5mW lasers— the first set of four is calibrated to measure (near field) close distance, while the second set is calibrated for (far field) farther distances. Calibration is achieved by adjusting four mounting screws on each laser. The laser beams are set to intersect at fixed distances (near and far field) in which a calibrated grid placed on a monitor allows for accurate measurements.

Figure 13: Seawolf IV at night with lighting and laser systems enabled.

Seawolf IV's third camera is mounted stationary inside of the ebox to focus on the bottom view of the ROV. A four input Ovation Systems video multiplexer is utilized to multiplex the camera signals, allowing the pilot to control which camera or groups of camera feeds are transmitted back to the surface. All of this data is routed through a single input to an Ethernet video encoder which operates as a web server. The video is then accessed through the surface computer via the tether's Ethernet cable. Also within the ebox are mounted 2 long 12V LED light strips to illuminate the surrounding area of the ebox.

2.6 Thrusters

Seawolf IV is equipped with eight SeaBotix BTD150 thrusters (four vertical and four horizontal) with continual bollard thrust of 2.2 KGF, running at 24 VDC and 110 W maximum. The four vertical thrusters are protectively mounted within two HDPE wings, while the four horizontal thrusters are mounted to custom in-house designed and printed mounts. These eight SeaBotix thrusters have proven reliable and capable in the past and have thus been reused.

Figure 14: (Left) A horizontal thruster can be seen fastened to a 3D printed mount. (Bottom) Vertical thrusters are shown mounted into an HDPE wing.

2.7 Manipulator

Our hydraulic manipulator was designed for Seawolf III under the motivation to create a functional manipulator with 2 degrees of freedom. The design was first drawn on paper and discussed, and then 3D printed prototypes were tossed around until the current design was achieved. The manipulator was drawn in CAD so that a 3D rendering could simulate the functionality of the manipulator.

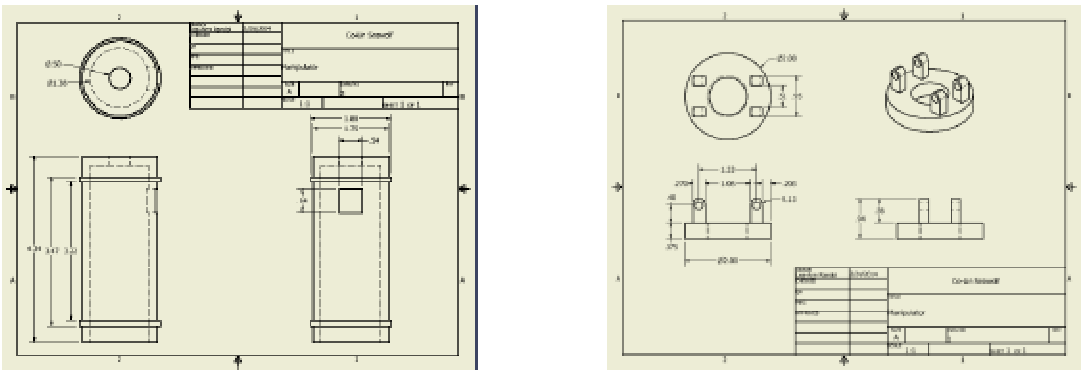


Figure 15: Technical illustrations of the manipulator's ABS printed actuator housing and aluminum allow jaw mount.

The jaws are composed of five layers of stainless steel cut by laser and welded together to create two single pieces. A machined in-house aluminum alloy mount positions the ends of the two jaws to allow for a pivot point upon the jaw's open and closing movements. Micro-sized hydraulic components enclosed within the ebox control the manipulator's movements.

The entire system including fittings, hoses, and components is rated at 2,068 kPa or more. Within the ebox is a pump with a built in reservoir and adjustable bypass, a servo controlled valve block to direct the flow of fluid, two linear actuators, and two pressure sensors. Pressure is controlled under the safety mark of 1034 kPa at 999.7 kPa. The pump is turned on an off in LabVIEW when the manipulator needs to be used. When the pump is on and the pressure reaches the maximum 999.7 kPa, servos direct the hydraulic fluid (biodegradable food grade hydraulic oil, ISO Grade 32/46, SAE grade 20) to the varying actuator components to control movement.

The manipulator is capable of rotating 90° by means of a 7.62 cm stroke hydraulic actuator mounted inside an ABS 3D printed rack and pinion assembly, while the grasping movements of the manipulator are controlled by a 2.54 cm stroke actuator. The claws are coated within yellow Plasti Dip in consideration of safety and visibility.

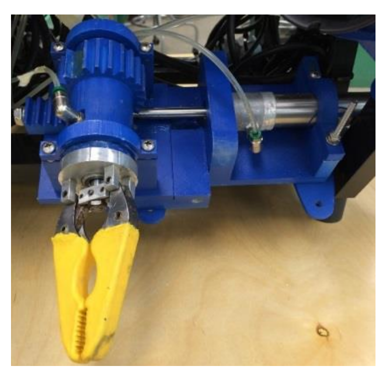


Figure 16: Hydraulic manipulator.

III. Software

Seawolf IV utilizes the National Instruments program LabVIEW. The program is complex enough to control the many components of Seawolf IV and is easily accessible in adjusting commands in its user friendly Graphical User Interface (GUI). LabVIEW allows the ROV to be controlled with a laptop computer in which the computer performs the majority of data processing rather than the microcontroller. Considering the gap in CPU performance between the pilot computer and microcontroller, communication process is sped up using LabVIEW.

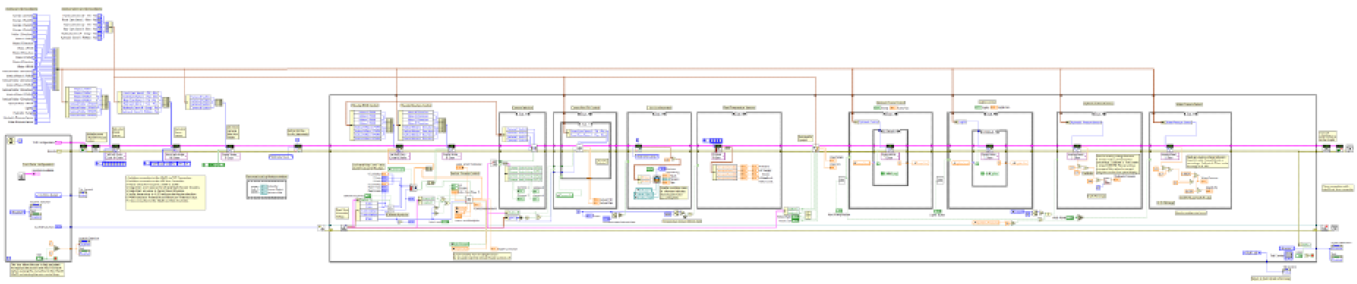


Figure 17: This is an overview of our LabVIEW program that controls our ROV. Each small sub .VI contains more code like shown below.

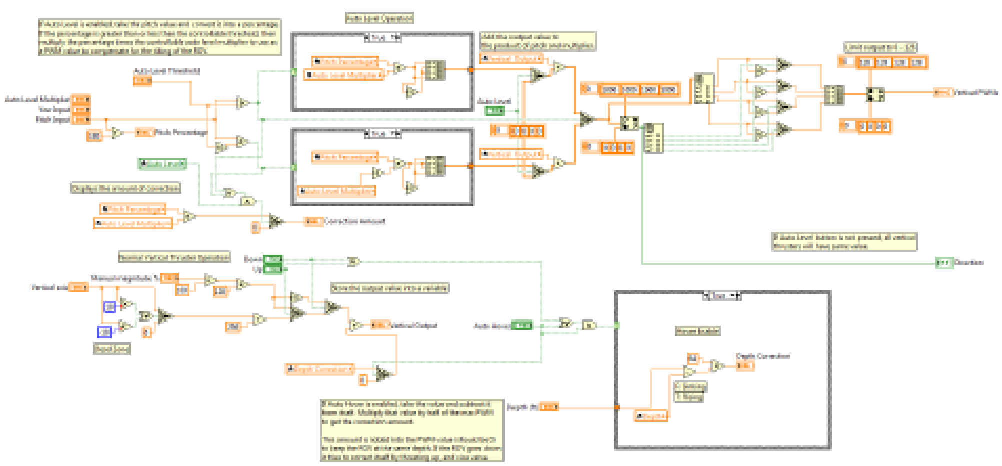
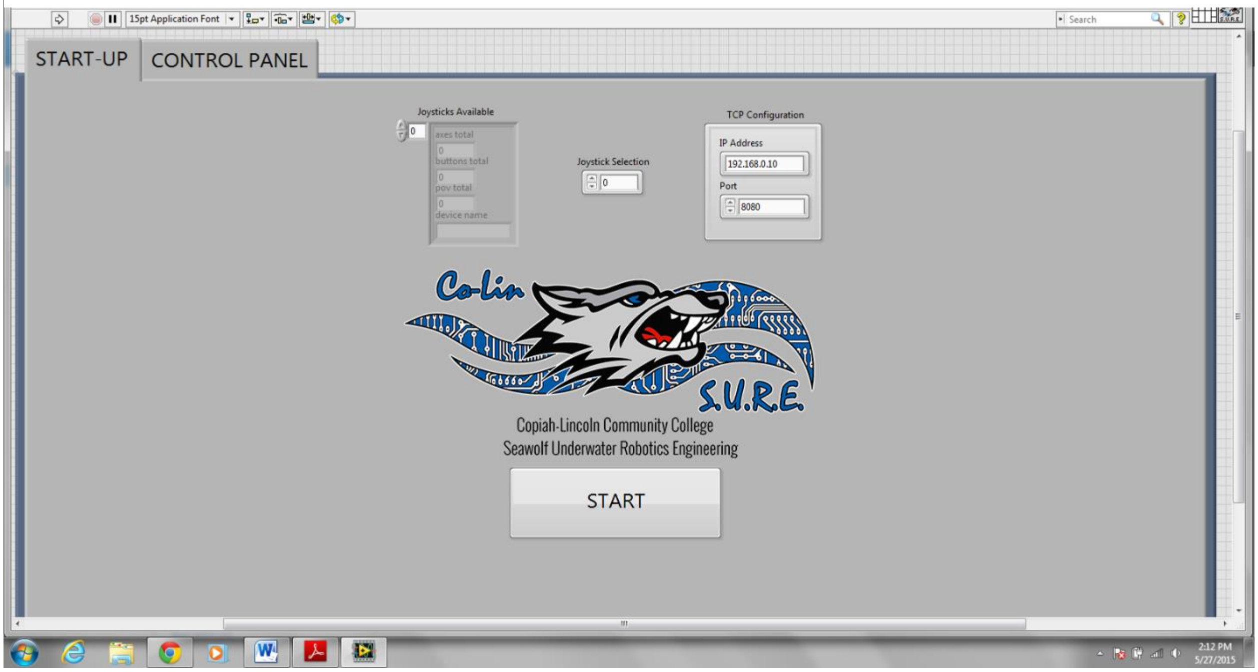


Figure 18: This is one of our sub .VI's that controls our vertical thrusters. It's also the code for our Auto Level and Auto Hover functions. If neither Auto functions are selected, the vertical thrusters are controlled by the Xbox controller and all thrusters rotate at the same speed. If Auto Level is selected, the code above will try to correct for any pitch in the ROV by taking the pitch value and converting it into a percentage so the correcting PWM value will be gradual instead of always fast or always slow. If Auto Hover is selected, it reads in the depth value from the water pressure sensor and tries to hold that value. If the value increases or decreases, the thrusters will thrust accordingly to return Seawolf IV to the target depth.

Figure 19: shows our front panel controls on start up. This allows you to select an available controller to drive with, and connects with the IP address that is on the microcontroller.



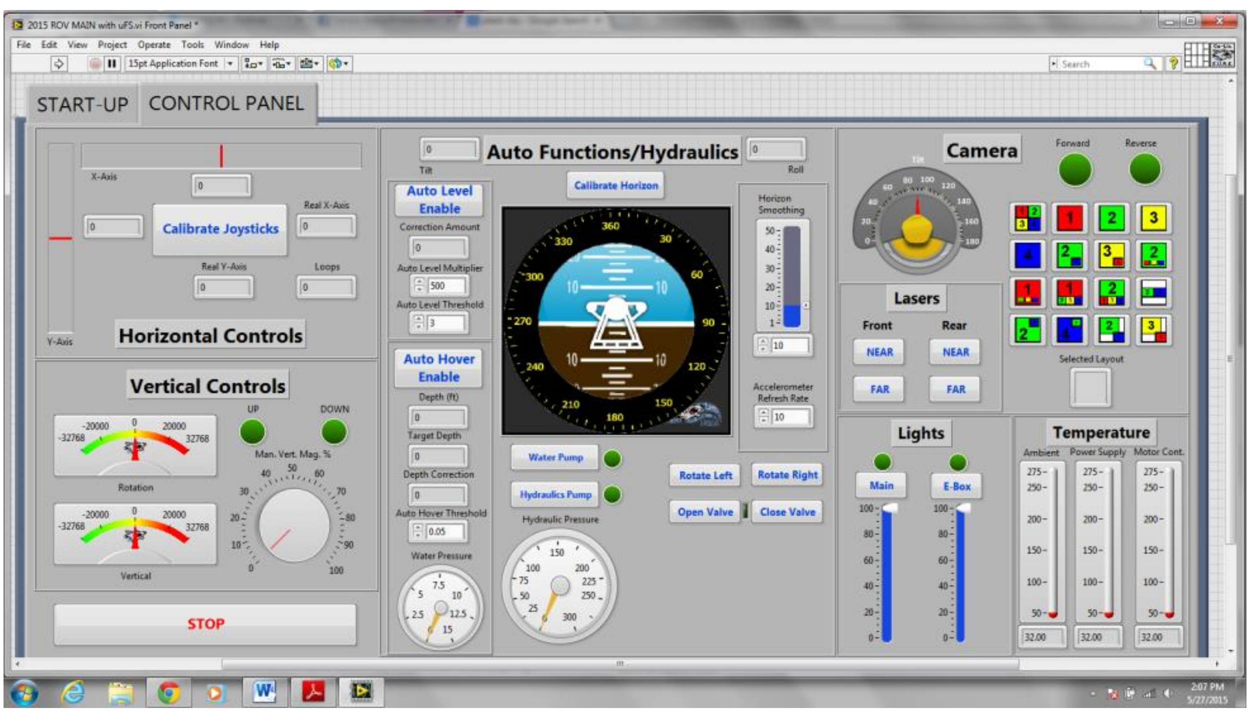
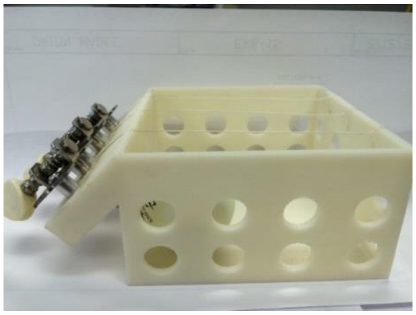


Figure 20: shows the front panel once it has made connection. This gives us controller values for the thrust, camera servo positions, hydraulic pressure, water pressure, water depth, temperatures readings for motor controllers, power supply and ambient temp., and a horizon indicator showing the position of the ROV.

IV. Tooling

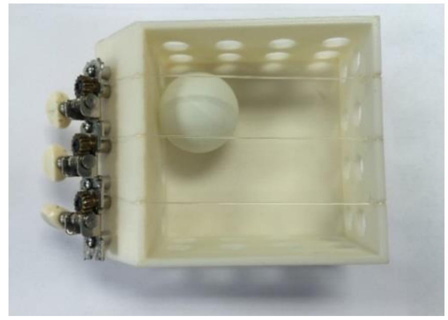
4.1 Algae Retrieving Cube (ARC)

Figure 21a:



(Left) shows a side view of ARC. (Right) shows a top view of ARC.

Figure 21b:



The Algae Retrieving Cube (ARC) serves to safely retrieve algae from underneath an iceberg. The ABS plastic box is an in-house print from the drafting department using AutoCad and was designed in consideration for water displacement and service drag utilizing holes. ARC's design utilizes tension knobs inspired by tuner knobs found on guitars to secure .86 mm clear fluorocarbon line (Martin and Company guitar string) so that the algae is not damaged in retrieval. The buoyancy created by the algae is not powerful enough to cause it to float out of the box by thrusting the lines apart.

4.2 Tool Basket

Seawolf IV utilizes a simply yet efficient tool basket which it carries down to the bottom of pool or ocean floor to carry items needed to complete tasks. The basket is manufactured from 1/2" PVC pipe with dimensions including 56.7cm (L) X 35.5cm (W) X 23.1cm (H) and is enclosed with nylon netting held in place by zip ties. One mission task the tool basket has been helpful in is the capping and hotstabbing of a wellhead in which the basket holds the items needed for the task.

Figure 22: Tool basket with hot stab and wellhead gasket.

V. Safety

At all times in S.U.R.E.'s efforts safety has come first in the design, construction, and testing of Seawolf IV. S.U.R.E. company members were initially briefed on safety when entering work zones such as the machining and electronics labs where safety glasses are worn always to protect each member's eyes (see Figure 23). Our SeaBotix thrusters are manufactured with warning indicators and propeller shrouds in consideration of the individual and environmental safety (see Figure 24). Seawolf IV's ebox is equipped with 8-H bridge thruster controllers mounted along the aluminum divider to serve as a heat sync for the electronics systems to dissipate heat. Keeping the components cool prevents catastrophic failure and the possibility of an on-board fire. On the power supply board, each DC-DC converter is suited with a slow blow fuse to provide fault and over current protection to the converters and electronic circuitry.

Figure 23: Machinist employing safe work procedure with safety glasses.

Figure 24: SeaBotix BTD150 with warning indicator.

Figure 25: Strain relief hook attached to tether and power supply

Figure 26: Quick disconnect in line 20A fuse holder.

On the tether, there is an in-line 20A fuse and a strain relief hook to prevent tether damage (see Figure 25). The tether is tested with a break away release rate at 40A 600V and in the instance that the emergency stop switch jams, the tether can be quickly disconnected to stop power output to the ROV (see Figure 26).

VI. Issues/Lessons Learned

6.1 Camera Tubes

The front and rear tubes in which Seawolf IV's camera and laser systems are mounted have proven a challenge in selecting the correct material to use. We first ordered extruded acrylic tubes, but found that these would be insufficient from a visibility standpoint because within the tubes, lines are present that fragment visibility for the camera and laser systems. This distortion would prevent accurate pipeline, iceberg, and keel measurement tasks. Research then led us to select cast acrylic tubes because these tubes are lineless and allow for optimal visual performance.

6.2 Camera Tube Endcaps

The construction of endcaps for the camera tubes proved to be a very difficult task. Several designs and materials were used in attempt to 3D print the endcaps. It has been determined that a 3D printed structure is not capable of being completely waterproof. The process of 3D printing causes a layered grid pattern of material which remains porous even with the use of external sealants. Ultimately, the endcaps were milled from a solid high density plastic, resulting in an enclosure that is waterproof to well below 6 meters.

VII. Future Improvements

After hours of testing and use in Arctic extreme environments, the Seawolf IV has proven to be excellently engineered machine. As a company we are seeking to advance ROV production mainly around the design and fabrication process itself. Time management and task delegation is the key to developing a superior product in a timely manner. The company members must learn to work consistently from the beginning of development through to completion. They must also learn to anticipate failure and budget time for it. Equally important is for individual company members to work on separate tasks that they can see through to completion. This prevents people from watching other people work while expecting others to accomplish the task.

VIII. Experience Reflections

"I learned to program and setup CNC machinery using Mastercam. During the design process I became familiar with SolidWorks, which later helped with the programming. Designing and manufacturing the ROV has been a challenge and helped me become a better machinist."

—Thomas Westrope (Precision Machining)

"Starting as a freshman and joining the Co-Lin Seawolves has been quite an experience. I have grown from not knowing anything about underwater ROV's to understanding more than I ever thought possible. I have learned so much about solid teamwork, and the effects of having a great team. This involvement has taught me more than I would ever have imagined."

—Lauren Westrope (Drafting, Safety Officer)

"From my involvement with the previous company I knew it was something I wanted to be an even bigger part of this year. Involvement with such a program has pushed me to not only advance my technical skills but also grow as a person. There is no better experience than hands-on."

—Josh Hart (Electronics, Pilot, CEO)

"Participating in Seawolf Underwater Robotics Engineering has opened my mind to the surrounding power of teamwork within engineering. The collaborative effort of multiple people with differing skills can bring together a more powerful product than anything a single individual can master. I have been enlightened in learning about each aspect of Seawolf IV and the ability to utilize technology to perform tasks otherwise impossible."

—Blake Pryor (CFO, Tech Writer)

IX. Project Costing

Material Expenses

Item	Quantity*	Unit Cost	Donated Value*	Reused Value*	Purchased In 2015
60ft. Tether — "Seatrepid"	(1)	$500.00	$500.00		
BTD150 Seabotix Thrusters	(8)	$578.92		$4,631.36	
Custom Manipulator	(1)	$400.00	$200.00	$200.00	
Custom Hydraulics System	(1)	$1,028.00		$1,028.00	
Custom HDPE Frame	1	$500.00			$500.00
Custom Electronic Control Subsystem	(1)	$1218.00	$140.00	$300	$778.00
Video Multiplex and Encoding Subsystem	(1)	$1800.00	$800.00	$1000.00	
Custom Camera/Lighting/Laser Canister Subsystem	(2)	$200.00			$400.00
Syntactic Foam "Outland Technology"	1	$100	$100		
Syntactic Foam "Seatrepid"	1	$100	$100		
Surface Control System	(1)	$800.00		$750.00	$50
2015 Material Donation			$340.00		
Total Material Donation			$1840.00		
2015 Material Expenditure					$1,728.00
Total Material Expenditure				$9,637.36	

*Note: ( ) contains items reused from previously purchased and donated inventory on-hand

Miscellaneous Expenses

Item	**Total Purchase**
Mission Props	$300.00
Apparel	$589.00
Mate Registration	$150.00
Travel/Lodging	$9,500.00
Total Miscellaneous Expenditure	$10,539.00

Monetary Donations/Fundraising

Event/Donor	**Amount**
Team Fundraising Events	$4,000.00
Personal Donations	$1,400.00
Co-Lin Career Technical Donation	$1,500.00
Co-Lin Foundation Donation	$1,000.00
Total Donation/Fundraising	$7,900.00

Summary

Monetary Donation/Fundraising	$7,900.00
Material Donations	$1,840.00
Material Expenditures	$9,637.36
Total Value of Seawolf IV	**$11,477.36**

X. ACKNOWLEDGEMENTS

MATE — Organizing ROV competition and education-based ROV society

Copiah-Lincoln Community College — Supporting the Seawolves through education, registration, travel expenses, and for providing facilities and technologies to conduct work.

Seatrepid — Hosting regional qualifying test, donating tether and syntactic foam.

Outland Technologies — Donation of syntactic foam and camera.

KDMC — Use of pool for testing.

Brookhill on Natchez — Use of pool for testing**.**

Brookhaven Country Club — Use of pool for testing.

Brookhaven City Glass — Donation of plexiglass for ebox.

XI. Special Thanks

Dr. Ronald E. Nettles II — President, Copiah-Lincoln Community College

Dr. Jane Hulon — Vice President of Instructional Services, Copiah-Lincoln Community College

Mrs. Jackie Martin — Dean of Career-Technical Education, Copiah-Lincoln Community College

Dr. Jill Logan — Dean of Academic Instruction, Copiah-Lincoln Community College

XII. References

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Appendix A: SID

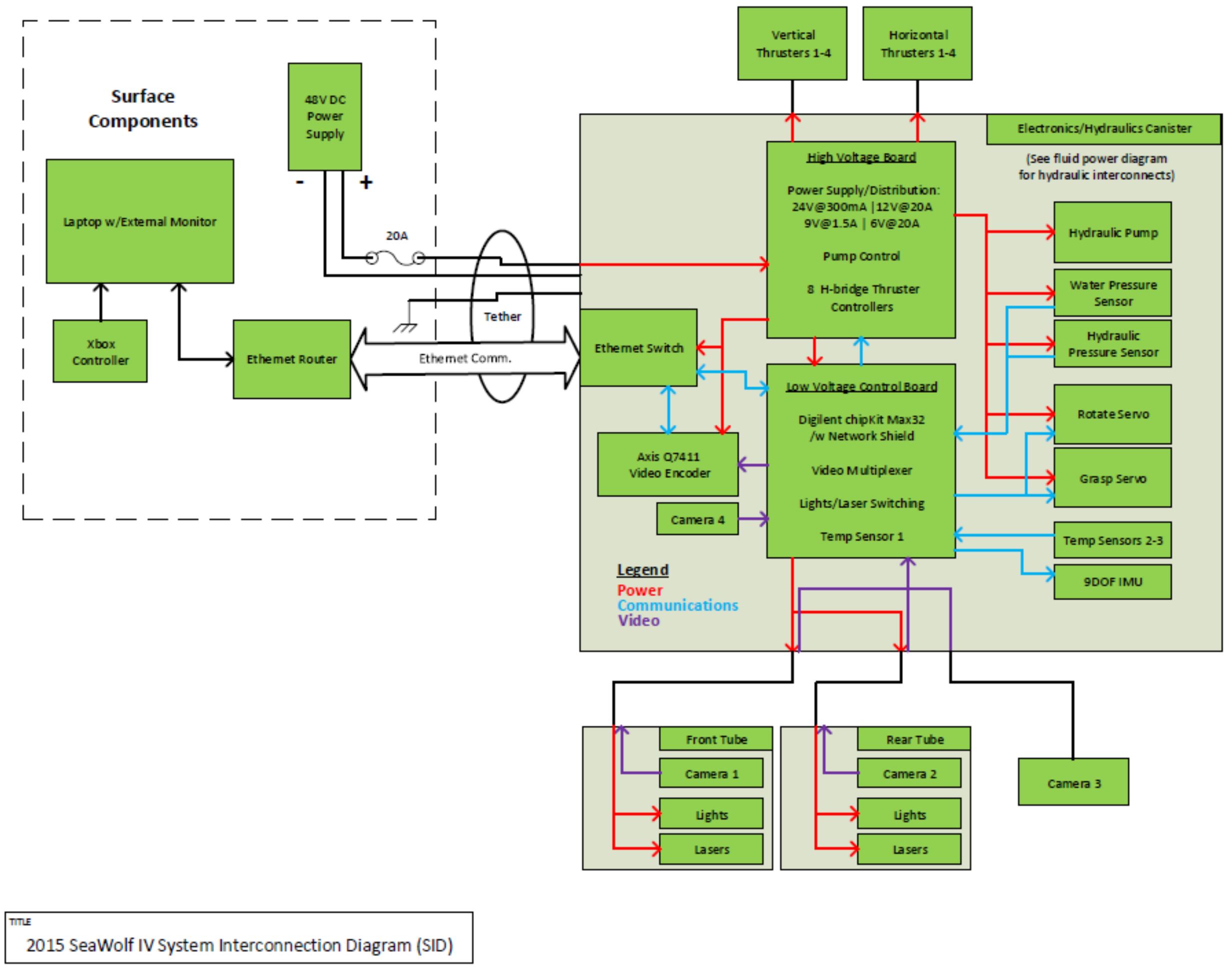

Figure 27: System Interconnection Diagram (SID) is a basic representation of how the electronics systems (surface and onboard components) interconnect to each other with data/energy flow represented by arrows.

Appendix B: FID

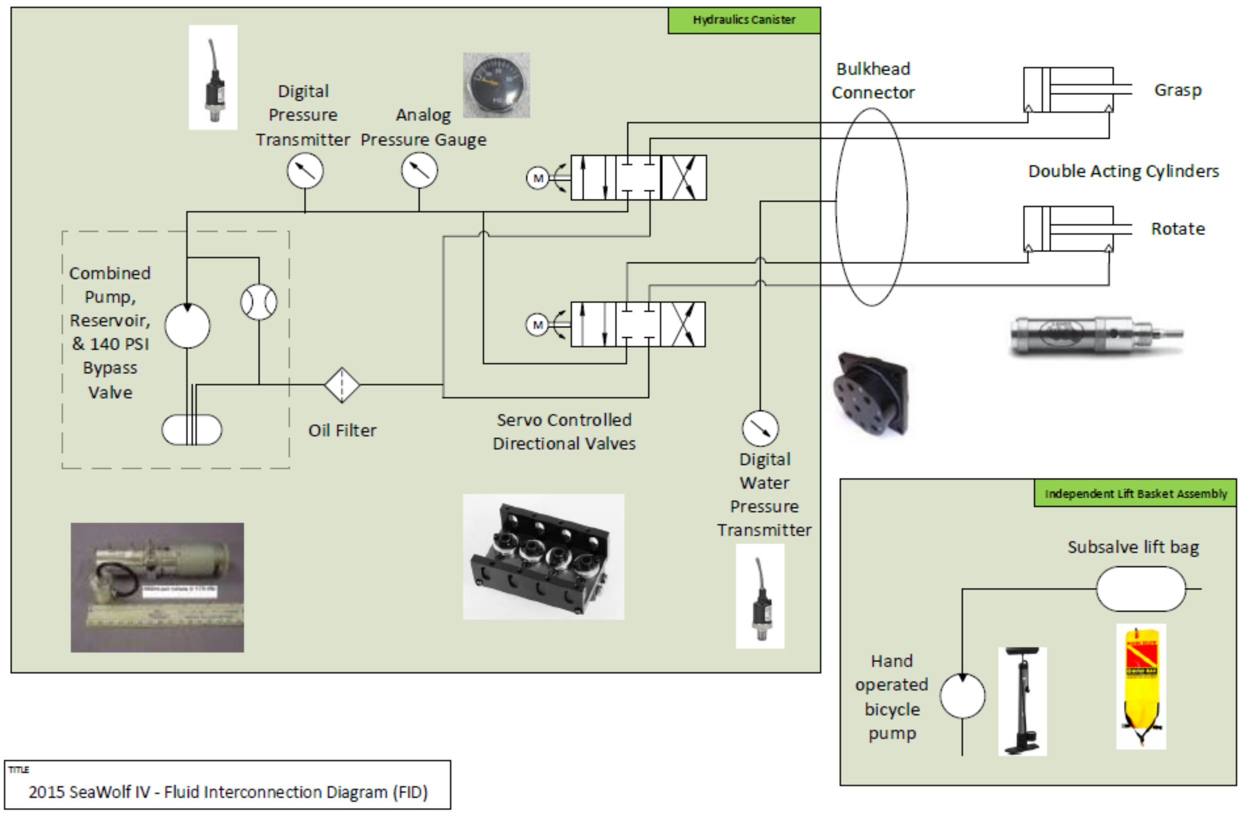

Figure 28: Fluid Interconnection Diagram (FID) represents Seawolf IV's hydraulic system components.

Appendix C: Software Flowchart

Figure 26: Software flowchart

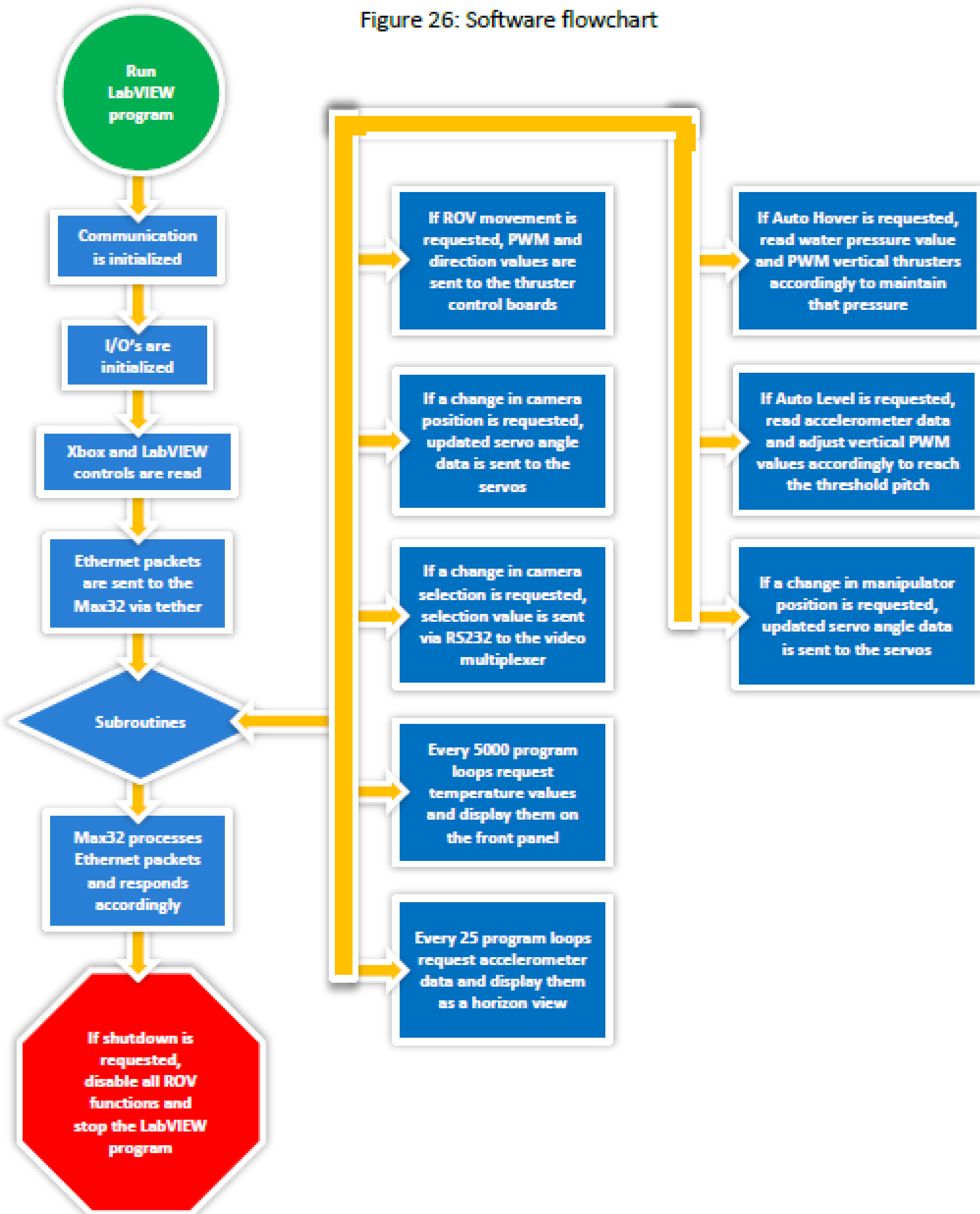

Figure 29: software flowchart shows basic functions of LabVIEW's operation of ROV

Appendix D: Pilot Controls

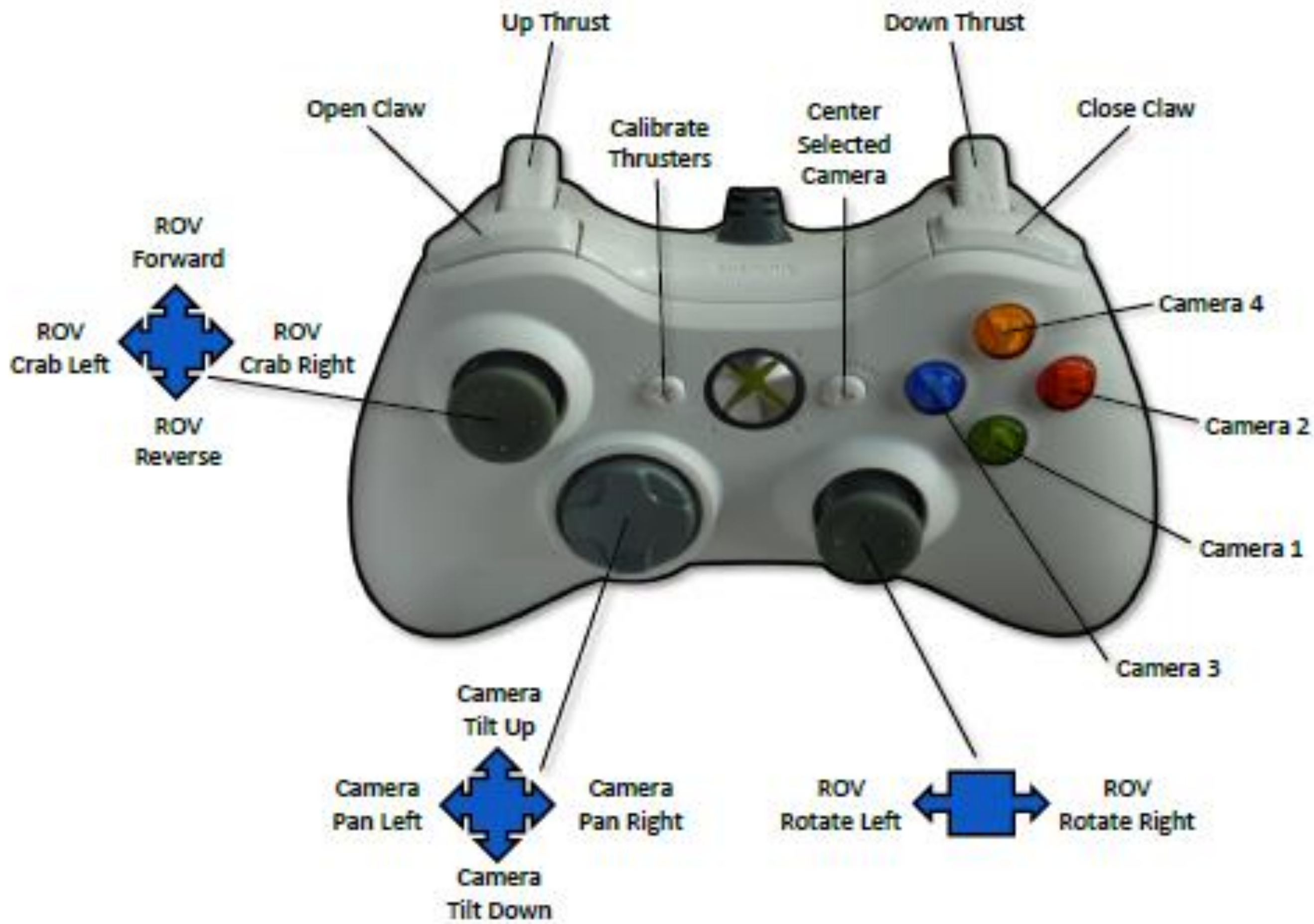

Figure 30: Labeled Xbox controller commands used to pilot Seawolf IV.

Appendix E: Budget

The 2015 Seawolf Company inherited $5,000 from the previous members. Upon learning that this year's competition is out of the country it was noted that travel would be very expensive. The company decided early on to hold fundraising events as often as possible. There was also a large effort to be put into soliciting commercial sponsors. A goal was set to raise $10,000 to bring the company account balance to $15,000. Throughout the designing and building of the ROV, items were selected with price in mind. This led to items being reused and the soliciting of donated items. All things taken into account, a budget deficit of $633 is considered a success in order to attend an international competition.

Budgeted Category	Budgeted Amount	Actual Expenditures
60ft. Tether	$0	$0
BTD150 Seabotix Thrusters	$0	$0
Custom Manipulator	$0	$0
Custom Hydraulics System	$0	$0
Custom HDPE Frame	$500.00	$500.00
Custom Electronic Control Subsystem	$1,000.00	$778.00
Video Multiplex and Encoding Subsystem	$0	$0
Custom Camera/Lighting/Laser Subsystem	$500.00	$400.00
Syntactic Foam	$0	$0
Surface Control System	$100.00	$50.00
Misc Expenses (including travel)	$12,000.00	$10,539.00
Budget Summary		
Beginning Account Balance	$5,000.00	
2015 Monetary Donation/Fundraising	$7,900.00	
2015 Expenditures	-$12,267.00	
Ending Account Balance	-$633.00	

Appendix F: Safety Checklist

Checklist	**Do the following in Order**
	Put on safety glasses
	Always team lift ROV with two members
	Make sure all plugs and caps are on ROV
	Connect the tether to the ROV and secure with strain relief
	Check that there are no exposed sharp edges
	Make sure all electrical connections outside of ROV are seated
	Check the in-line 20A fuse
	Connect the tether to the 48V power supply and secure with strain relief
	Turn on power to the laptop and monitor and make sure charger is connected
	Connect Xbox controller
	Start LabView and open the main program
	Turn 48V power supply on
	Allow the 3rd LED on internal Ethernet switch to come on
	Start program
	Check that all thrusters, manipulator and lights are working
	Put ROV in water and trim with weights