Floyd

Rose-Hulman Robotics Team

Rose-Hulman Institute of Technology
Terre-Haute, IN
Marine Advanced Technical Education
2016 International ROV Competition

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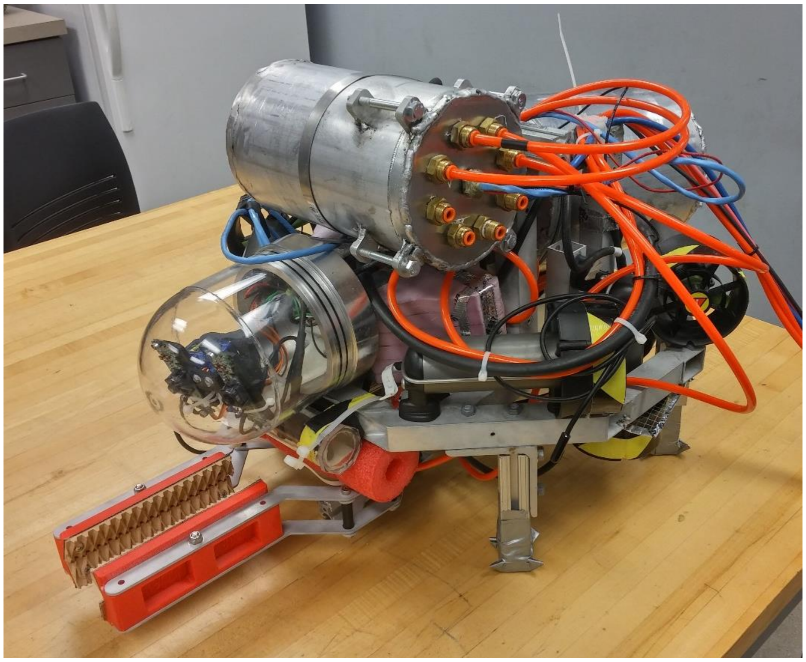

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Abstract

The Rose-Hulman Robotics Team (RHRT) is a student-led company based at the Rose-Hulman Institute of Technology in Terre Haute. The company is a five-year participant in the Marine Advanced Technical Education (MATE) underwater robotics program, and a two-time attendee at the international product demonstration. *Floyd* is RHRT's newest remotely-operated vehicle (ROV). As a work-class ROV, *Floyd* is well-suited to a broad array of challenging terrestrial missions, ranging from coral reef observation, subsea petrochemical infrastructure maintenance, and sample retrieval. *Floyd* is also designed with interplanetary missions in mind; its compact dimensions and light weight make it a good candidate for spaceflight and deployment in the subsurface oceans of Jupiter's icy moon Europa.

Superficially, *Floyd* is similar to RHRT's 2015 ROV, *Aegir*, with a similar vectored thruster configuration and electronics enclosure location. Under the hood, however, *Floyd* is a much more powerful and capable vehicle. Most visibly, *Floyd*'s primary camera is a three-axis stereo gimbal, providing the operator with an unparalleled field of view in front of the vehicle. A high-speed USB-over-Ethernet communications backbone allows for low-latency digital video transmission to the surface. Vertical thrusters powered at 24 VDC allow for sustained fast ascents and dives. Three pneumatic solenoids are available to actuate mission tools.

The bulk of design work took place between September and December for 2015, with fabrication and testing beginning in November and continuing through May of 2016. The total project budget was approximately $13,000, provided by Rockwell-Collins and Rose-Hulman Institute of Technology.

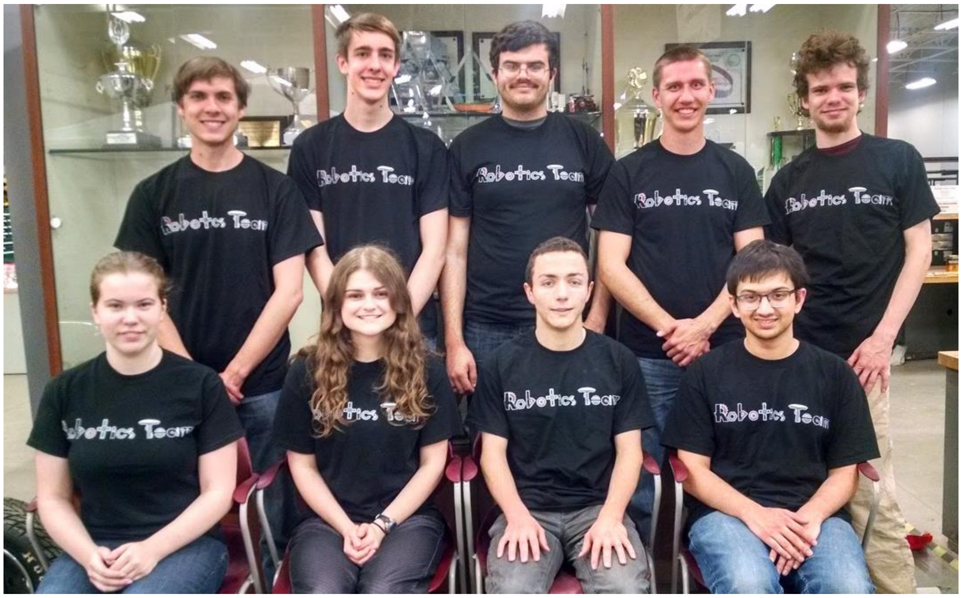

Figure 1: RHRT company photo, clockwise from top left: Joe Schornak, Parker Phillips, Brad Drake, Nick Kiesel, Connor Crenshaw, Sabeeh Khan, Sam Lawrence, Betsy Tainer, Amelia Rolf

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Safety

A. Safety Philosophy

The Rose-Hulman Robotics Team (RHRT) places a high value on the safety of its employees. Through the implementation of and adherence to proper safety procedures, we can protect our valued employees from injury and accidents.

B. Employee Safety

Employees are required to complete an hour long training session, which includes how to use Personal Protective Equipment (PPE), to be allowed access to the workspace. Additional hands on training is required to access the higher risk areas such as the machine shop or welding room, and Employees never work alone in these places. The buddy system both ensures that employees are following proper procedures and that in the event of a problem there is someone on hand to assist. New employees also receive additional on the job training from experienced employees.

All company employees use situationally appropriate PPE, which includes, at minimum, wearing safety glasses and long pants at all times in the workspace. Employees with long hair ensure that their hair is appropriately secured when using equipment. Additional PPE is used as needed including wearing welding face shields, gloves, and flame retardant smocks when welding or using respirators when using the sandblaster.

C. ROV Safety

Floyd has numerous features to ensure safe operation. *Floyd* is equipped with a 10A fuse in the main switch box.. Electrical systems are properly insulated in order to prevent electrical shocks and short circuits. Sharp edges were filed down in order to prevent cuts. The air compressor has a built in regulator which is always set to 40 psi. The system is only maintained pressurized during operation; it is always depressurized between missions and during travel. The six electric thrusters are fully shrouded.

D. Operational and Safety Procedures

RHRT carefully follows a set of operational and safety procedures, documented in Appendix A.

Design Rationale

A. Design Process

RHRT began by reviewing past products' successes and failures and decided that the ROV should be able to quickly ascend and descend, incorporate a camera gimbal with at least 2 axes of rotation, and have minimal latency in video and control. The company developed a plan for a general-purpose ROV in advance of the release of the product specifications and began assembling the core control system.

After receiving the desired product specifications, the company split off into smaller groups and brainstormed mission-specific concepts. Ideas were then evaluated based on cost, ease of manufacturing, and weight. The most promising designs were modeled in SolidWorks, and the best aspects of each proposal were then merged into a final ROV design. The company carefully budgeted vehicle mass for each component into order to create a lightweight product, and used SolidWorks CAD to confirm that the completed ROV would fit within a 58cm-diameter sphere, which would maximize the ROV's useable volume while remaining within the most advantageous size category. SolidWorks was heavily used to generate manufacturing files for waterjet cutting and machining. Since *Floyd* was designed to operate at a depth greater than the company's current test location, ANSYS Workbench was used for finite-element analysis to verify calculated depth ratings for watertight enclosures.

B. Design Evolution

Floyd is a successor to *Aegir*, RHRT's first successful ROV. *Aegir* included many useful features that the company wished to carry onto the next vehicle. In particular, *Aegir*'s gimbaled camera system was very popular among company pilots, and its electronics housing was convenient to service thanks to its removable canister and position at the rear of the vehicle. Both of these features were included and improved in the design of *Floyd*. The new camera gimbal is enclosed within an acrylic housing and sealed by a double O-ring, eliminating the need for the specialized waterproof servos used on *Aegir*. *Floyd*'s electronics housing has a cross-sectional area 36% greater than the previous one, removing many restrictions on the size and relative locations of electronic components.

The company decided to commercially source individual components such as thrusters, BeagleBone Black, servos, cameras, and other similar components. These decisions were made based on available manufacturing capabilities and time constraints of the company. Commercial sourcing of products is discussed more in depth in the products' respective sections.

C. Frame

Floyd's frame is made from 2.54 cm square 6061-T6 aluminum tubing welded into a single octagonal structural member. The thrusters and watertight housings are attached to the frame with stainless steel machine screws. Four landing legs at the diagonal corners of the frame keep the gripper and other moving parts from contacting the seafloor.

D. Thrusters

Floyd features six Teledyne/Seabotix BTD150 brushed DC thrusters. These off-the-shelf thrusters were selected for their reliable operation at depth. The challenging task of designing reliable watertight thrusters in-house would have strained company resources and limited the ability of employees to work on other complex tasks. Seabotix thrusters have previously been successfully used in 2015 on *Aegir*.

Floyd is equipped with four thrusters for lateral motion powered at 12V each and mounted in a vectored configuration to permit free horizontal motion. *Floyd* also has two vertically mounted thrusters for ascent, descent, and vertical position regulation, run at 24V.

The vertical thrusters have attached mesh grates to keep cabling from being ingested by the thrusters.

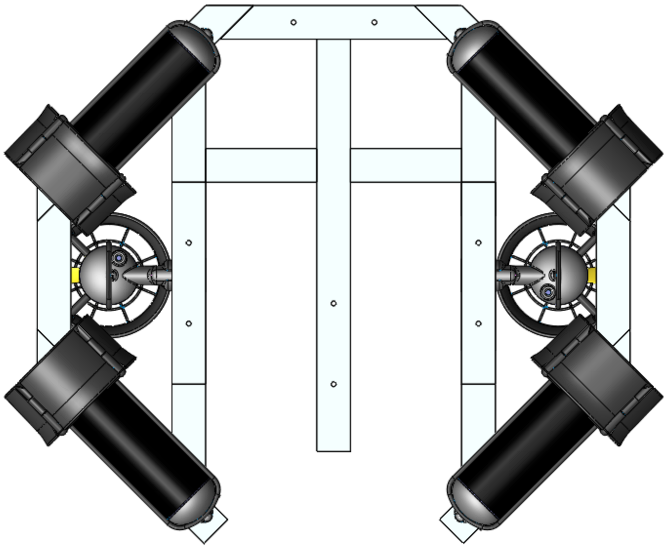


Figure 2. *Floyd*'s Thruster Configuration. ROV forward is at top of figure.

E. Buoyancy

The majority of *Floyd*'s buoyancy is provided by the electronics and pneumatics enclosures. These enclosures are located along the vehicle's spine to provide symmetric buoyant force. Their positions along the spine were chosen to place the center of buoyancy near *Floyd*'s geometric center. Blocks of rigid polystyrene insulation foam provide auxiliary buoyancy. Previous ROVs with rear-mounted electronics enclosures required aft ballast to make them float level, so the careful placement of *Floyd*'s buoyant volumes allows more of the vehicle's mass budget to be used for mission systems.

F. Power Distribution

In order to power the control systems, 3 DC-DC converters are used to step down the 48VDC to outputs of 5V, 12V, and 24V. These provide the required operating power for all onboard ROV systems. DC-DC converters were used for relative efficiency, small size, and low heat output. These converters were selected by calculating the power draw for each ROV system and applying at least a 25% overhead margin.

G. Control Systems

Floyd's onboard systems are controlled by a BeagleBone Black, an inexpensive single-board computer. The company had used the BeagleBone on *Aegir* and decided early on to continue to use it for 2016. The BeagleBone supports I2C, 4 UART channels and USB communication.

The BeagleBone communicates with the surface station through a USB-over-Ethernet extender unit. The company was interested in long-distance USB communications as a way to minimize latency while using three C920 USB webcams. Additionally, the BeagleBone can be controlled over USB. Since regular USB signals have an effective range of about 2 meters, the extender unit is required to transmit USB along the entire length of the tether.

The two vertical thrusters are controlled by two single-channel Pololu motor controllers which supply up to 24V. This configuration produces very high thrust at the expense of fine motor control, allowing *Floyd* to quickly ascend and descend. The four lateral thrusters are controlled by two dual channel Sabertooth motor controllers operating at 12V. These controllers were reused from the 2015 vehicle. We chose to drive the lateral thrusters at 12V instead of a higher 24V to maximize our fine maneuvering capability.

H. Surface Control Station

The guiding design principle behind our surface control station was to reduce costs for the consumer by allowing any computer with low to mid range specifications to run the ROV control software and operate the ROV. Each member of our company owns a Lenovo W530 laptop which runs the ROV control software. The laptop outputs video signals and reads sensor data from the ROV. The software interfaces with a 3-axis Logitech joystick which allows the operator to maneuver the robot and control the camera gimbal. In addition to the control station computer The surface station also includes an air compressor to provide pressure for the pneumatic gripper and Power supplied to the ROV. Power is supplied at 48 Volts, and current draw is typically below 10A. The tether is also secured to the operations deck with a carabiner to prevent the tether from pulling control components off the deck.

I. Cameras

Floyd includes two separate camera systems. Both systems use Logitech C920 USB camera boards, which connect to the surface station through the USB-over-Ethernet extender. The company had previously used the C920 cameras in 2014, and decided to reuse them due to their high resolution, excellent image quality, and low latency.

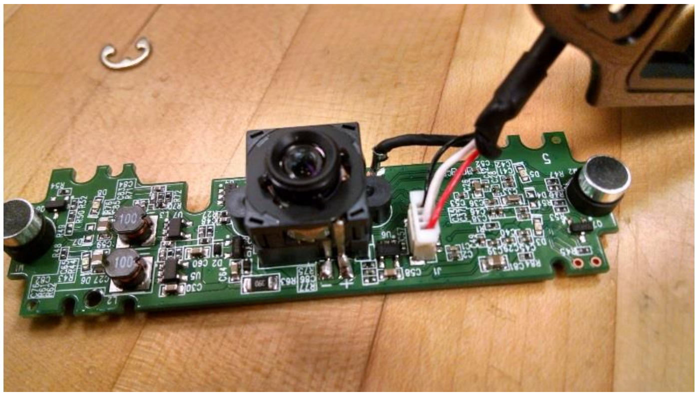


Figure 3: Logitech C920 webcam board, removed from original housing

The primary camera system is the Panopticon, a stereo USB camera pair attached to a three-axis servo gimbal. The cameras are spaced at approximately human eye width to provide optional stereo vision through an Oculus Rift virtual reality headset, and the servo axes allow provides an extremely broad field of view, allowing its cameras to be pointed in any direction the camera positions to match the roll, pitch, and yaw of the pilot's head.. The Panopticon within a hemisphere extending from the front of *Floyd*'s frame. The gimbal is driven by three Tower Pro micro-servos which operate at 5V and are controlled via PWM.

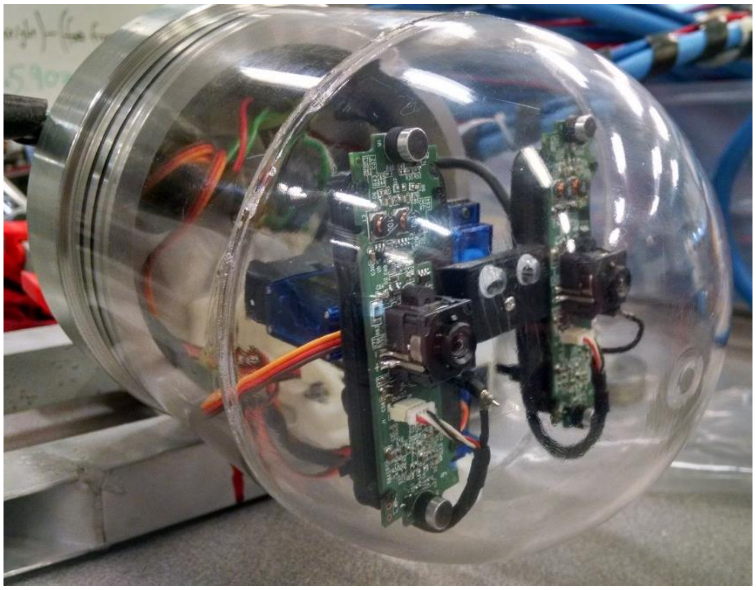


Figure 4: Panopticon internal detail

The secondary system is a single stationary C920 camera board in a separate enclosure. This camera is designed to be manually repositioned around *Floyd* to provide many possible perspectives on mission tasks. It has previously been mounted as a rear-view camera as well as a gripper-view camera.

Figure 5: Secondary camera housing configured as a fixed gripper camera.

J. Sensors

Temperature

The robot is equipped with two external environmental sensors. The first is a waterproof Maxim DS18B20 (Sparkfun 11050) temperature sensor. Pre waterproofing and simple serial communication to a physically small sensor were motivations for choosing this sensor. It can easily interface to the BeagleBone with no more than an external pull up resistor and can accurately report celsius temperature. It's probe-like shape allows for its easy insertion into sensing zones.

Pressure

The pressure measurement task required a sensor able to detect pressure at depths of at least 40 feet, and reasonably good precision to bring us within the competition specifications. We chose the ms5803 pressure sensor IC. It uses I2C, which is a protocol that our company members have experience writing code for. We had a couple issues with the commercially available prefabricated pressure sensor boards using the ms5803 IC. We felt that the expense was too high to be justified and the commercially available boards had more features than we needed. We decided to fabricate our own printed circuit board to interface with it. The PCB was smaller than the commercially available board and required fewer connections to the main electronics container.

K. Electronics Housings

Floyd's electronic systems are housed within four containers. This design allows for a more distributed approach to wiring and control, since control boards can be located nearer to their individual subsystems. It also helps to protect the main control system in the event of a failure in the pneumatic system, since only one housing would be compromised if the pneumatic system lost pressure and flooded.

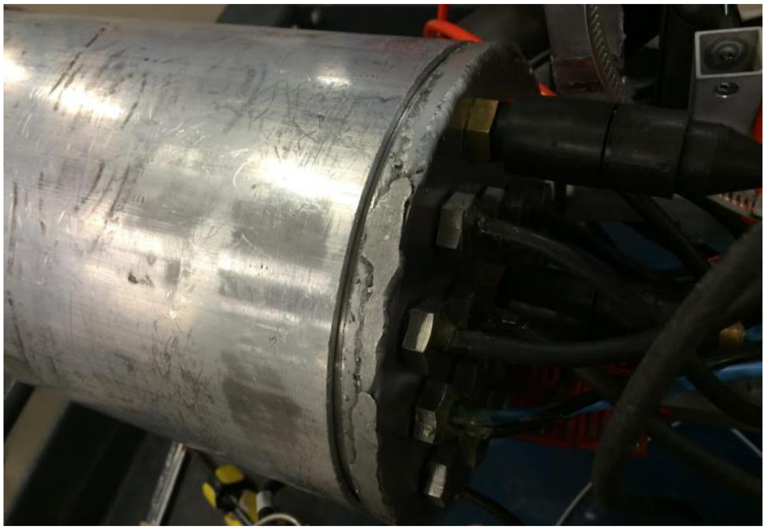


Figure 6. Primary Electronics Housing

The primary electrical housing was manufactured entirely from 6061 aluminum. Previous ROVs were limited by the small diameters of their electronics housings, so the company sought to produce a wider housing than usual for *Floyd*. The body of the housing is made from two pieces: a 17.78 cm diameter 6061-T6 aluminum tube with 0.3175 cm wall thickness, and a round 0.3175 cm cap welded to one end of the tube using an aluminum spool MIG process. The housing plug was machined from 17.78 cm OD, 0.9525 cm wall aluminum tube using a lathe, and includes two grooves for 0.4763 cm Buna-N O-rings. A faceplate welded onto one end of the plug includes tapped holes to accommodate bulkhead penetrators and electrical connections.

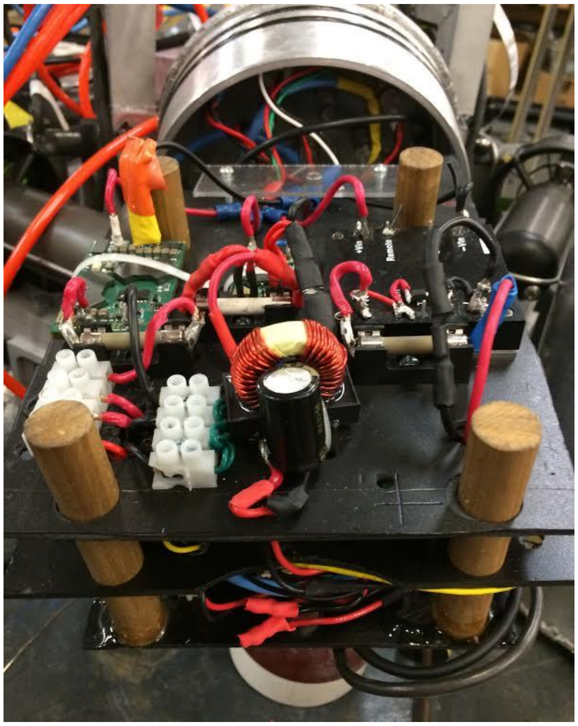


Figure 7. Electronics shelving unit

The electronics are mounted within the electronics housing on three plastic boards that insulate the electrical connections and facilitate system troubleshooting and maintenance. The boards are separated by wooden dowels that prevent contact between electrical systems while allowing space for air circulation.

The solenoids are housed separately from the main control system in a designated solenoid container in order to keep the remaining electronics in

Figure 8. Solenoid housing

a 101.3 kPa environment that is more robustly sealed. The solenoid housing was manufactured entirely from 6061 aluminum. The housing was designed using 12.7cm aluminum tubing using a similar process to the primary electronics housing.

The Panopticon is housed within a 12.7cm diameter ⅛”-thick acrylic dome made from a hemisphere cemented to a short length of straight tube. This housing is designed to give the greatest possible field of view to the Panopticon stereo cameras. The dome seals against an aluminum plug fitted with a double O-ring seal, which also provides a bulkhead penetrator for the camera and servo cables and a hardpoint to attach the Panopticon to the ROV frame. While the acrylic walls appear much thinner and less durable than the other vehicle housings, finite element analysis found that the housing will conservatively be useable without cracking or other failure to 250 ft depth, and likely beyond. All manufacturing, design, and analysis of electronics housings was performed by company employees.

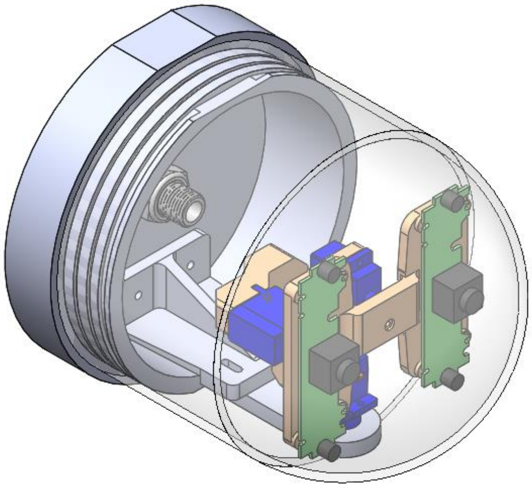


Figure 9: Panopticon CAD rendering

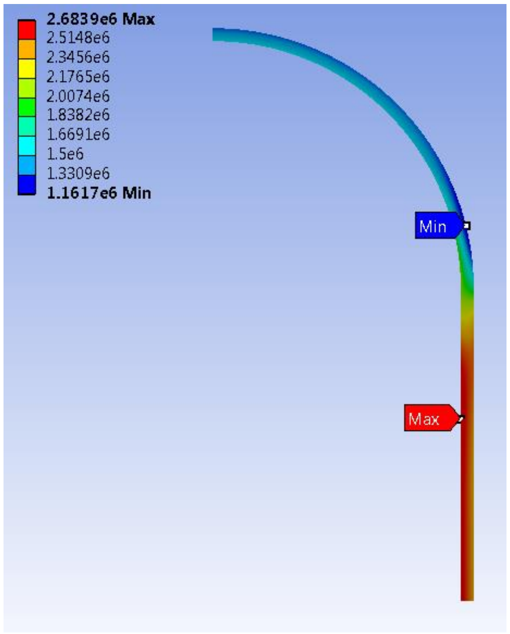


Figure 10: FEA results of Panopticon acrylic wall in ANSYS Workbench

L. Bulkhead Penetrators

The electrical interfaces connecting to the surface via the tether pass through Subconn wet-mateable connections to allow the tether to be detached for transportation and storage. These connectors have functioned reliably on previous RHRT products, so the company chose the same approach for *Floyd*.

The connections linking systems within the vehicle do not need to be removed regularly, so static penetrators were chosen as a cost-saving measure. Employees fabricated custom stainless steel connectors by drilling through the centers of 1”-long ½-20 stainless steel bolts and facing the undersides of the bolt heads on the lathe to produce a smooth mating surface. A Buna-N O-ring underneath the bolt head seals against the bulkhead surface. The wires passing through the connector are sealed with binary epoxy. These connectors can either be threaded through a tapped hole in the bulkhead or held in place by a locknut on the inside of the bulkhead.

The pneumatic connections through the wall of the solenoid enclosure are off-the-shelf brass bulkhead penetrators with quick-disconnect hose ports on both ends.

Figure 11: Employee manufacturing a static bulkhead penetrator

Figure 12. Static bulkhead penetrator.

M. Tether

Floyd’s tether was designed to meet the specifications of the new deeper environment. The tether contains a single shielded Category 6 Cable (Cat6) cable for communication, two insulated 12AWG XHHW copper wires, and two lengths of ⅛” pneumatic tubing. Cat6 cabling was chosen because its shielding makes it less susceptible to interference than the Category 5 Ethernet Cable (Cat5e) cabling which was used in previous products.

The tether on RHRT’s 2015 ROV was adapted from an off-the-shelf 3-conductor extension cord. The company decided to replace this tether in order to meet the mission’s weight limitations and depth requirements.

Stranded XHHW was used because it is both waterproof and flexible.

One pneumatic line supplies 40psi compressed air to the onboard solenoids, while the other provides an unpressurized route to the surface for exhaust.

N. Software

The challenges *Floyd* will face require software that is constructed to be both flexible and scalable. *Floyd* connects with inputs in the form of sensor devices, and cameras, and outputs in the form of motor controllers, servos and solenoid valves. These devices use a wide range of protocols which can change depending on requirements. The software is based on a modified client-server model. There is a program that runs on a host computer on the surface and a server program running on the BeagleBone. The organization of the script can be seen in the flowchart in Appendix B.

The host laptop on the surface station runs a MATLAB script to read joystick inputs and display sensor readings to the operator. The company chose to use MATLAB because all employees had at least a basic level of familiarity with it thanks to Rose-Hulman's curriculum. Additionally, MATLAB's academic license has extensive support for a multitude of different packages at no additional cost. MATLAB can directly control the BeagleBone Black over USB, which greatly simplified the development of the surface station software. Additionally, using MATLAB allows future development into image processing and computer vision.

ROV Software

MATLAB interfaces with the Debian Wheezy distribution of Linux to enable functionality of all hardware available on the BeagleBone Black. The commands are specified by the MATLAB script on the surface; the commands are then sent to the BeagleBone and translated into signals to be sent to the hardware connected to the BeagleBone Black.

Custom Python scripts on the BeagleBone return temperature and pressure sensor data to the surface station. To return temperature readings, example scripts for the waterproof DS18B20 were modified to interpret the sensor's I2C communication protocol and return values to the main MATLAB script. The readings were written to a text file on the surface station laptop, which MATLAB would then read and display on screen.

A separate Python script communicates with the MS5803 pressure sensor using C libraries provided by SparkFun. The script also performs conversions to return the current depth of the ROV based on the pressure reading. As with the temperature sensor, the data is written to a text file, which is then read by MATLAB. Each of the Python scripts are automatically initialized when the BeagleBone boots up.

O. Gripper

Floyd's principal manipulator is a pneumatically-actuated parallel-jaw gripper made of two overlapping parallel bar linkages. This design is based on the gripper used on RHRT's 2015 ROV, with several improvements based on operational experience. The gripper is actuated by a 1.4cm-diameter Bimba pneumatic cylinder with a

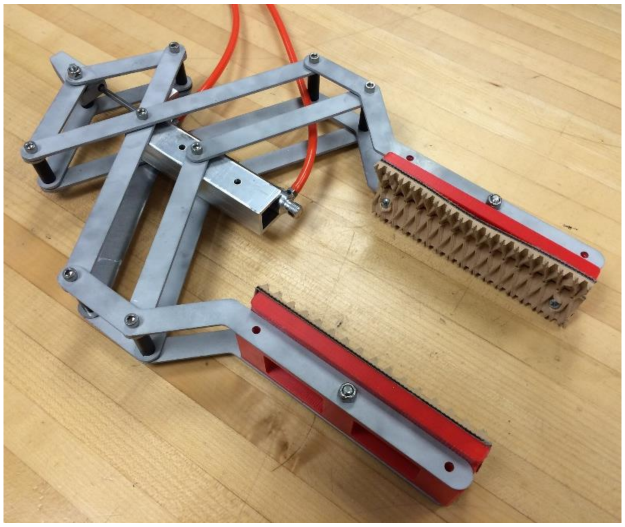


Figure 13. Pneumatic-jaw parallel gripper

range of motion of 7.6cm. The gripper linkages are waterjet-cut 0.1” 7075 aluminum plate. The linkage joints are held together with 6-32 cap-head stainless steel machine screws. Extensive use of Solidworks allowed employees to design the gripper with the desired kinematic range of motion while reducing its size and mechanical complexity.

The parallel bar linkages are designed such that the gripper jaws are 12 cm apart at full extension, which allows the gripper to hold the widest part of the electrical connector. The jaws press against each other when the gripper is fully closed, so small-diameter objects like bolt heads and cables can be held securely. The gripper jaws are made from 3D-printed ABS plastic. The gripping surfaces are fabric-backed waffle-treaded conveyor belt, which exhibits superior gripping ability in wet conditions compared to the foamed rubber strips used on *Aegir*’s gripper.

Floyd also features a static hook designed to hook around handles, allowing the ROV to open doors. This hook was specifically added to open the door on the electrical connector door after the original gripper jaws were found to be ineffective.

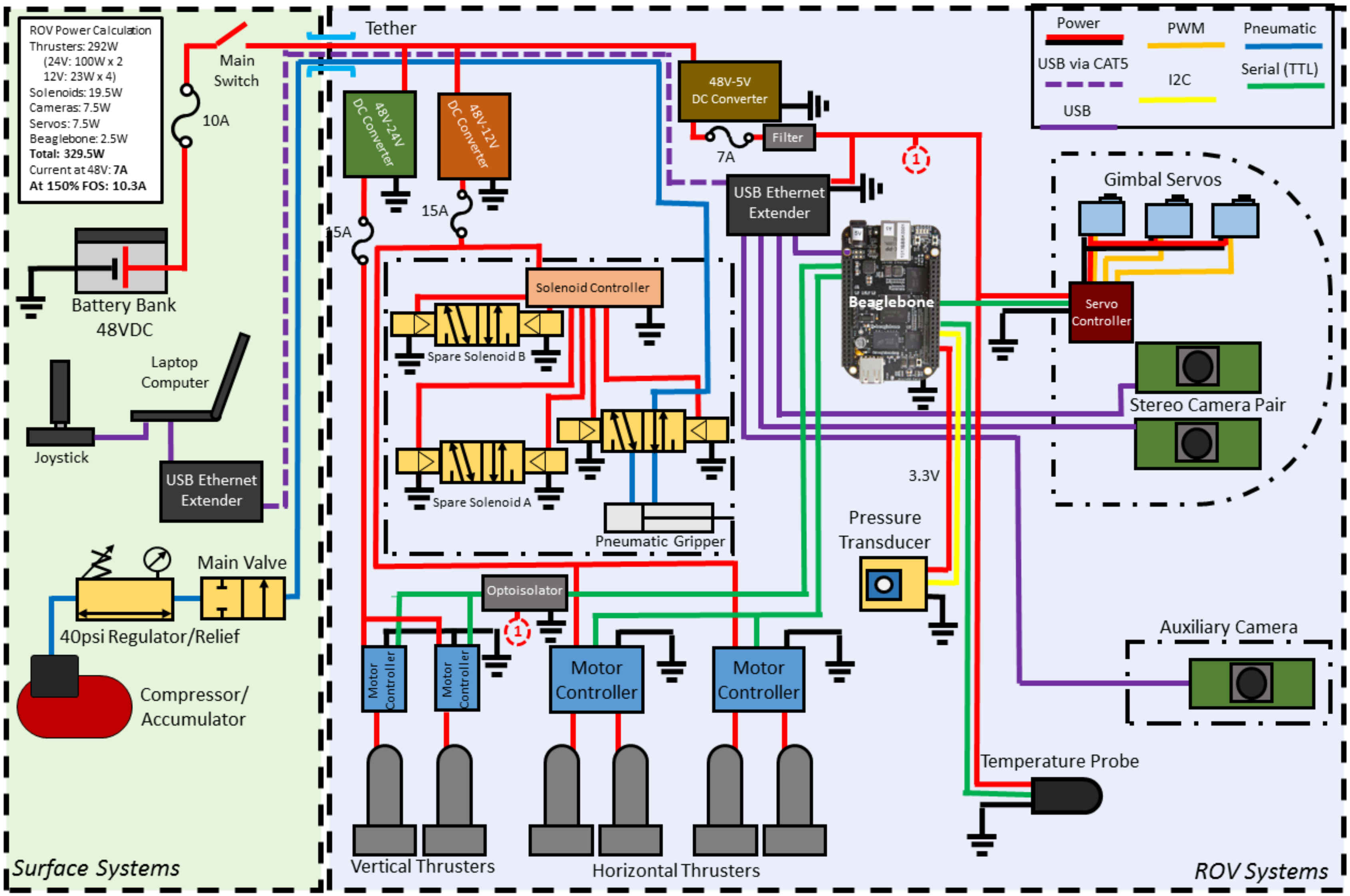
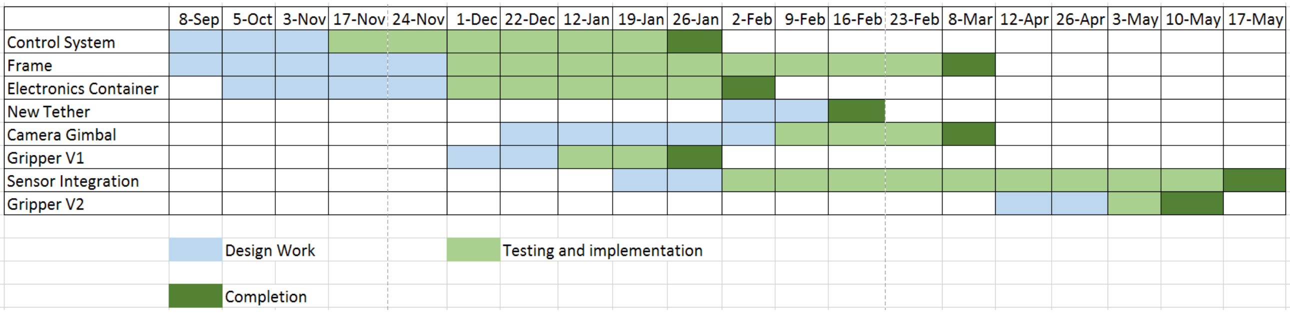


Figure 14. ROV system interconnection diagram (SID)

4. Logistics

A. Schedule and Project Management

Our project management plan was designed to keep the design and construction of the robot on a schedule to ensure that we had a viable product ready before the date of the competition. We divided members of the company into separate groups for significant components of the design. Each row of the Gantt chart below contains a significant portion of the design. We decided to divide tasks into project groups to accomplish significant components of the robot design. Each group was interdisciplinary and contained members from many different majors including software, electrical and mechanical engineering. At each meeting we first met to discuss the goals we were to accomplish for that day and then divided tasks accordingly. Our project leader kept track of our progress on each task using the gantt chart below. Although we broke off into smaller groups for much of the design. All major design decisions were made with input from the entire company.



	8-Sep	5-Oct	3-Nov	17-Nov	24-Nov	1-Dec	22-Dec	12-Jan	19-Jan	26-Jan	2-Feb	9-Feb	16-Feb	23-Feb	8-Mar	12-Apr	26-Apr	3-May	10-May	17-May
Control System	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	■										
Frame	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	■					
Electronics Container		🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟩	■									
New Tether											🟦	🟦	■							
Camera Gimbal							🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	■					
Gripper V1						🟦	🟦	🟩	🟩	■										
Sensor Integration									🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	■
Gripper V2																🟦	🟦	🟩	■	

🟦 Design Work
🟩 Testing and implementation
■ Completion

B. Software Project Management

In the past our company has struggled with software tasks that have multiple people working on the same set of code. Versions easily become out of date and it is hard to integrate code changes made by multiple people. In order to solve this problem we implemented Subversion using a networked server. This allowed us to keep the code base consistent even with many people working on the same software set.

The company's project repository is at https://svn.riouxsvn.com/mate. Only company members can checkout the repository. The company is part of a university and, in the spirit of supporting the academic community, we created a git repository for easy viewing of the code base. The repository is at https://github.com/kieselnb/MATE-Robotics-2016.

C. Project Costing and Company Budget

Rose-Hulman Robotics Team 2015-2016 Operating Expenses						
Category	Item	Description	Type	Qty	Amount	Total
Control and Communication Systems	BeagleBone Black		Reused	1	60.00	60.00
	Sabertooth Motor Controller		Reused	2	80.00	160.00
	Pololu Motor Controller		Purchased	2	45.00	90.00
	USB-over-Ethernet Comms Unit		Purchased	1	298.00	298.00
	Optoisolator		Reused	1	8.00	8.00
Sensors	Logitech C920 Webcam		Reused	3	70.00	70.00
	Tower Pro Micro Servo	Stereo camera gimbal	Purchased	3	5.00	5.00
	Temperature Probe		Purchased	1	9.95	9.95
	Pressure Sensor		Purchased	1	30.00	30.00
Power Supply	48V to 24V Converter		Purchased	1	220.00	220.00
	48V to 12V Converter		Purchased	1	75.00	75.00
	48V to 5V Converter		Purchased	1	30.00	30.00
	Fuse Assembly		Purchased	1	14.98	14.98
Tether	Subconn Power connector Pair		Reused	1	60.00	60.00
	Subconn Ethernet Connector Pair		Reused	1	162.00	162.00
	Power Cable	12ga, 125ft	Purchased	2	32.00	64.00
	Ethernet Cable	Cat53, 125ft	Purchased	1	14.00	14.00
	Pneumatic Line	0.125” ID, 250 ft	Purchased	1	210.00	210.00
Structure, Housings, and Hardware	Main Enclosure Tube		Purchased	2	25.00	50.00
	Main Enclosure Seal Ring		Purchased	2	18.00	36.00
	Solenoid Enclosure Tube		Purchased	1	25.00	25.00
	Solenoid Enclosure Seal Ring		Purchased	1	22.00	22.00
	5.25” Al Round Stock		Purchased	1	25.00	25.00
	1.5” Al Round Stock		Reused	1	12.00	12.00
	O-rings		Purchased	1	50.00	50.00
	⅛” Aluminum Sheet		Purchased	1	42.00	42.00
	0.1” Aluminum Sheet		Donated	1	60.00	60.00
	½-20 Stainless Steel Hex Bolt	For intrasystem waterproof connections	Purchased	30	1.50	45.00
	10-32 Stainless Machine Screw		Purchased	30		34.30
	10-32 Stainless Nut		Purchased	30		8.20
	6-32 Stainless Machine Screw		Purchased	100		10.17
	6-32 Stainless Nut		Purchased	100	0.06	6.00
	5” Acrylic Tube		Purchased	1	66.00	66.00
	5” Acrylic Hemisphere		Purchased	1	15.00	15.00
	1.5” Acrylic Tube		Purchased	1	12.60	12.60
Pneumatic Systems	Solenoid		Purchased	3	60.00	180.00
	Solenoid control board		Custom	1	15.00	15.00

	Compressor		**Reused**	**1**	**50.00**	**50.00**
	Barbed Fittings		**Purchased**	**12**	**2.10**	**25.20**
	Quick-Connect Fittings		**Purchased**	**10**	**5.84**	**58.40**
	Bulkhead Fittings		**Purchased**	**8**	**2.18**	**17.44**
Gripper	**3” Actuator**		**Reused**	**1**	**31.50**	**31.50**
	8” Actuator		**Purchased**	**1**	**32.97**	**32.97**
	Gripper Pad	**3D printed**	**Donated**	**2**	**1.75**	**3.50**
	Gripping Surface		**Reused**	**1**	**24.00**	**24.00**
Pilot Console	**Lenovo W540 Thinkpad**		**Loaned**	**1**	**1200.00**	**1200.00**
	3-axis Joystick		**Reused**	**1**	**35.00**	**35.00**
	Auxiliary Monitor		**Reused**	**1**	**70.00**	**70.00**
Total ROV Cost						**3843.21**
Total Purchased Cost						**1861.21**
Registration	**MATE Competition Registration**		**Purchased**	**1**	**250.00**	**250.00**
Travel	**ROV Shipping**		**Purchased**	**2**	**200.00**	**400.00**
	Human Shipping	**Averaged**	**Purchased**	**11**	**500.00**	**5500.00**
	Lodging		**Donated**	**11**	**-**	**-**
Total Operational Cost						**8011.21**

5. Conclusion

A. Challenges

Electrical

RHRT ROVs using the Beaglebone Black, including *Aegir* and *Floyd*, occasionally experienced communication outages requiring a full system reboot. These outages impeded mission operations, since completing the reboot required at least a minute and multiple reboots were sometimes required during a single mission run. This year, company employees specializing in electrical engineering determined that these outages were probably the result of noise produced by the 48V power converters. The addition of optoisolators and filters between the 5V control system and the 12V and 24V motor control units greatly reduced the frequency of communication outages.

Software

Development through MATLAB was more of a challenge than anticipated. Though MATLAB supports communication with the BeagleBone over USB, proper documentation was not provided. It was initially very difficult to debug or understand where issues were coming from. For example, we found that MATLAB will only connect to the BeagleBone if it is running Debian-Wheezy, an older operating system than the version we had initially installed.

RHRT had hoped to implement full stereo vision through the Panopticon using an Oculus Rift virtual reality headset, but this system was not functional as of this writing.

Mechanical

The company had never designed or fabricated double O-ring seals of the size required for the main enclosures. The lathes in the company workspace were not large enough to accommodate the aluminum tube and round stock that would make the primary enclosure, so the company used a larger lathe in the Rose-Hulman Mechanical Engineering machine shop instead. Even with larger tooling, it was often very difficult to fixture the stock in the lathe such that the desired profiles could be safely cut while maintaining an acceptable surface finish. Employees had to devise novel machining strategies for each part.

Figure 15: A novel approach to facing the end of the main electronics housing.

Challenges continued even after the enclosures were fabricated. The mating surfaces on the main enclosure’s plug had to be recut and the O-rings resized after initial tests showed that the O-rings were not uniformly sealing around the canister perimeter. The solenoid container seal did not provide as much friction as expected and occasionally opened due to increased internal pressure following actuation of the pneumatic gripper, which required the addition of tabs and bolts to retain the lid.

B. Lessons Learned

The Rose-Hulman Robotics Team struggled with scheduling and timeline issues. The robot was not completed in time to have adequate practice and testing before competition. We plan on having an operational frame in the water that can do basic maneuvering tasks by the end of December to allow for an adequate testing period. Many of the tasks required for completing the ROV are sequential so it is imperative that a schedule is followed. Too many deadlines were not met in 2015-2016.

C. Future Improvements

RHRT already has an improved frame in development for *Floyd*. While the current welded-tube frame is sturdy and functional, it was not manufactured to correct tolerances and is out of square in important dimensions. Redesigning the frame allows the company to use capabilities acquired after the construction of the original frame, especially waterjet cutting.

Employees are also developing an improved control system based around custom motor driver boards and microprocessors. Using two different brands of motor controllers (Pololu and Sabertooth), introduced communications problems that could have been easily

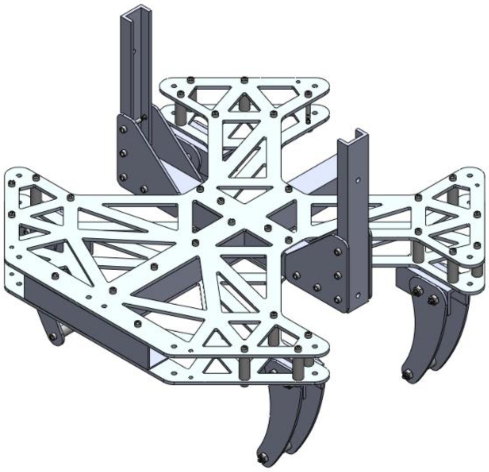


Figure 16: Improved waterjet-cut ROV frame.

avoided if one, in-house produced, type of controller was used. Due to the requirements of many sensors, the company tended to favor serial communication, which quickly used the BeagleBone's limited number of ports. Designing an application-specific microprocessor allows the company to have some more freedom with the total number of serial ports.

The company aspires to create a versatile 6-DOF manipulator suitable for use underwater. Experiments with applying rubberized coatings to fabric duct tubing showed that it is probably possible to create a flexible watertight sheath around an arm made from non-waterproof servos while retaining a significant range of motion. There are numerous challenges remaining before this system could be reliably deployed. In particular, since the flexible housing would not have the resistance to external pressure as a traditional rigid housing, its interior would have to be maintained at the same pressure as the surrounding water to prevent the housing from being crushed.

The company plans to supplement our design process through internal design review. The design review will help to ensure that money and time are being spent efficiently and effectively and help to keep the RHRT on schedule.

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E. References

"Seal design guide." [Online]. Available: http://www.applerubber.com/src/pdf/seal-design-guide.pdf.

"O-ring reference guide." [Online]. Available: http://www.sealdynamics.com/o-ring-reference.pdf.

"Smarter Adhesive Solutions." [Online]. Available: https://www.curbellplastics.com/research-solutions/technical-resources/technical-resources/bonding-acrylic-with-scigrip-3-4-or-16.

"Compressive Strength Testing of Plastics," *Compressive Strength Testing of Plastics*. [Online]. Available: http://www.matweb.com/reference/compressivestrength.aspx.

"Propellor Geometry." [Online]. Available: http://traktoria.org/files/personal_submarine/propulsion/propeller/lecture_notes/propeller_geometry.pdf.

H. am Aissaoui, "Numerical Simulation of Radial and Axial Compressed Elastomeric O-Ring Relaxation," Jul-2012. [Online]. Available: https://globaljournals.org/gjre_volume12/1-numerical-simulation-of-radial.pdf.

"Stingray Rovotics Underwater Solutions MATE 2015", Jesuit High School. Carmichael. , CA. 2015.

Y. Shahidi, "O-Ring Assembly (Contact Analysis)," *O-Ring Assembly (Contact Analysis)*. [Online]. Available: http://engineering-inventions.blogspot.com/2012/04/o-ring-assembly-contact-analysis-in.html.

M. Triantafyllou, "Lecture Notes," *maneuvering-and-control-of-surface-and-underwater-vehicles*. [Online]. Available: http://ocw.mit.edu/courses/mechanical-engineering/2-154-maneuvering-and-control-of-surface-and-underwater-vehicles-13-49-fall-2004/lecture-notes/.

Appendices

A. Operational and Safety Checklists

Before Powering On:

- ☐ Safety Glasses on
- ☐ Area Clear (free of debris/tripping hazards)
- ☐ Electronics Container Sealed
- ☐ Solenoid Container Sealed
- ☐ Panopticon Sealed
- ☐ All bolt tightened and no twisted cables
- ☐ Thrusters free of obstructions
- ☐ Verify power switches and circuit breakers
- ☐ Air Supply Properly Regulated at 40psi
- ☐ Call out: “Ready for Power”

Power On:

- ☐ Verify receiving 48 volts nominal
- ☐ Control computers up and running
- ☐ *Control Station:* Call out: “Powering On”
- ☐ Power on ROV
- ☐ *Control Station:* Call out: “Testing Thrusters”
- ☐ *Tether Managers:* Check movement of vertical and horizontal thrusters
- ☐ *Control Station:* Call out: “Testing Gripper”
- ☐ Check for gripper actuation
- ☐ *Tether Managers*: Call out: “Thrusters Operational”
- ☐ Verify video feeds
- ☐ *Control Station:* Call out: “Prepare for Launch”

Launch:

- ☐ *Tether Managers*: Call out: “Launching”
- ☐ ROV is lowered into water
- ☐ Check that bubbles NOT coming from enclosures
- ☐ *Control Station:* Call out: “Release”
- ☐ ROV is released into water

Egress:

- ☐ *Control Station:* Call out: “ROV surfacing”
- ☐ *Tether Managers:* Call out: “ROV surfaced”
- ☐ Catch ROV
- ☐ *Tether Managers:* Call out: “Power Off”
- ☐ Remove ROV from water
- ☐ *Tether Managers:* Call out: “Mission Completed”

B. Software Flowchart