Stingray

rovotics
underwater solutions

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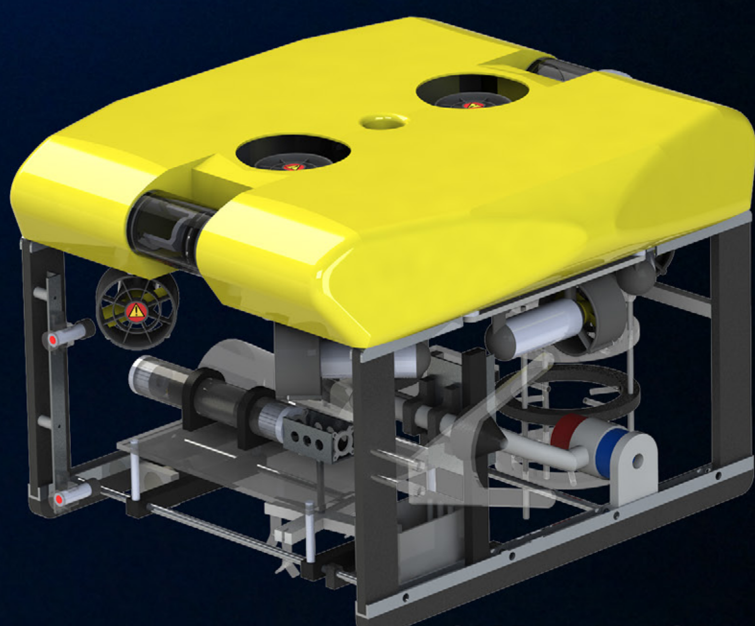

CADD model of *Stingray* prepared for offshore oilfield production and maintenance.

I. Introduction

A. Abstract

Designed to operate in the extreme environments of the Arctic and North Atlantic Oceans, Rovotics' newest vehicle, *Stingray*, comes fully equipped with specialized tools to demonstrate: (1) scientific exploration under the ice, (2) subsea pipeline inspection and repair, and (3) offshore oilfield production and maintenance, all while operating in wave surges and powerful currents.

Rovotics, an eighteen-person company shown in Figure 1, has the capability to deliver state-of-the-art Remotely Operated Vehicles (ROV) like *Stingray*, custom-designed to meet mission requirements. Efficiently organized into departments by specialty, including design, software, electronics, and manufacturing, Rovotics utilizes program management methods and source code management systems to manage their development cycle. Designs are produced completely in house, using a Computer Numeric Control (CNC) mill, custom-printed circuit boards, composites, and a 3D printer.

Stingray is the result of months of planning, manufacturing, and testing under strict safety protocols. *Stingray* has three detachable subframes, each customized with tools for mission-specific tasks for each product demonstration. Its hydrodynamic shell generates minimal drag in currents and fits through small openings in ice sheets. With twice as much space for electronics as any of its predecessors, *Stingray* has more room for camera systems, sensors, and control systems, making it Rovotics' most advanced vehicle yet.

This technical documentation describes the development process and design details that make *Stingray* the best ROV to perform scientific data collection on the U.S. Coast Guard's icebreaker *Healy,* and pipeline maintenance and wellhead preparation on Suncor Energy's vessel *Terra Nova*.[5]

Figure 1. Rovotics 2015 company photo with their newest ROV, Stingray.

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II. Design Rationale

A. Mechanical Design Process

To streamline the design process, Rovotics used a multi-step approach to allow the team to envision the end result early in the design process, reducing the number of mistakes and revisions. The process began with a brainstorming session where many creative ideas and designs were sketched on the whiteboard and alternatives were explored. Weighing factors such as cost, complexity, ease of manufacturing, and serviceability, the company selected the best designs using a process similar to a trade-off matrix. Complicated designs were mocked up with foam board to create physical models as shown in Figure 2. At this stage, different ideas were quickly shared, debated, and changed until a favored concept emerged.

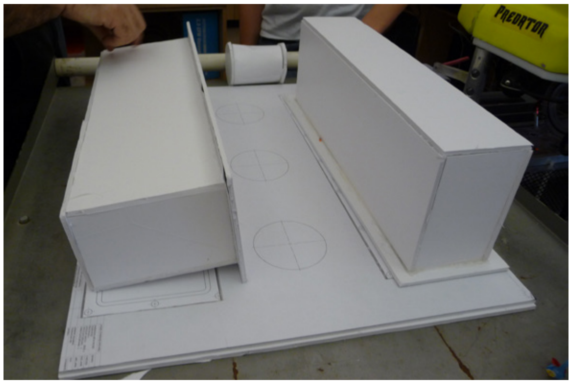


Figure 2. Foam board model of electronics housings.

Next, component designs were rendered digitally into Computer-Aided Design & Drafting (CADD) files using either SolidWorks or DraftSight (See cover page for full vehicle rendering). The CADD files were prepared for machining, being converted into Drawing Exchange Format (DXF) files for our CNC mill, .x3g files for our 3D printer, or detailed work orders for manual manufacturing.

For parts targeted for production on the CNC mill, the CADD models were converted into a Computer Aided Manufacturing (CAM) package, SheetCam. Using SheetCam, engineers generated the “G-Code” tool path files from the drawings, which were then loaded into the “Mach 3” machine control software. Mach 3 controls the CNC mill movements based on the G-code, allowing the machinist to quickly and accurately produce parts.

B. Design Evolution

Stingray is the next step in the evolution of Rovotic’s product line. Designed from the ground up specifically for Arctic operations, *Stingray* benefits from the company’s experience in designing vehicles for capping oil wells, removing hazardous materials from World War II era shipwrecks, deploying underwater sensor networks and conducting research and conservation on historic shipwrecks in the Great Lakes.

A vast majority of the components that make up *Stingray* and the associated tools are original designs by Rovotics’ engineering staff and manufactured in house. Some components are updated designs of previous company developments, such as our new and more compact camera pods and miniaturized custom video switching board. Details of these proprietary components and other systems are described in the following sections.

Every manufacturer must consider “make/buy” decisions during the product development process. Components that can be produced in house with available capabilities are generally more economical to “make”. Components that require specialized manufacturing processes that exceed Rovotics’ manufacturing capability or certain services (such as welding or large scale printing for posters) are sourced commercially. For *Stingray* itself, commercially-sourced major components are limited to motor cores, thrusters, speed controllers, servos, cameras, microcontrollers, and similar components.

Similarly, efficiency may be gained by reusing certain proprietary components or designs that were developed on previous projects. The decision to reuse any component on *Stingray* is discussed in that component’s description in the following sections.

C. Frames

For the three product demonstration environments, the company created a central core vehicle and three specialized, interchangeable subframes. The core vehicle contains all vital components required for basic vehicle operation, such as electronics, buoyancy, thrusters, and cameras. Each subframe has features and tools specific to the conditions of a particular product demonstration, and can be quickly interchanged with the other subframes both mechanically and electrically. By having three specialized subframes, the company keeps each subframe simple, uncluttered, and lightweight, which is preferable to a single, overly-complicated frame that is not specialized or optimized for each product demonstration.

The core vehicle has a central plate made of High Density Polyethylene (HDPE), to which all vital components are attached. HDPE was chosen over aluminum because it is cost effective, nearly neutrally buoyant, non-corrosive, non-conductive, and easy to machine. The flat horizontal mounting plate also results in a small frontal cross section which is critical for performance in ocean currents. Figure 3 shows the core vehicle that attaches to the top of each subframe.

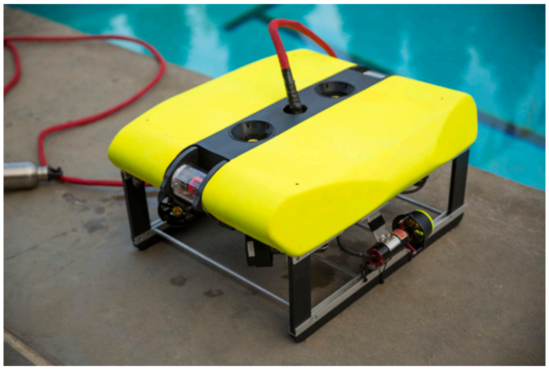


Figure 3. Core vehicle of Stingray.

Each subframe is manufactured from HDPE and aluminum to give all the strength of a solid aluminum frame with minimal weight. Subframes can easily detach from the core vehicle by removing four screws. Each subframe has a series of easily-removable parallel aluminum mounting bars. The standardized size and spacing of the parallel mounting bars allows for standardized mounting of mission tools and cameras. Removable bars make the mission tools highly serviceable and allow multiple versions to be developed and tested without changes to the subframe structure. Figure 4 shows the three subframes made for the three different demonstration environments (ice, wave, and flume).

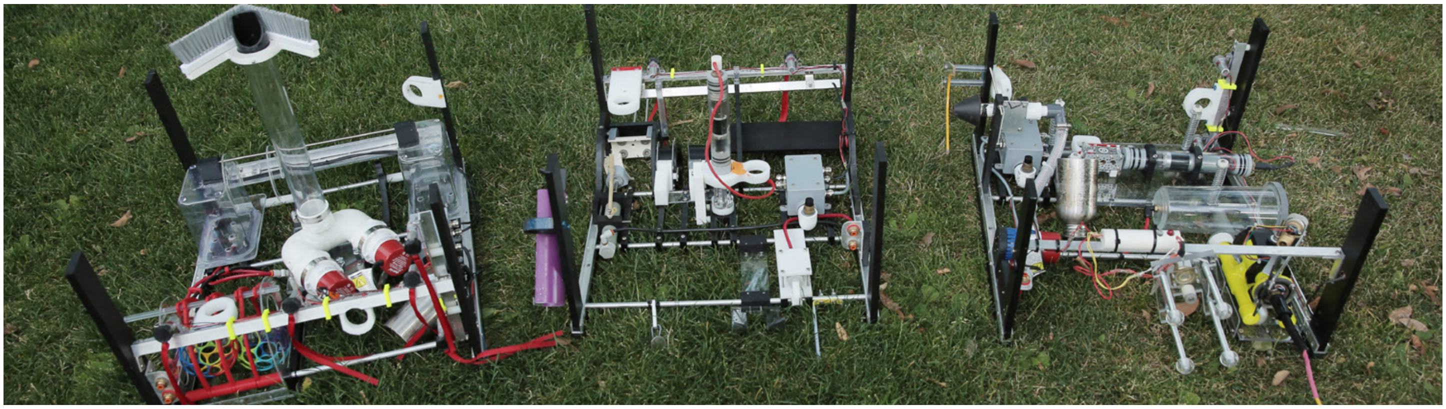


Figure 4. Stingray's ice, wave, and flume subframes, respectively.

D. Thrusters

For primary propulsion, *Stingray* utilizes six commercially-sourced Seabotix BTD150 thrusters, selected for proven reliability and performance on previous Rovotics products. In addition, two high-powered CrustCrawler 400 HFS thrusters have been added to provide additional forward thrust for speed when operating in strong ocean currents.

For horizontal control, four of the Seabotix thrusters are mounted at 45° angles in the corners of the vehicle to provide vector control, to allow all thrusters to contribute to the total propulsion in the cardinal directions, and to minimize flow interference with accessories in the center of the vehicle. For example, comparing four 45° thrusters with two parallel thrusters in each direction shows that the 45° mounting results in greater thrust [4 * COS(45) = 2.8x thrust vs. 2x thrust]. The CrustCrawler thrusters are mounted fore-aft on easily-detachable mounts so they can be removed for missions where they are not required (Figure 5).

Figure 5. *Stingray's* front pair of 45° thrusters with a side-mounted thruster.

For vertical control, two Seabotix thrusters are mounted along the centerline of the vehicle, convenient for the split electronics housing arrangement, where they can be shielded by the buoyancy shell for reduced horizontal drag.

Each Seabotix thruster provides a maximum rated thrust of 28 N and a sustainable thrust of 21 N. With an operating voltage of 19.1 VDC and a maximum operating current of 4.25 A, the six Seabotix thrusters fit well within *Stingray's* power budget (discussed in the Electronics section).

Each CrustCrawler thruster provides a maximum rated thrust of up to 67 N. They each have an operating voltage of 24 VDC and a maximum operating current of 5.26 A.

Previous Rovotics vehicles had a maximum forward speed of .17 m/s, which is not enough to combat the anticipated current of 0.257 m/s. With the addition of two CrustCrawler thrusters and a streamlined buoyancy, *Stingray* has a maximum forward speed of .5 m/s.

For the safety of personnel and equipment, grates mounted in front of each thruster's intake prevent fingers, cabling, and foreign objects from getting sucked into the thruster.

E. Buoyancy

Stingray is outfitted with a fiberglassed buoyancy float system designed to neutralize the ROV's mass in water. Specific attention was given to hydrodynamic flow characteristics to optimize performance in the product demonstration environments. Rovotics engineers, with several years of experience with this construction method, designed a sleek profile to reduce drag for operating in wave or current conditions, and sized to fit through a 75 cm x 75 cm hole in the ice.

Rovotics engineers chose Insulfoam® for the buoyancy material because it is affordable, easy to shape, and commercially available. Wooden guides were cut from templates based on our CADD models, then a heated wire was pulled over the wooden guides to cut through the foam and shape the buoyancy (Figure 6).

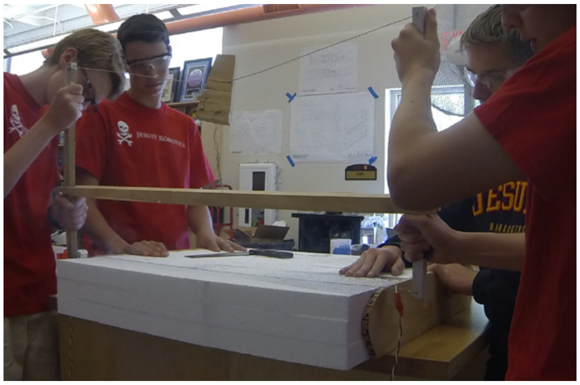


Figure 6. Rovotics employees shaping the buoyancy with wooden guides and heated wire.

The foam framework was then sanded down to eliminate any imperfections before being coated in multiple layers of fiberglass and epoxy resin. The fiberglass shell encapsulates the foam to resist compression due to hydrostatic pressure, providing uniform buoyant force through all operational depths. The vehicle buoyancy was painted a bright yellow for safety and visibility under the water, and labeled with company branding and safety information.

The added buoyancy made the vehicle neutrally buoyant by providing 15 kgs of water displacement which, as defined by Archimedes principle[2], brought the ROV to an equilibrium weight in water. The buoyancy profile was designed in SolidWorks and peer reviewed by our engineers, undergoing more

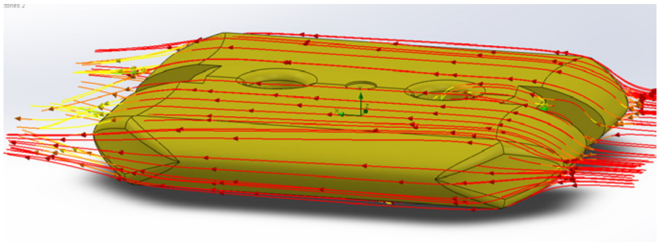


Figure 7. Fluid dynamics simulation to show drag points.

than fifteen design revisions based on the results from a computational fluid dynamics simulation in SolidWorks that identified points of drag (Figure 7).

Stingray's buoyancy was designed to shield the rectangular electronics housings and enclose the two vertical thrusters, making the vehicle profile similar to the streamlined body profile shown in Figure 8. This shape reduces the vehicle's hydrodynamic drag coefficient[3], reducing the force of drag on the vehicle. Additionally, the design fully incorporates the cylindrical shape of the camera pods, so that their potential to create drag is mitigated.

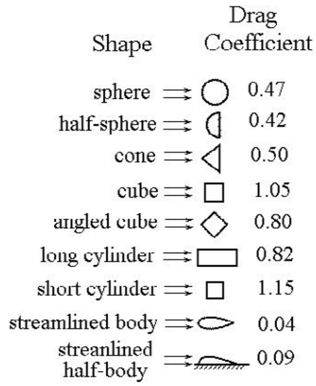


Figure 8. Measured drag coefficients for common shapes[8].

For tether buoyancy, adjustable aluminum air chambers are fitted at evenly-spaced increments along the tether. These chambers, a standard on several generations of Rovotics products, are proven incompressible to depths in excess of 13 m.

F. Electronics Housings

Stingray encloses all electronics in two rectangular housings located on the top of the vehicle for accessibility, quick removal, and space efficiency, as shown in Figure 9. This two-housing design doubles the space for electronics versus past Rovotics vehicles, and separates power conversion components from communication components to minimize possible interference. Rectangular housings are used because they have more stacking efficiency for rectangular electronics boards, larger flat surface area for waterproof connectors, and are easier to manufacture than cylindrical housings.

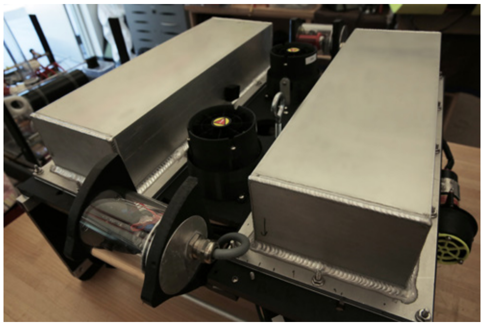


Figure 9. Top view of Stingray without buoyancy, exposing the two rectangular housings.

Manufactured entirely from aluminum, each housing cover was machined from an extruded U-channel and TIG welded to CNC end caps and a mounting flange. The mounting flange seals against a rectangular base plate with an O-ring placed inside of a machined groove to provide a water-tight face seal, held in place by twelve bolts.

Aluminum was selected because it is corrosion resistant, has high compressive strength, and provides efficient heat transfer from the internal air space to the external environment of the water. Any heat generated by the enclosed electronics transfers to the water rather than cause overheating in the enclosed environment. During testing, *Stingray* has never experienced overheating, even after several hours of continuous operation.

Electrical interfaces from our electronic housings are provided with waterproof Subconn connectors for components that need to be easily removable, such as tether and thrusters. More permanent components are interfaced with affordable submersible gland seal connectors.

All electronics are mounted permanently to the ROV with the fully-removable housing lids, providing generous access for testing and maintenance. This approach has proven superior to previous models of Rovotics ROV housings where there was insufficient access for test probes when electronics were installed.

G. Electrical Systems

Tether Control Unit (TCU)

The Tether Control Unit (TCU) is a hub for power, communications, and video distribution for *Stingray,* and is a critical safety subsystem. The copilot can monitor vehicle status via the TCU's sensor display, as well as shut down ROV power in case of emergency. Pneumatic controls are operated via buttons on the TCU. Most of *Stingray's* TCU is reused from last year's product demonstration for cost efficiency, but modified to: add a second pneumatics channel for operating the additional accessories on *Stingray*; upgrade to the latest Rovotics custom video switcher board; and add a cooling fan to improve reliability (Figure 10).

Figure 10. Stingray's TCU and incorporated Electronics.

As illustrated in the Systems Interconnect Diagram (SID) in Figure 11, ship-supplied power for the ROV system (48 VDC) enters the TCU through a 40 A fuse (for ROV system protection), a 30 A switchable circuit breaker (which doubles as a redundant power switch for added safety), and the primary power switch. A 48-12 V power converter supplies a secondary TCU power bus supporting networking components and an Ethernet inline power injector for our deployable flow sensor (described in the Flume Subframe Tools Section). Analog voltage and current meters on the TCU control panel allow the copilot to monitor power issues, such as short circuits.

The TCU video system receives two video lines from the ROV: one goes to an Axis Internet Protocol (IP) video server, and the other to an integrated monitor. The Axis video server can stream video to any IP-enabled device, such as an iPhone, Android, or tablet, allowing multiple users to view current operations, and enables the use of image analysis software for tasks such as dimension measurements of objects in view. The integrated monitor allows the copilot to monitor the accessory video feed from the TCU control panel.

Regulated compressed air is connected to the TCU and routed to two electrically-activated pneumatics control valves. During operation, buttons on the TCU control panel open selected valves, providing air pressure to accessories onboard the ROV via tubing in the tether.

Tether

Stingray's newly-developed tether utilizes a method of construction proven reliable on previous Rovotics products. The tether shelters multiple communication cables within a single flexible sheathing to keep them organized, prevent tangles, and protect the cables.

The tether contains one Category 5 Ethernet (Cat5e) cable, a 2/12 American wire gauge (AWG) DC power line, two 735 A coaxial video cables, and two 6.35 mm pneumatics lines. The Cat5e carries data via the Ethernet protocol from the ROV to the TCU. Cat5e was chosen over alternatives such as coaxial, Cat4, or Cat6a cables based on its ability to resist interference, cost, and flexibility. The 735 A coaxial video cables were chosen for resistance to interference, impedance (75 ohm), and small diameter.

The power lines are a sufficient gauge to minimize any voltage drop over the 30 m tether while maintaining flexibility. The power cable is sized for the maximum fuse-limited current draw of 30 A. The power cable has a calculated resistance of 0.16 ohms with a maximum voltage drop of 30 A * 0.16 ohms = 4.8 V. This gives *Stingray* a minimum operating voltage at the ROV of approximately 43.2 V, well above the 36 V minimum cut-off voltage of the ROV power converters.

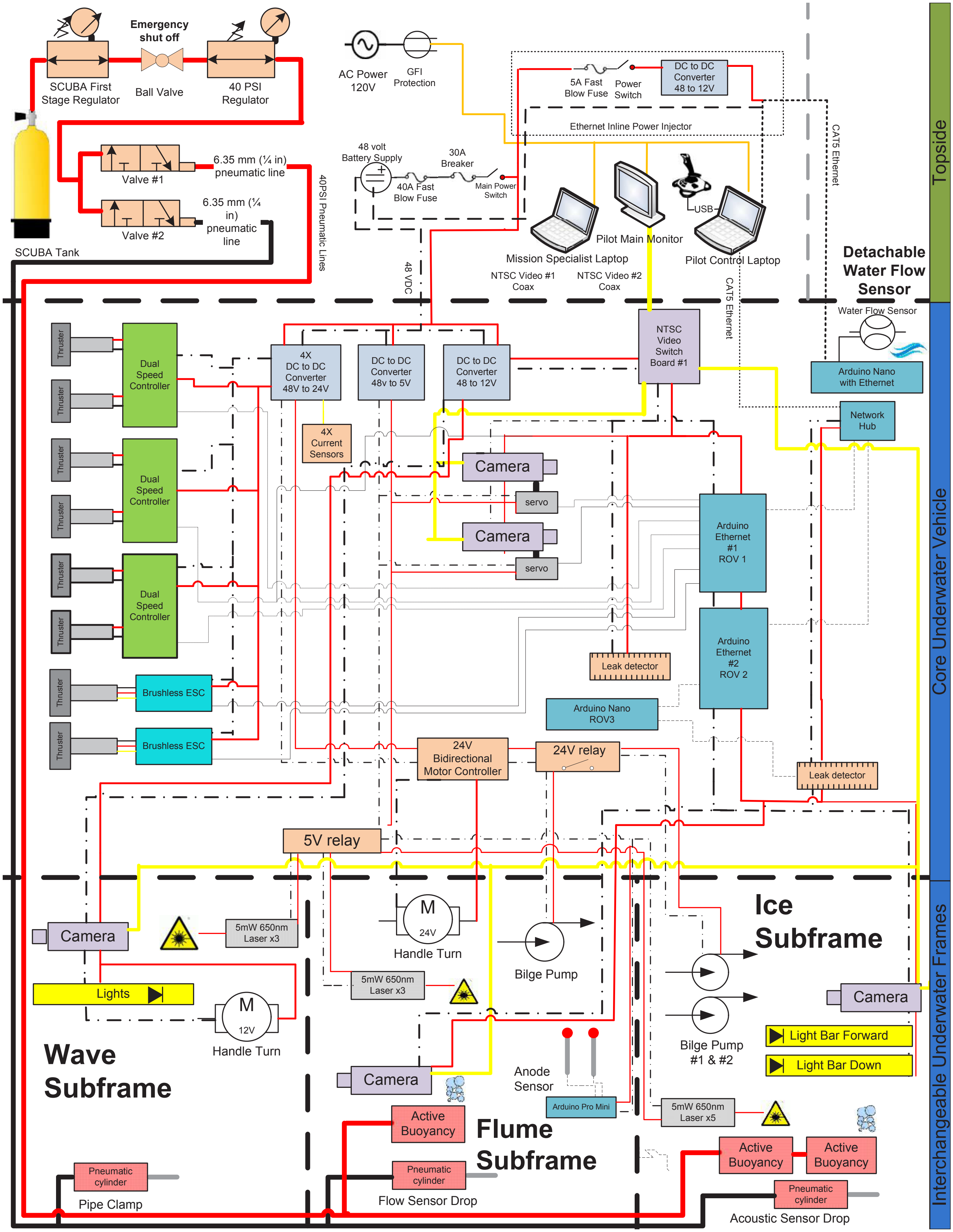


Figure 11. Rovotics System Interconnect Diagram (SID).

The tether plugs into the ROV with two Subconn connectors, and has a strain relief to prevent any unsafe stress on connectors. On the topside, the tether breaks out into six connections to the TCU: a Mod 8 connector for Ethernet, two BNC connectors for video, an Anderson Stack for power, and two pneumatics lines.

Electronics

The power cable connects into the electronics housing on the left side, which contains all high-voltage electronics, while low-voltage boards are in the right-hand housing. This separation minimizes any electromagnetic interference generated by the high-voltage power conversion, reducing operational risk to the highly-sensitive communication systems. All electronics were laid out in SolidWorks so that a compact and efficient layout could be visualized prior to manufacturing.

On-vehicle power conversion of 48 V to 24 V is achieved by four Zahn DC to DC converters providing 280 W each (Zahn model DCDC48/24/280)[9]. Zahn power converters were selected due to their proven reliable performance on previous Rovotics products and their adjustable output voltage that is compatible with the unique 19 V Seabotix thruster voltage ratings. Three Zahn converters each power a dual Sabertooth brushed Electronic Speed Controllers (ESC), providing power to the Seabotix thrusters, and the fourth Zahn converter powers a pair of brushless ESC (HobbyKing 50A Boat ESC) dedicated solely to *Stingray's* CrustCrawler boost thrusters.

The power for accessories and other electronic components is distributed across the 19 V power converter. Additional voltage regulation is done on the communications side to provide a 12 V and a 5 V power bus.

Power budget analysis proves that *Stingray*'s power delivery system is robust and capable of meeting the sustained needs of the ROV during even the most demanding, full-power operations (Figure 12).

The electronics housings have built-in leak sensors and humidity sensors. Leak sensors (Groove Water Sensor SEN11304P) in both housings will detect water intrusion by changing resistivity. Humidity sensors offer a secondary leak detection method for added security.

Stingray's Power Budget					
Unit	Current, A	Voltage, V	Max Power/Unit	Quantaty	Max Power/ W
Arduino Ethernet	1.5	12	18	2	36
Seabotix Thruster	4.2	19	79.8	6	478.8
Crust Crawler Thrusters	5	19	95	2	190
Ethernet Hub	1.5	12	18	1	18
Light Bar	2	12	24	1	24
Lasers	0.5	5	2.5	5	12.5
Video Switching Board	0.5	5	2.5	1	2.5
Camera	0.75	12	9	5	45
Bilge Pump	3	24	72	2	144
Arduino Nano	1.5	12	18	1	18
Servos	0.5	5	2.5	2	5
Anode Sensor	0.5	12	6	1	6
DC Motor	1	24	24	1	24
Peak Power, ROV, W(Total)					1003.8
				Peak Power Available at Top of Tether W(30A*48V)	1440
				Power Loss Due to Tether Resistance (30A^2 * 0.16Ohm)	144
				Peak Power Available to ROV end of Tether	1296
				Regulator Efficieny, % (Estimated)	85
				Power Loss, W (Peak Power/Efficiency)	194
				Power After Conversion at ROV(4@Zahn 280W each)	1102

Figure 12. *Stingray's* maximum power budget.

Our primary control electronics consists of three Arduino microcontrollers (designated ROV1, ROV2, and ROV3), connected via an Ethernet hub (see Figure 11). ROV1 is dedicated to thruster and camera control to keep the code simple, clean, and robust for integrity of the latency-sensitive primary control system. ROV2 is dedicated to accessory control, communications housing telemetry, and relaying power housing telemetry data from ROV3, all of which are less time critical. ROV3 is located in the power housing and transmits telemetry (leak sensor status, humidity, temperature, current sensors) to ROV2 via a serial link. The five-port Ethernet hub in the communication housing connects ROV1 and ROV2 to the topside system via the tether.

ROV2 activates a dual Silicon Switch Relay (SSR), which is used to control lights and lasers. A high-current mechanical relay is used to switch 24 V to multiple onboard bilge pumps.

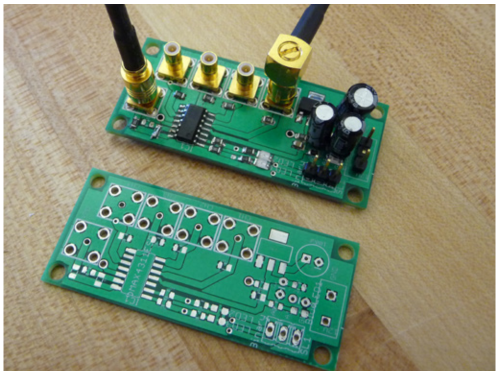


Figure 13. Rovotics-designed video switchboard.

For selecting video feeds from our multiple on-board cameras, we use in-house designed video switchers. Our four-channel Rovotics custom video switch board (Figure 13) leverages a prior eight-channel switcher designed by a former employee, modified to reduce channels and board size. ROV2 controls the board, selecting which camera feed is sent to the topside to allow for multiple views of mission-specific accessories. The board utilizes shielded coaxial cable connections to match impedance and reduce interference, as well as power filtering to protect sensitive video electronics. A supplier manufacturers the printed circuit board for Rovotics, but the design and assembly (soldering) of the board is performed in house.

Junction Box

The junction box is key to *Stingray's* modular design (Figure 14). On each subframe, many tools require wiring and electrical power and it would be inefficient to connect all wires individually each time a subframe is interchanged. To solve this problem, Rovotics engineered a junction box for the subframes. Each wire is permanently connected to the junction box, located on each of the three subframes. A single cable then connects the junction box to the electronics housings. With the removal of only one electrical connection, subframes can be quickly interchanged and operational for the next mission.

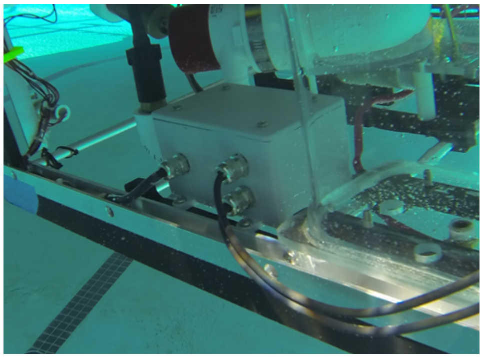


Figure 14. *Stingray's* junction box allows for easy subframe connection.

H. Programming

Overall

Stingray is controlled via a laptop running a C++ application, *Sailfish*, written in Qt Creator, the latest evolution in Rovotics control software. *Sailfish* is controlled through a Graphical User Interface (GUI) and a joystick. The goal during development was to give the pilot and copilot complete and intuitive control over *Stingray*. This freedom of movement was accomplished by a unique vector drive algorithm and state-of-the-art control system. *Sailfish* has a GUI to display information from the ROV's communication network and to accept commands from the copilot (Figure 15). In the case of a communication loss or joystick disconnect, *Sailfish* promptly alerts the copilot with an alert message, so the copilot always knows the status of the entire control system.

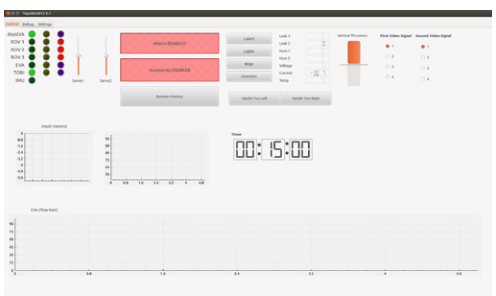


Figure 15. *Stingray's* GUI interface allows for quick shortcuts and piloting information.

Stingray's motor layout, with four horizontal thrusters mounted at 45° angles on each corner, lends itself to using vector thrust control. The joystick's x, y and z axes are read and then mathematically rotated 45° to match the layout of the motors, enabling *Stingray* to smoothly follow the motion of the joystick for excellent control. A user-adjustable dead zone prevents the analog joysticks from allowing the ROV to wander when the joystick is near neutral. The joystick utilizes a bilinear reading scale, allowing for gradual, precise motions when docking, with an intuitive progression to full speed sprints when moving to the worksite. For the complete Topside Flowchart, see Appendix C.

Bottomside

Two on-board Arduino microcontrollers called ROV1 and ROV2 reside in the communication housing and communicate with *Sailfish* via Ethernet and translate topside commands to motor speed controller or accessory inputs, or sense and relay vehicle telemetry. A third Arduino microcontroller, ROV3, resides in the power housing, monitoring sensors there and transmitting data to ROV2 via a serial link. ROV2 relays data received from ROV3 to *Sailfish*, avoiding the need to route Ethernet to the power housing. All firmware is written C++ using various Arduino libraries.

ROV1 controls the thruster speed controllers and camera pod servos only, to keep critical functions separated from other functions that could block the code flow and cause latency issues. ROV1 receives twenty User Datagram Protocol (UDP) packets per second with the motor values for all thrusters and the primary camera servo positions. Upon parsing the UDP packet, ROV1 confirms those values are within safe operating ranges, then outputs the appropriate Pulse Position Modulation (PPM) signal to each device. This simple architecture ensures robust and responsive operation.

ROV2 manages accessory control, video switching, and transmits telemetry to *Sailfish*. Similar to ROV1, upon packet receipt, ROV2 extracts the control values for each accessory and writes the appropriate output (PPM control for motor controllers for pumps and valve actuators, or digital outputs for video switching and lights, as required by the particular subframe in use). ROV2 then reads and returns telemetry from onboard sensors, including leak detectors and temperature/humidity detectors. In addition, ROV2 communicates with ROV3 via a serial bus and relays telemetry received from the opposite electronics container to the topside. ROV3 monitors leak detectors, temperature/humidity sensors, and current sensors in the power enclosure.

For safety, ROV1 and ROV2 disable all thrusters and accessories upon initialization, or if communications are lost with the topside, within a fraction of a second. While in safe mode, ROV1 and ROV2 will continue to listen for UDP packets to immediately resume normal operation if communications are restored, a self-healing feature. ROV2 and ROV3 both continuously monitor leak and humidity detectors, periodically sending the current status to *Sailfish*. For the complete Bottomside Flowchart, see Appendix C.

I. Mission-Specific Tools

Figure 16 on the following page shows photographs of the tools mounted on each subframe that were built by Rovotics to accomplish the mission tasks for the three product demonstrations. The figure includes each tool's name, the reference number, and the mission task it was built to perform. The reference number indicates the section of this document where the tool is described in detail.

1. Universal Subframe Tools

The universal subframe tools are tools that are installed on more than one subframe.

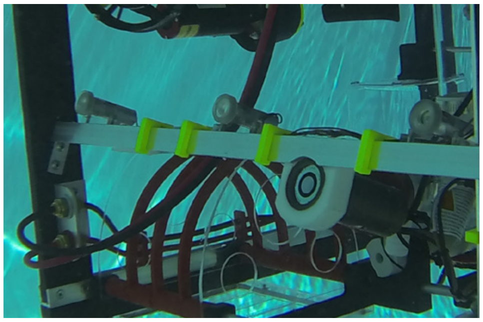
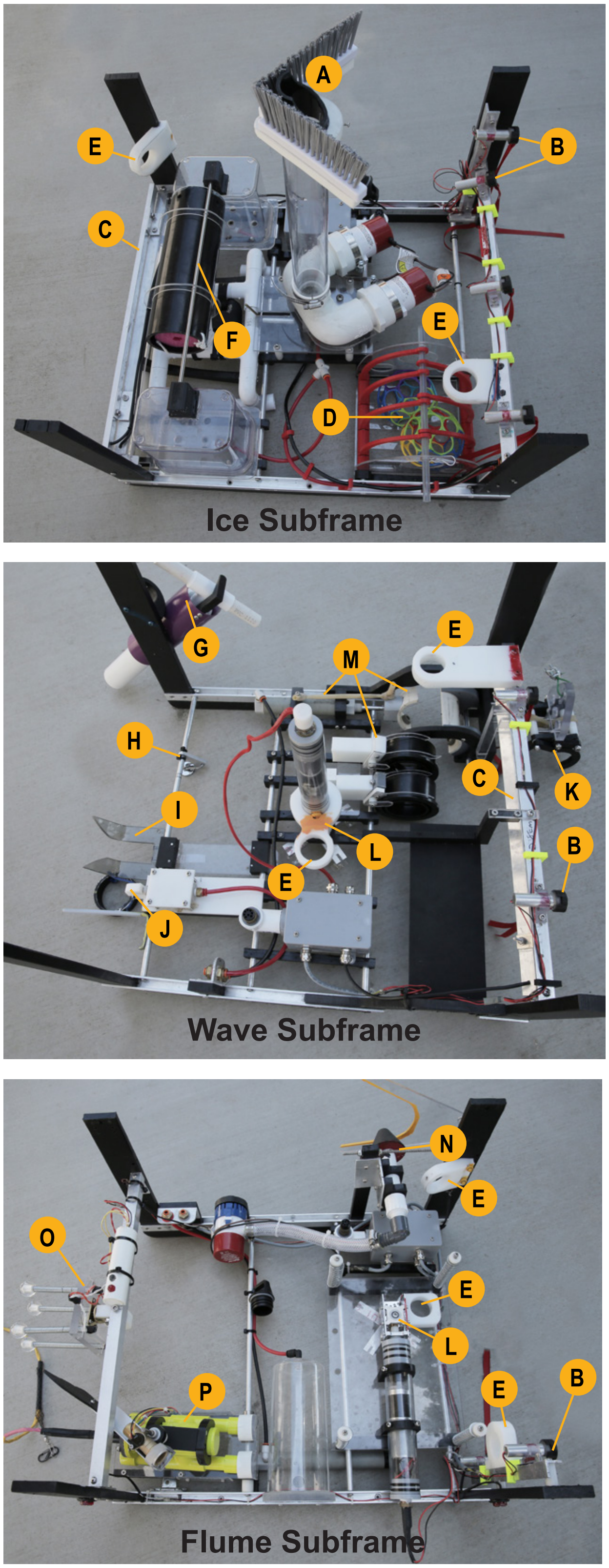


Figure 17. *Stingray's* lasers and mounted stationary camera preparing to measuring the dimensions of an iceberg.

a. Lasers--*Measure Icebergs, Pipelines, and Wellheads*
Stingray uses 5V, 5-mW, 650-nm wavelength, red, Class IIIa category, collimated beam (dot) lasers to take measurements underwater (Figure 17). Dot lasers were chosen over line lasers because dot lasers are brighter at 5 V. The lasers are used to measure the dimensions of an iceberg, the length of a section of corroded pipeline, and the height, length, and angle of a wellhead. They project a grid with known dimensions onto subsea objects. Screenshots are taken of this grid and fed into a pixel measurement

Stingray's Subframes



Ⓐ **Algae Sampler** *(2.a)* Collects a sample of algae from the underside of an ice sheet

Ⓑ **Lasers** *(1.a)* Measure Iceberg (ice subframe), measure corroded pipeline section (wave subframe), measure height and length of wellhead (flume subframe).

Ⓒ **Light Bar** *(1.d)* Lights up the work area for mission tasks (ice and wave subframes).

Ⓓ **Sea Urchin Recovery** *(2.c)* Collects an urchin located on the sea floor.

Ⓔ **Mission-Specific Camera Mounts** *(1.b)* Hold the cameras used to view the mission tool operations.

Ⓕ **Acoustic Lift Assembly** *(2.b)* Deploys a passive acoustic sensor in a designated area.

Ⓖ **Hot Stab Insert** *(3.b)* Inserts a hot stab into the port on the wellhead.

Ⓗ **Cap Lifter** *(3.d)* Removes and replaces the wellhead's protective cover.

Ⓘ **Hot Stab Removal** *(3.b)* Removes the hot stab and returns it to the surface.

Ⓙ **Gasket Installer** *(3.e)* Installs a gasket into the wellhead.

Ⓚ **Pipe Clamp** *(3.a)* Attaches a lift line to a corroded section of pipeline. Removes the pipeline section and returns it to the surface.

Ⓛ **Active Valve Turner** *(1.e)* Turns a valve to stop the flow of oil through a pipeline (wave subframe). Turns valves for specified oil pathway (flow subframe).

Ⓜ **Flange Installer** *(3.c)* Installs flange adapter over both cut ends of the pipeline.

Ⓝ **Pipeline Pump** *(4.a)* Moves water through the pipeline system.

Ⓞ **Anode Sensor** *(4.b)* Tests the grounding of anodes on the leg of an oil platform.

Ⓟ **EVE Flow Sensor** *(4.c)* Determines average flow rate of current.

Figure 16. How *Stingray's* three subframes are configured to complete the mission tasks.

program called PixelStitch[6] to determine the dimensions of the subsea object based on the known dimensions of the laser grid. This system was proven accurate during preseason testing. *Stingray's* predecessors used pixel measurement software to compare object sizes; however, *Stingray* projects its own grid so that dimensions can be determined even without existing points of comparison. All lasers have black protective caps for safety purposes when not in use.

b. Cameras--*Pilot Navigation and Tool Operations*
Stingray has two tilting cameras with 140° wide-angle lenses for pilot navigation, shown in Figure 18. Each camera is mounted on a 180° servo motor, and made waterproof with a proprietary bayonet-sealed acrylic tube. The camera, along with the servo mount, gives the pilot nearly 240° vision. The camera pods are third-generation renditions of a successful Rovotics product, having undergone four years of design improvements. The newest version, found on *Stingray*, is compact, comes with a full ultra-luminescent LED lighting strip, and is constructed from easily-interchangeable parts, all produced by Rovotics.

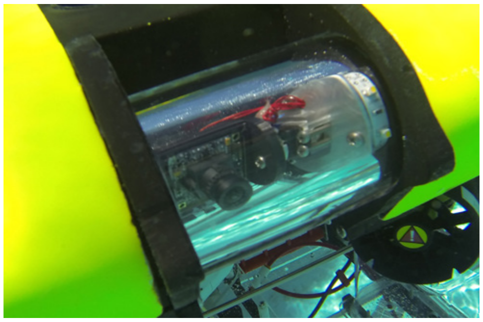


Figure 18. *Stingray's* front tilting camera inside our 3rd-generation camera pod.

To avoid condensation from the air within the camera pods in the frigid Arctic waters, the volume of the camera pods was minimized based on data from a psychrometric chart[7]. Since the maximum amount of condensation is proportional to the humidity per unit volume, the camera pod was made as compact as possible to prevent any potential fogging issues. The company also added desiccants to the pods as an additional precaution against fogging.

In addition to the two tilting cameras, *Stingray* has three stationary mission-specific cameras used to view subframe tool operations. The cameras are connected to the core vehicle electrically and are placed in the camera mounts on each subframe (Figure 17).

c. Depth Sensor--*Measures Iceberg and ROV Depth*
On previous Rovotics' products, depth sensors have had a margin of error of up to 10 cm. To improve sensor accuracy, the company modified a SparkFun Breakout Pressure Sensor Board from the OpenROV project[4]. This modification has proven accurate within 1 cm, reducing error by a factor of 10. This board relies on a gel membrane and an anti-magnetic stainless steel cap above a finely tuned pressure sensor. The pressure sensor measures gel compression as barometric pressure increases. We calibrate the depth sensor by comparing it to a known barometric pressure when the ROV is out of the water. Rovotics designed a compact, watertight casing in CADD. This casing is made from high-strength polycarbonate and filled with epoxy to protect electronics, while leaving the gel sensor exposed to the environment.

d. Light bar--*Vehicle Lighting for Tasks*
For operating in low light conditions beneath the ice sheet, LED lighting strips were placed within a piece of U-channel aluminum, then potted in clear epoxy. The system is completely waterproof, inexpensive to manufacture, and can illuminate a large area around *Stingray*, which is ideal paired with our wide-angle camera system. A natural white LED was selected for minimal color distortion, allowing for easier color identification of sea stars.

e. Active Valve Turner--*Directs Oil Through the Specified Pathway and Stops the Flow of Oil Through a Pipeline*
For the active valve turner, a high-torque DC motor is mounted to a pronged docking receptacle, which fits and locks easily onto the handle. The motor is horizontal and its motion is converted to vertical with a 90° right-angle gear box. This compact method cleverly provides all the benefits of an electric motor, such as torque, cost, and simple housing manufacturing, while taking up a small

volume. Additionally, the whole valve turning system is spring loaded so that it sits below the ROV bottom, and can therefore extend down to grip the handle, but retracts into the subframe when not needed (Figure 19).

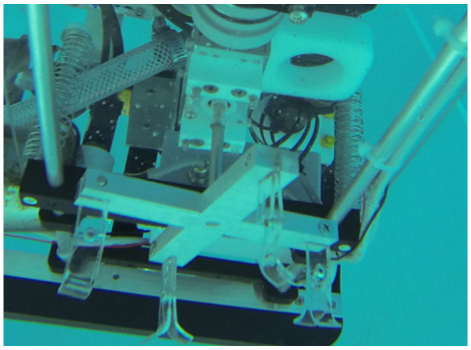


Figure 19. *Stingray's* active valve turner preparing to turn a pipeline valve.

2. Ice Subframe Tools

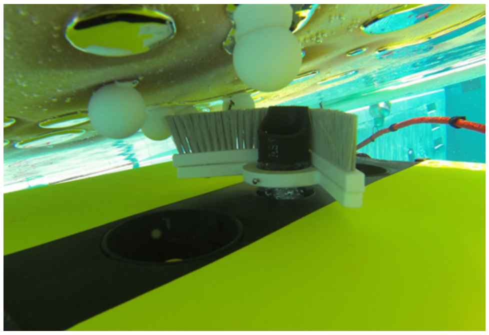


Figure 20. *Stingray's* algae sampler moments before suction pumps were activated to collect algae sample.

a. Algae Sampler--*Collects Algae Sample from Under the Ice*
Two 3,000-liters-per-hour bilge pumps work in parallel to maintain suction through a vertical pipe, through which any passing algae samples will be pulled. A V-shaped pipe nozzle guides samples into the mouth of the suction tube (Figure 20). Once a sample is secured, a one-way gate at the mouth of the tube prevents any algae from escaping until *Stingray* surfaces with the sample.

b. Acoustic Lift Assembly--*Deploys a Passive Acoustic Sensor*
The acoustic sensor is held inside *Stingray's* subframe by an extended pneumatic piston. When the piston is retracted, the sensor falls away from the ROV onto the sea floor (Figure 21). A polycarbonate brace holds the acoustic lift's buoyancy tube clear of the camera feed. *Stingray's* pistons are made of composite plastics, chosen over stainless steel for their non-corrosive nature and low cost.

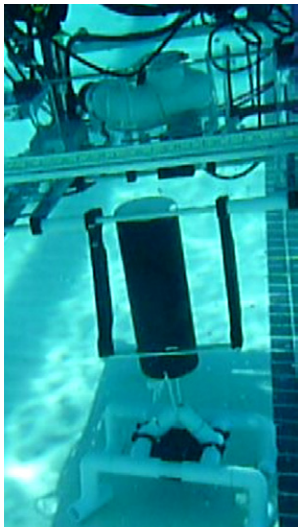


Figure 21. The acoustic sensor being deployed onto the sea floor.

Stingray has an active ballast system to counteract the 30-N water weight of the sensor. This buoyancy consists of two modified acrylic containers, into which pneumatic lines run. When carrying the acoustic sensor, the containers are filled with air to provide just enough lift to make the ROV neutrally buoyant in the water. This air is released through a bleed hole after the sensor is placed.

c. Sea Urchin Recovery Device--*Collects Urchin from Sea floor*
The design of this tool was based on last year's successful bottle recovery device. Flexible polycarbonate strips act as a one-way gate used to secure the sea urchin within the ROV interior. The power of *Stingray's* downward thrust is enough to force the sea urchin through the gate and into a holding chamber, from which it cannot escape. 3D-printed ribs hold the captured urchin firmly in place until it can be returned to the surface.

3. Wave Subframe Tools

a. Pipe Clamp--*Attaches Line to Corroded Section of Pipe and Returns Section to the Surface*
The fully-mechanical pipe clamp is powered by a section of durable surgical tubing, chosen because it is inexpensive, commercially available, and highly elastic. The clamp is held open by two bracing rods while on-board the ROV. As soon as the pilot attaches the clamp to the pipe and slides the clamp off the vehicle, the elastic tubing pulls the clamp shut around the pipe. A lift line attached to the clamp, now secured to the pipe, then pulls the pipe to the surface (Figure 22).

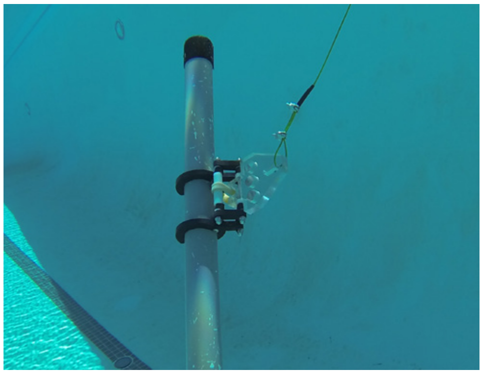


Figure 22. The corroded section of pipe being returned to the surface.

b. Hot Stab Insert and Removal--*Simulates Injection of Corrosion Prohibiter into the Wellhead and Returns to Surface*
Flexible polycarbonate ribs firmly hold the hot stab in a half-tube guide at a 45° angle, the same angle as the docking pipe (Figure 23). After the hot stab is inserted into the pipe, operators can twist *Stingray* away from the pipeline so the polycarbonate ribs flex, releasing the hot stab. The whole platform is mounted on the outside of *Stingray* so that the release is unrestricted. This system was chosen over a gripper because it is simpler, less expensive to construct, and is fully mechanical. A dedicated camera helps the pilot with alignment. For hot stab removal, simple curved forked fingers, made of smoked polycarbonate for pilot visibility, cradle the T-handle of the hot stab for returning to the surface.

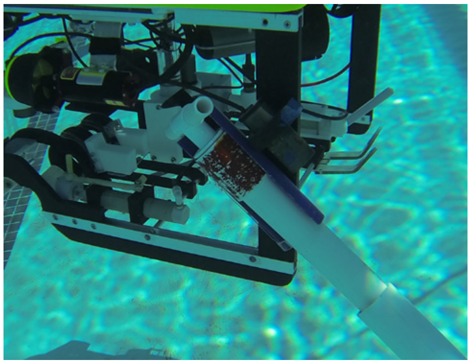


Figure 23. *Stingray* inserting the hot stab into the wellhead.

c. Flange Installer--*Installs Adapter Flange*
Two replacement adapter flanges are carried on the ROV in flexible polycarbonate fingers. The ROV aligns itself with the pipeline using centering rails and recesses cut into the frame. The first replacement flange is positioned alongside the exposed end of the pipeline, then the ROV translates sideways to slip the flange over the exposed pipe end. A pneumatic ram extends, pushing the ROV back away from the pipe horizontally, pulling the flange free from the fingers. This method prevents the pipe from being accidentally lifted from the cradle, an issue that was encountered during early prototype testing. With the first flange deployed, the second flange can be positioned and installed in a similar manner.

d. Cap Lifter--*Removes and Replaces Wellhead Cap*
A rare-earth neodymium magnet mounted on a carabiner hanging from the frame has proven to be a very simple and reliable tool for removing and replacing the wellhead cap. To remove the cap, the magnet captures the ferrous U-bolt on top of the cap and the pilot lifts away. The cap hangs from the magnet during gasket replacement operations. When the cap is in place, the pilot slides the magnet to the bottom of the U-bolt, where resistance with the cap forces the magnet to disengage.

e. Gasket Installer--*Installs a Gasket into a Wellhead*
The gasket is held by its string between two pieces of HDPE attached to a piston. When the piston is activated, the top piece of HDPE pushes the gasket string off of the stationary bottom piece, allowing the gasket to fall straight down over the wellhead.

4. Flume Subframe Tools

a. Pipeline Pump--*Moves Water Through the Pipeline System*

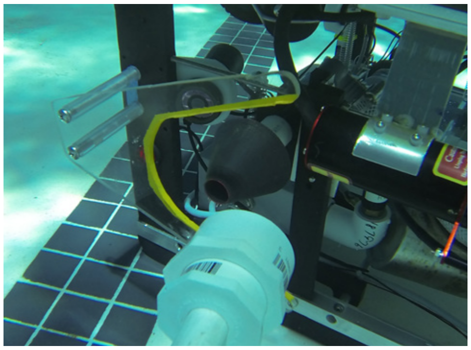


Figure 24. *Stingray's* pipeline pump aligning to the pipeline system opening.

To push water through the pipeline system, *Stingray* uses an on-board bilge pump. Docking with the pipeline is simplified with a V-shaped polycarbonate guide, so that the ROV's outflow nozzle is self aligning. The outflow nozzle itself is a 3D-printed rubber-painted cone, designed to fit squarely within the subsea pipeline and make a complete seal to prevent leakage (Figure 24).

b. Anode Sensor--*Tests the Grounding of Anodes*
The anode sensor consists of exposed flexible contacts strategically placed to make contact with the grounding strap and two anodes at the same time. The probe is designed to analyze all four anodes by coming into contact with the oil platform leg

only twice, saving valuable demonstration time (Figure 25). A key design feature is a bridge rectifier connected to the probe contacts, allowing the probes to be polarity flexible, generating a positive signal for an Arduino micro-controller to detect. The sensor scans for potential voltage differences between an anode and the platform grounding strap. During each of the scans, LEDs indicate the status of each probe. The LEDs flash at different rates to indicate which has the greatest potential voltage difference.

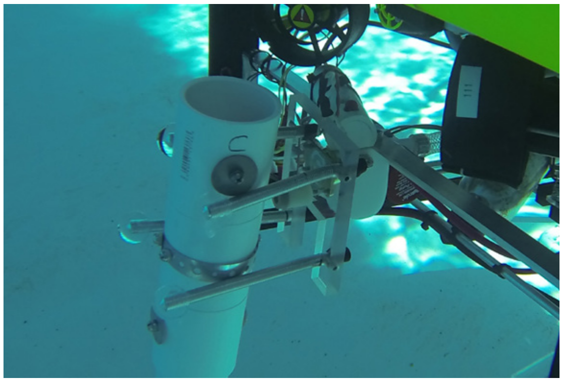


Figure 25. *Stingray's* anode sensor testing the grounding of anodes.

The primary challenge to this task is the unknown angle of the anode platform itself. To counteract this variable, the entire tool is suspended from the subframe with a rocker joint. This joint allows the tool to freely align with the platform leg, regardless of the angle.

c. Flow Sensor (EVE)--*Determines the Water Current Flow Rate*

Our newly-designed Experimental Velocity Evaluator (EVE) flow sensor is released from *Stingray* by a pneumatic piston and autonomously records flow data at the work site (Figure 26). EVE's electronics are enclosed by a cylindrical housing, made from an extruded aluminum tube welded to a custom flange and sealed with a face seal. The housing is coated with high-visibility anti-corrosive safety-yellow paint. EVE's enclosed flow impeller-based sensor is mounted to a swivel joint with a large tail fin, to align with the current. Rate of flow is measured by counting the rotations per minute of a rotary impeller. All data is transmitted to the surface with an independent tether. Rovotics calibrated the EVE sensor by towing it on a weighted cart through water while recording the number of impeller ticks over a known distance and time.

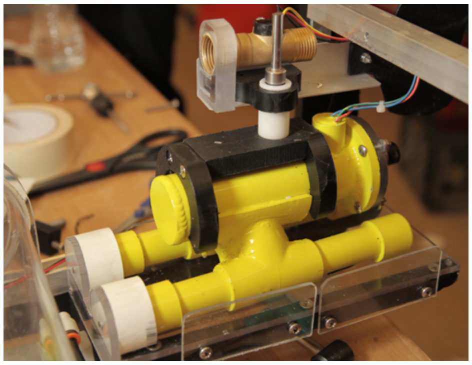


Figure 26. EVE held in a pneumatic gate, ready for launch.

J. Troubleshooting and Testing Techniques

Rovotics began the troubleshooting process by identifying and isolating the problem through root cause analysis and applying the principle of “5 Whys”[1]. Small-scale component tests were run until the problem was located. Company employees then brainstormed various ways to remedy the problem before deciding on a course of action based on factors such as simplicity, cost, and time required.

All components were tested above water and then again in the pool immediately after completion. For example, the Anode Sensor worked well when tested out of water, but failed when tested in the pool. It was not sensitive enough to detect the reduced voltage of the subsea anodes on the oil platform leg because of water conductivity (Figure 25). After troubleshooting with a voltmeter, the anode reference voltage was lower than the expected six volts. We then increased the sensitivity of the anode sensor.

The entire vehicle was tested in a full-scale “dry run” in which the vehicle was powered and bench tested, where the environment was controlled to avoid any safety incident. The vehicle was then placed into a practice tank for several rounds of integration testing to determine its center of buoyancy, adjust for camera diffraction, and find the vehicle's limits. The vehicle was also specifically tested under adverse environmental conditions to simulate the parameters of the product demonstrations. We placed *Stingray* in an ice bath to simulate polar conditions and to monitor condensation and frost in camera and electronics housings. We then tested *Stingray* under a fully-covered pool to simulate the reduced ambient lighting under an ice sheet.

III. Safety

A. Company Safety Philosophy

Employee Safety is a Rovotics core value and our company's highest priority. We believe that all employees have the right to a safe work environment and that all accidents are preventable. Our rigorous training, safety procedures, and safety protocols allow us to avoid accidents preemptively.

B. Lab Protocols

Since safety is our core value, specific safety protocols are implemented while working in the lab (Figure 27). We use Job Safety Analysis (JSA) forms for employees to create and review before performing risky operations. New forms are created whenever a new manufacturing process is introduced. We use our handbook to train everyone on safety practices such as back safety, electrical safety, hazardous materials handling, housekeeping, and tool safety. We encourage employee observation and investigation of near-miss accidents. We also have Material Safety Data Sheets (MSDS) for every product used in Rovotics production.

Our lab facility features a chemical vent hood so that soldering of electronics can be completed without fume exposure. The work area maintains a negative pressure relative to the room and the fumes are carried up ducting to a roof-mounted vent.

A peer-to-peer system is used for the safety training of new employees. Newly-hired employees observe veteran employees operating machinery. Veteran employees then closely supervise and mentor new employees as they begin to operate the machinery. Once the new employee demonstrates safe and proper operating practices, then they can work independently. All employees must police each other at all times in making sure that everyone follows established safety protocols.

Figure 27. Employee using personal protection equipment while operating machinery.

C. Vehicle Safety Features

Stingray contains numerous safety features designed to keep the crew, ROV, and work environment safe during operation. In addition to electrical protection and software safe modes discussed in previous sections, mesh netting and motor shrouds cover the thrusters. The four HDPE supports on the subframes act as handles for easy launch and removal of the ROV, preventing injuries to the crew. Various waterproofing techniques ensure all electronics remain dry, protecting both personnel and equipment from short circuits. In the event of leakage, a leak detector monitored by one of the Arduinos detects moisture and humidity in the electronics housings and alerts the pilot to shut down and return to the surface. Eye safety is ensured by lasers designed with black covers to prevent accidental exposure during maintenance and testing, and with red ribbons attached for a visible reminder to remove before launch. Also, pneumatic activation switches on the TCU have 3D-printed safety covers to prevent accidental actuation. Since safety is our core value, *Stingray* was built with many additional safety features, which are described in the Design Rationale.

D. Operational and Safety Checklists

Operational safety protocols are dictated by Rovotics' Operational and Safety Checklists (Appendix A), and are closely followed before and after deployment of *Stingray*. The company also follows operational JSAs for ROV launch, recovery, and waterside safety.

IV. Logistics

A. Scheduled Project Management

To complete *Stingray* on time, Rovotics leadership used a Gantt chart to guide their decisions about scheduling and resources. The chart displayed Rovotics' internal deadlines, along with external deadlines set by MATE. The company CEO delegated responsibility to the heads of each department, who in turn led all department employees in the development of components and deliverables required by MATE. Resources such as the CNC mill were managed with production schedules arranged by component priority. Figure 28 shows one of the Gantt charts used for scheduling.

Task	Resource	10-Jan	17-Jan	24-Jan	31-Jan	7-Feb	14-Feb	21-Feb	28-Feb	7-Mar	14-Mar	21-Mar	28-Mar	4-Apr	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May	23-May	30-May	31-May
		Start	Housing Comes	SAT					Fluids		SAT			Easter/Spec Sheet & SID			Qual vid	SAT		Finals			Ship
ROV																Qual Prep	Qual	~~Pool Practice~~	~~Pool Practice~~	Pool Practice	Pool Practice	Pool Practice	
PROGRAMMING														GOAL	Slip		Rev 1		DONE	Adjust	Adjust	FINAL	
*ROV 1	Ben												GOAL	Slip			Rev 1		DONE	Adjust	Adjust		
*ROV 2	Ben												GOAL	Slip						Adjust	Adjust		
*Topside	Alex/Cassidy													DONE						Adjust	Adjust		
*Telemetry	Nick/Gavin									DONE										Adjust	Adjust		
*EVA	Cassidy		Rev 1					Rev 2				GOAL			Calibrate	DONE				Adjust	Adjust		
ELECTRONICS														GOAL	Slip				DONE	Adjust	Adjust	FINAL	
*Comm	Ben/Andrew	Start				Goal	Slip			Rev 1							Rev 2		DONE				
*Power	Ben/Matt							Goal															
*Video	Matt	Start												DONE						Adjust	Adjust		
*Tether	Risheek	Order Parts						Start		DONE													
*TCU	Matt/Gavin	Order Parts		Build	DONE																		
BUILD																		DONE	Adjust	Adjust	Adjust	FINAL	
*Top frame				Rough									Rev 1			Rev 2		DONE	Adjust	Adjust	Adjust		
*Bottom frames		CADD	Order	Rough									Rev 1			Rev 2		DONE	Adjust	Adjust	Adjust		
*Accessories	Ryan						Prototype						Rev 1			Rev 2		DONE	Adjust	Adjust	Adjust		
*Cameras	Jared		Bullet		PTZ	DONE													Adjust	Adjust	Adjust		
*Buoyancy	Jared				Design				Build					GOAL	Slip				DONE	Adjust	Adjust		

Figure 28. Rovotics' Gantt chart for main components.

Each workday began with a kickoff meeting, where the Gantt chart was reviewed and the CEO assigned specific production goals to each employee. At each workday's closing meeting, the daily production goals and accomplishments were reviewed, and the Gantt chart was updated. Production goals not met would be worked on individually by employees between workdays. Employees that completed their work on time in a skillful and enthusiastic manner were rewarded with more interesting and complex assignments designed to keep them motivated and further develop their skills.

B. Source Code Management

To better manage parallel software development by multiple programmers, Git was used as a Version Control System (VCS). By using a VCS, the company kept track of every change made to every file. Git was chosen because it is a well-supported and highly-polished Distributed VCS (DVCS), meaning there is no central repository and each client has a local copy of the full repository. If something goes wrong, files can be easily reverted to earlier versions. By making detailed commit messages standard, everyone could monitor the progress that each division was making. This was critical in Rovotics' parallel development environment. Git simplifies software branching and merging, which is important when multiple people are working on the same file or interdependent files.

For accountability and organization, each file had a designated custodian who had primary responsibility for the development of a particular source code file. Any issues or questions could be directed toward the proper custodian and resolved quickly.

C. Budget and Project Costing

At the beginning of the year, a budget was prepared by Rovotics with estimated expenses based on the prior year's actual expenses. The airfare expense was estimated but listed separately since Rovotics employees pay for their own air travel. Each year, the company also plans for one large capital expense to improve lab tools and resources. This year we budgeted for the purchase of a 3D printer. Income was estimated from Jesuit High School, fund-raisers, and employee dues, and added to the budget. See Appendix B for our complete budget.

As a high-school-based company, Rovotics' income is limited and the company must adhere to the budgeted expenditures. On a monthly basis, purchase receipts were entered into a Project Costing sheet and tracked against the budget. The 2015 Project Costing sheet is shown in Figure 29.

Rovotics 2015 Project Costing						
	Item	Description/Notes	Type	Qty	Amount	Total
Stingray Core Vehicle Expenses	Arduino Ethernet		Purchased	3	$ 56.35	$ 169.05
	Arduino Nano		Purchased	3	$ 25.17	$ 75.51
	Arduino Support Electronics	Shields, Programmers, Transistors, Resistors	Purchased	1	$ 157.60	$ 157.60
	Zahn Power Converters		Purchased	4	$ 109.87	$ 439.48
	NTSC Cameras	Front and Back ROV cameras	Purchased	2	$ 41.99	$ 83.98
	Inertial Measurement Unit (IMU)		Purchased	1	$ 81.95	$ 81.95
	Seabotix BT150Thruster	Re-used from our 2013 ROV	Re-used	6	$ 495.00	$ 2,970.00
	Crust Crawler Thrusters		Purchased	2	$ 650.00	$ 1,300.00
	Brushless ESC Motor Controllers		Purchased	2	$ 22.25	$ 44.50
	Gland Seals	McMaster Liquid Tight Connectors	Purchased	4	$ 7.95	$ 31.80
	Networking Hub		Purchased	1	$ 14.95	$ 14.95
	Custom PCB	Video Switching Board	Purchased	3	$ 19.95	$ 59.85
	Silicon Relay Board		Purchased	2	$ 19.89	$ 39.78
	Sabertooth Speed Controller		Purchased	3	$ 125.00	$ 375.00
	Subconn Connectors		Purchased	17	$ 75.35	$ 1,280.95
	Subconn Connectors	Re-used from our 2013 ROV	Re-used	9	$ 75.35	$ 678.15
	Tether Cabling	100 Feet (12/2 wire, 1/4" Pneumatic Line) 2@75 ohm Video	Purchased	1	$ 250.18	$ 250.18
	Leak Detectors		Purchased	2	$ 2.90	$ 5.80
	Lasers	5mW 650nm Red	Purchased	10	$ 5.95	$ 59.50
	LCA Camera	Lights Camera Action LCA-7700	Re-used	3	$ 255.00	$ 765.00
Stingray Subframes Expenses	Ice - Bilge pumps		Purchased	2	$ 58.00	$ 116.00
	Ice - LED lights		Purchased	2	$ 25.00	$ 50.00
	Ice- Pneumatics		Purchased	1	$ 55.00	$ 55.00
	Flume - Motor and gear box		Purchased	1	$ 125.50	$ 125.50
	Flume - Pneumatics		Purchased	1	$ 55.00	$ 55.00
	Flume - Lights		Purchased	4	$ 7.95	$ 31.80
	Flume Bilge pump		Purchased	1	$ 57.90	$ 57.90
	Wave - Pneumatics		Purchased	2	$ 64.99	$ 129.98
	Wave - LED lights		Purchased	1	$ 24.95	$ 24.95
	Mcmaster Connectors	for Junction Boxes	Purchased	12	$ 7.95	$ 95.40
Stock Expenses	Acrylic Stock	From TAP Plastics	Parts Donated	1	$ 125.00	$ 125.00
	Aluminum Stock	Tubing, Channel, Plate	Purchased	1	$ 199.99	$ 199.99
	HDPE Stock		Purchased	1	$ 311.24	$ 311.24
	Polycarbonate		Purchased	1	$ 300.00	$ 300.00
	Type II PVC		Purchased	1	$ 122.11	$ 122.11
	Nuts, Bolts, Screws	Stainless Steel	Purchased	1	$ 392.18	$ 392.18
	Shop Consumables	Drill Bits, Sand Paper, Epoxy, Solder, Saw Blades Mill Bits	Purchased	1	$ 565.69	$ 565.69
	3D Filament	ABS Printing Filament	Purchased	3	$ 22.45	$ 67.35
Services	Welding	Upper and Mid Can and Mounting Plate	Purchased	1	$ 325.78	$ 325.78
	Custom machining		Purchased	2	$ 150.00	$ 300.00
Rework Expenses	Rework Costs	Replacement Parts, Supplies	Purchased	1	$ 535.46	$ 535.46
Total Invested in ROV Stingray (Purchased plus Re-used, and Donated)						**$ 12,869.36**
Tether Control Unit Expenses	TCU Case	Dewalt Modular Toolbox, from 2014	Re-used	1	$ 75.00	$ 75.00
	Netgear Router	Re-used from 2014	Re-used	1	$ 65.00	$ 65.00
	Netgear Switch	Re-used from 2014	Re-used	1	$ 25.00	$ 25.00
	Axis IP Video Server	Re-used from 2014	Re-used	1	$ 125.00	$ 125.00
	DC-DC Power Converter	56V-12V, re-used from 2014	Re-used	1	$ 16.00	$ 16.00
	Ethernet Connectors	Nutric Panel Mount Mod 8 Pass Through, from 2014	Re-used	8	$ 7.00	$ 56.00
	BNC Video Connectors	Re-used from 2014	Re-used	4	$ 6.00	$ 24.00
	LED Panel Lights	Re-used from 2014	Re-used	5	$ 5.00	$ 25.00
	Main Power Switch	Re-used from 2014	Re-used	1	$ 28.00	$ 28.00
	Amp Meter	Re-used from 2014	Re-used	1	$ 12.00	$ 12.00
	Air Button	Re-used from 2014	Re-used	1	$ 4.00	$ 4.00
	Pneumatic Relay	Re-used from 2014	Re-used	1	$ 12.00	$ 12.00
	Laptop LCD Display	Laptop LCD and Video Converter Board, from 2014	Re-used	1	$ 130.00	$ 130.00
Mission Control Center	Mission Monitor	Re-used from 2014	Re-used	1	$ 295.00	$ 295.00
	Mission Laptop	Re-used from 2014	Re-used	1	$ 1,195.00	$ 1,195.00
	Mission Joystick	Re-used from 2014	Re-used	1	$ 39.00	$ 39.00
Total Invested in ROV Control System (Purchased plus Re-used and Donated)						**$ 2,126.00**
Printing Expenses	Printing Expenses	Marketing Displayes, pamphlets, decals, etc.	Purchased	1	521.19	$ 500.00
Shipping Expenses	Shipping ROV	Estimated	Purchased	1	$ 5,000.00	$ 5,000.00
Travel Expenses	Transportation Expenses	Air Fare for coaches	Purchased	2	$ 1,093.50	$ 2,187.00
	Lodging	Competition Lodging for employees 12 rooms x 6 nights	Purchased	72	$ 120.00	$ 8,640.00
	Meals	Breakfast included with lodging, lunch included from MATE	Purchased		$ -	$ -
Registration Expenses	MATE Fees	MATE Competition Registration	Purchased	1	$ 100.00	$ 100.00
Capital Expenses	Shop Tools	3D Printer	Purchased	1	$ 2,499.00	$ 2,499.00
Total Invested (Purchased plus Re-used and Donated)						**$ 33,921.36**
Total Purchased						**$ 27,257.21**

	Item	Description/Notes	Type	Qty	Amount	Total
Income	Fundraising	QSP Magazine Sales				$ 3,000.00
	School Funding	Jesuit High School				$ 14,000.00
	MATE 1st Place Prize	Won at 2014 MATE Competition				$ 500.00
	MATE 1st Place Poster Prize	Won at 2014 MATE Competition				$ 100.00
	Donations	Sponsor Donations	Cash Donated			$ 5,000.00
	Employee Dues	Team Member Dues		18	$ 175.00	$ 3,150.00
Total Income						**$ 25,750.00**
					Balance (Income minus Purchased)	**$ (1,507.21)**

	2015 Employee Expenses	
Estimated Travel	Air Fare ($1,093.50 each)	$ (19,683.00)
	Additional Meals $180 each	$ (3,600.00)
	Total Individual Expenses	$ (23,283.00)

Figure 29. 2015 Rovotics Project Costing Sheet.

V. Conclusion

A. Challenges

Many technical challenges were present when constructing and operating *Stingray*, but none so difficult as those encountered with the electronics housings. It is critical that these housings remain watertight. Welding made the thin aluminum housings warp slightly. Even with extra-thick O-rings, they leaked heavily, which halted the progress of electronics installation. This challenge was overcome using a large wooden framework to apply a torque to the housing and bend it gradually back into shape (Figure 30).

Figure 30. Wooden framework ready to bend the electronics housings into the correct shape.

A non-technical challenge resulted from schedule compression. Our schedule was laid out at the beginning of the year with a Gantt chart and was sensitive to setbacks. International shipping from California to St. John's takes more time than standard shipping due to international customs. A compressed build and design schedule influenced the decision to use multiple development teams working in parallel to complete *Stingray* and its tools, with emphasis on simplicity. The company began to add additional workdays to compensate for the loss. In this manner, we managed to finish in time and also preserve some of our in-the-water testing and practice time.

A financial challenge this year was the loss of an anonymous benefactor who generously paid for shipment to the competition. This loss occurred mid-season, so we needed to absorb the expense and dip into some reserve funds that we had saved from previous seasons.

B. Lessons Learned and Skills Gained

As a large company with many interdependent departments, Rovotics faced many technical challenges. Early in the season, a lack of clear communication led to an issue regarding the sources of file libraries. The company learned a lesson about the importance of managing not only our internal code but also external code sources included in our programs. Common libraries were added to our company Git repository so all external code could be sourced from a single location. Additional technical organizational tools used include a Gantt chart, Git for source code management, and Google Drive for all important documents and photo galleries.

Interpersonally, the company gained skills in employee self management. With our highly-varied workload and resource contention, employees would sometimes find themselves with little to do. The company learned how to preemptively plan and organize. We created a list of auxiliary tasks that would contribute toward the final ROV without disrupting other employees. Any employee who had completed their daily tasks could look at this list and find a way to productively occupy their time. Standing items on this list include lab organization, tool maintenance, required safety inspections, and housekeeping.

C. Future Improvements

The two-housing design of *Stingray* offers many benefits, but can be improved upon. To prevent any possible leakage issues, the electronics housings would be oil filled and have double O-ring seals, so the ROV could function at much greater depths without risk of leaking, and be more tolerant to O-ring defects or minor debris. While leaks were not a significant issue for *Stingray*, any large-seal-area housing has a higher risk for leakage, especially at depth.

For expanding mission capabilities for future customers, our adaptable subframe architecture allows for easy addition of new capabilities by developing custom subframes specific for new requirements.

The company had great success with the introduction of high-performance CrustCrawler thrusters, creating a hybrid configuration with our existing vector control system. Since having two different types of thrusters has increased the cost of maintaining our on-hand spare parts inventory, we would replace the Seabotix thrusters with the high-performance brushless CrustCrawler thrusters. With this change, *Stingray* would gain more speed and maneuverability without affecting the power budget.

Additionally, the company would invest in HD cameras for improved visibility. *Stingray* has had success converting some camera systems from NTSC signals to IP video signal, and intends to do so for all on-board camera systems. Tilting cameras have also proven beneficial to *Stingray*, so, in the future, the company will pursue camera systems that can both pan and tilt for additional visibility.

D. Senior Reflections

Reflections were written by the seniors retiring from Rovotics this year, photographed in Figure 31.

Figure 31. Rovotics seniors with *Stingray*. (Picture left to right) Alex Aprea, Ryan Kenneally, Jared Borg.

I would like to thank my fellow teammates, the amazing coaches, MATE, and my parents for providing me with the opportunity to participate on the Jesuit High School Robotics Team. As a four-year team member and former team captain, this competition has helped me determine my future career as well as enhance my interest in computer science. I am more prepared for my future because of the practical applications MATE has provided me in programming and leadership. My experience on this team and in the MATE competition has been nothing but positive, and I look forward to studying electrical engineering and computer science at UC Berkeley next year.

~**Alex Aprea**, *2014 CEO, Lead Programmer*

Jesuit Robotics and the MATE competition have been both adventures and blessings. While a company like any other in some ways, it is like no other in terms of the shared passion behind every workday. The experiences I've gained from the MATE competition have influenced my career path, and I can say with pride that the memories of MATE will stay with me for years to come. I am a member not only of a successful company, but also of the community and family, that is Jesuit Robotics and MATE. Thanks for the memories!

~**Ryan Kenneally**, *Lead Pilot, Designer/Builder, Technical Writer*

I would like to thank the MATE Center and the countless volunteers that make this competition possible. The people I have met and grown close with through the course of completing these past four years will remain lifelong friends. They share a passion of mine, working with others for the common goal of educating ourselves, others, and the future. My skills in designing and manufacturing have increased exponentially as the result of excellent leadership and mentors, and I am looking forward to continuing in the MATE competition on the Purdue team next year.

~**Jared Borg**, *Lead Builder and Machinist*

E. Acknowledgments

Rovotics' would like to thank the following benefactors:

- MATE Center and Marine Technology Society - Sponsoring this year's competition
- Jesuit High School - Generous donation of funding, pool time, and a new lab
- Rolf Konstad, Head Coach - His leadership, wisdom, time, and patience for six years
- Jay Isaacs, Senior Asst. Coach - His time, creativity, and knowledge for the last ten years
- Alice and Lloyd Gabbert - Generous monetary donation to fund our 3D printer
- Jim Claybrook of Weldmasters - Welding our electronics pressure vessel
- Fish Eye Scuba - Providing SCUBA tanks for in-pool sessions at a reduced rate
- MacArtney Connectors - Providing connectors at a reduced rate
- Github - Providing complimentary private code repository
- TAP Plastics - Donation of stock plastic
- SolidWorks - Donation of SolidWorks 3D software
- Schilling Robotics - For facility tour and interview with Steve Barrow, Sr. Applications Engineer
- Student Mentors - Marc Aprea, LisaMarie Isaacs, Steve Kiyama, Cindy Meissner, Dawn Remme, & David Unter
- Operational Support - Sharon Aprea, Tim Kenneally, Andrea Konstad, Cheryl Kiyama, Stacy Paragary
- Our Parents - For their continued support and encouragement

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VI. Appendices

A. Operational and Safety Checklists

Pre-Power

- □ Laser safety glasses on
- □ Area clear/safe (no tripping hazards, items in the way)
- □ Verify power switches and circuit breakers on TCU are off
- □ Tether flaked out on deck
- □ Tether connected to TCU
- □ Tether connected to ROV
- □ Electronics housings sealed
- □ All underside seals properly sealed
- □ Nuts tight on electronics housings
- □ Thrusters free from obstructions
- □ Verify air supply is properly regulated at 40 PSI
- □ Ensure air supply is securely connected to TCU
- □ Power source connected to TCU

Power-Up

- □ TCU receiving 48 volts nominal
- □ Control computers up and running
- □ Ensure team members are attentive
- □ Call out, "Powering On!"
- □ Power on TCU
- □ Call out, "performing thruster test"
- □ Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity)
- □ Verify video feeds
- □ Test accessories

Launch

- □ Load accessories
- □ Remove laser covers
- □ Call out, "Prepare to launch"
- □ Deck crew members handling ROV call out "Ready"
- □ Call "Launch"
- □ Launch ROV, maintain hand hold
- □ Wait for release order

In Water

- □ Check for bubbles
- □ If there are large bubbles, pull to surface immediately
- □ Wait 5 minutes, then check leak detector
- □ Engage thrusters and begin mission

ROV Retrieval

- □ Pilot calls "ROV surfacing"
- □ Deck crew calls "ROV on surface"
- □ "ROV captured", kill thrusters
- □ Operation Technician (OT) powers down TCU
- □ OT calls out "Safe to remove ROV"
- □ After securing the ROV on deck, deck crew calls out "ROV secured on deck"

Leak Detection Protocol

- □ Surface immediately
- □ Power down TCU
- □ Inspect (May require removal of housings)

Loss of Communication

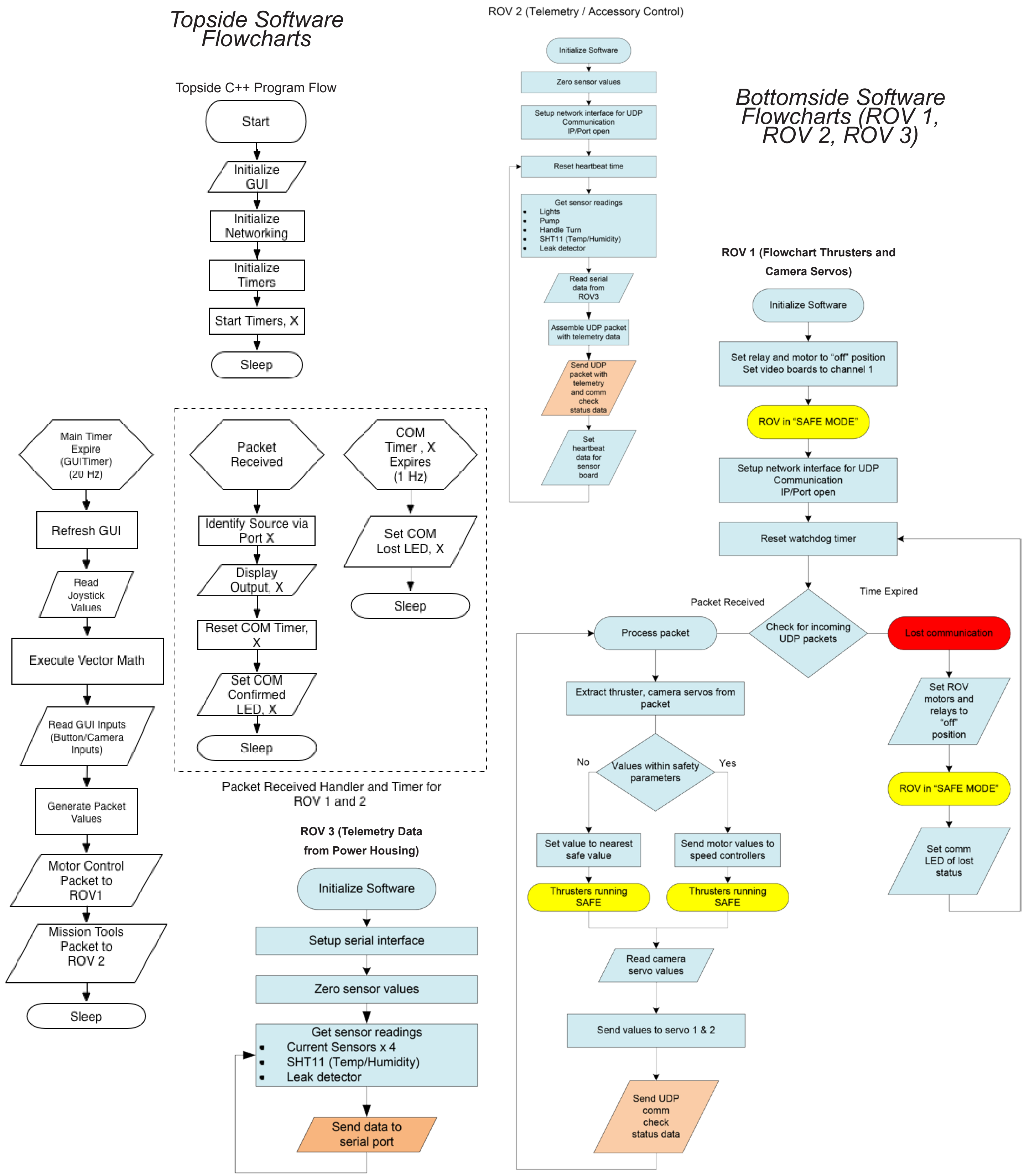
- □ Turn off/ back on TCU to reboot ROV
- □ If no communication
- □ Power down ROV
- □ Retrieve via tether
- □ If communication restored
- □ Confirm there are no leaks
- □ Resume mission

B. 2015 Budget

	Budget Item	Amount
Operational Expenses	Coaches' Airfare	$ (2,200.00)
	Vehicle Rental (x2)	$ (1,000.00)
	Competition Meals/Lodging	$ (4,500.00)
	Welding and Machining Costs	$ (800.00)
	Printing	$ (500.00)
	ROV Components	$ (8,000.00)
	Shipping	$ (5,000.00)
	MATE Entry Fee	$ (100.00)
	Tools/Consumables	$ (500.00)
	Rework	$ (500.00)
Capital Exp.	3D Printer	$ (2,500.00)
	Total Expenses	$ (25,600.00
Income	Jesuit School Funding	$ 14,000.00
	MATE 1st Place Poster	$ 100.00
	QSP Magazine Sales	$ 3,000.00
	MATE 1st Place Prize	$ 500.00
	Employee Dues	$ 3,200.00
	Donations	$ 5,000.00
	Total Income	$ 25,800.00
	Surplus/(Deficit)	**$ 200.00**

	2015 Projected Employee Expenses	
Travel Exp.	Airfare ($1,100 each)	$ (19,800.00
	Meals ($150 each)	$ (2,700.00)
	Total Individual Expenses	$ (22,500.00

C. Software Flowcharts



ROV1 UDP Packet Structure	UDP Header, motor1, motor2, motor3, motor4, motor5, motor6, motor7, motor8, servo1, servo2
ROV2 UDP Packet Structure	UDP Header, laser, lights, bilgep, hmotor
ROV3 Serial Packet Structure	Serial Header, current1, current2, current3, currnet4, leak1, temp1, humd1