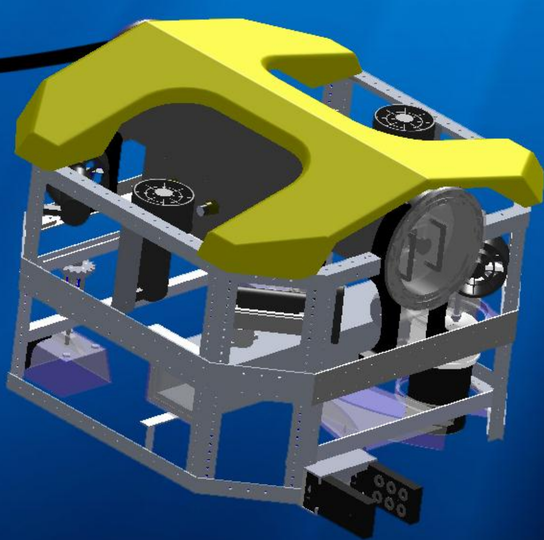
LEVIATHAN rovotics

Jesuit High School
Carmichael, California
MATE 2013



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Abstract

Unlike man's vast knowledge of the land, atmosphere, and solar system, humanity knows relatively little about the oceans, especially deep below the surface. With global climate change a growing concern, understanding the dynamics of the oceans is imperative. Sensor networks, similar to underwater weather stations, must be deployed globally to gather the data needed to support ocean research.

Rovotics has the capabilities and technologies to install and maintain ocean observation systems worldwide. A twenty person company, Rovotics has the people and capabilities to deliver state-of-the-art Remotely Operated Vehicles (ROV), custom designed to meet mission requirements. Efficiently organized into departments by specialties, including design, software, electronics, manufacturing, Rovotics utilizes program management methods and source code management systems to streamline their development cycle. Advanced manufacturing capabilities include precision machining with a Computer Numerical Control (CNC) mill, design and assembly of custom printed circuit boards, and composites manufacturing.

For this mission, Rovotics introduces its latest ROV, *Leviathan*. *Leviathan* is designed with separable upper and lower sections to allow for the rapid change of mission-specific tools and incorporates many customized components and subsystems, including connectors, circuit boards, accessories, and tailored buoyancy. Precise control is delivered intuitively by our vector control system via a joystick interface, with maximum situational awareness provided by a quad-feed display. *Leviathan*'s highly modular design allows for rapid servicing in the field, if needed.

This technical report details the development process and design details that make Rovotics' *Leviathan* the best ROV for the MATE contract.

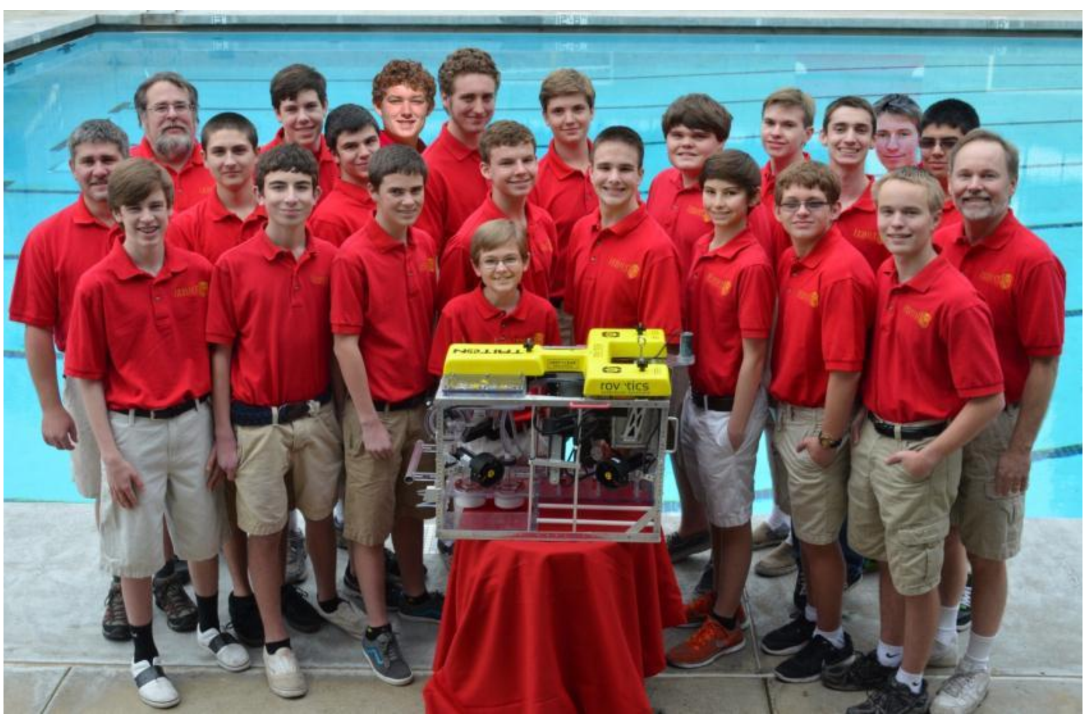

Figure 1: Rovotics with an earlier model ROV, Triton

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II. Design Rationale

A. Focus

When building *Leviathan (Figure 2)*, our priority was to design it to complete the mission tasks as specified in the MATE request for proposal, while maximizing safety, reliability, serviceability and cost effectiveness. *Leviathan* is the result of an intricate build process completed by a group of dedicated employees (Figure 1).

Figure 2: Leviathan and WALL-E

B. Mechanical Design Process

To streamline the design process, Rovotics utilizes a multi-step approach to allow the team to better visualize the end result early in the design process to reduce the number of mistakes and revisions. The first step is to sketch out the concept on a whiteboard during a brainstorming session. For more complicated parts, often where fit and size are critical, cardboard mock-ups are built to create a physical model (Figure 3). At this stage, different ideas are quickly shared, debated and changed until a favored concept emerges.

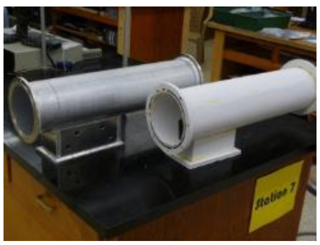


Figure 3: Final Product with Mockup

Once the design team is satisfied with the concepts through sketches and mock ups, a detailed Computer-Aided Design and Drafting (CADD) model in either 2D or 3D, depending on the need, is created using DraftSight or SolidWorks, respectively. For parts targeted for production on the CNC mill, the CADD models are converted into a Drawing Exchange Format (DXF) file, and then imported into a Computer Aided Manufacturing (CAM) package, SheetCam. Using SheetCam, engineers generate the "G-code" tool-path files from the drawings, which are then loaded into the "Mach 3" machine control software (Figure 4). The Mach 3 software controls the CNC Mill movements based on the G-code, allowing the machinist to quickly and accurately produce parts. This rapid and precise development, afforded by a dedicated team of "CADDers" and a constantly running mill, allows Rovotics to produce more advanced designs on aggressive schedules, providing customers more optimized solutions.

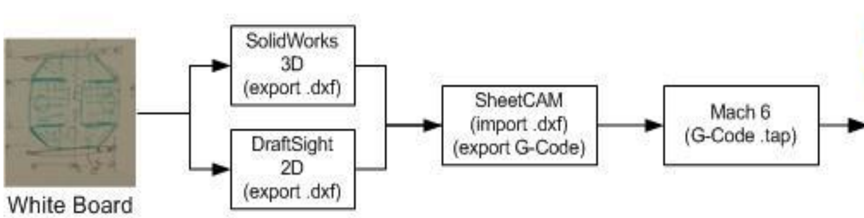


Figure 4: Manufacturing Process

C. Frame

Through many years of innovative design and experience, Rovotics understands the benefit of a sturdy, open frame design. An open frame provides the least drag, fewer obstructions to thrust, easier access for service and allows for quick and easy modification during development and service. The frame is constructed from light weight angled aluminum stock machined with holes every 1.27

centimeters along their lengths for versatile tool attachment and enabling quick alterations. The octagonal shape alleviates the chances of corner snags, important due to the large quantity of cabling expected in the mission area. Thrusters are naturally placed in the beveled corners to support the vector thrust control system. The symmetric design allows both ends to be the "front," increasing possible tool mounting locations. Skids, located on the bottom of the frame, prevent the ROV from scraping the pool.

The most dramatic new feature of the frame is its novel separable two-part design (Figure 5). The top half houses the main electronics pod, basic sensory and telemetry tools, thrusters, and the main buoyancy unit, meaning it has the capacity to function as a standalone ROV capable of collecting telemetry data with full vector control. The bottom half, known as the tool payload, houses the mission-specific manipulators, tools and additional cameras. The two halves are mechanically connected, one on top of the other, using four nut-bolt couplings to provide for easy separation, and electrically connected with a single inter-communications cable. This unique system allows for pilot training while accessories are being serviced in the shop, and allows the vehicle to be easily tailored for other missions or clients by replacing or modifying the tool payload.

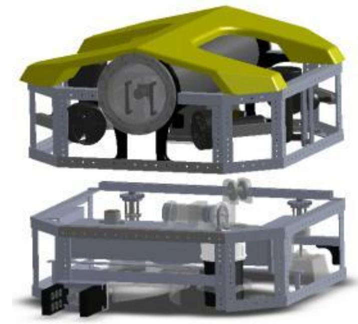


Figure 5: Two-Part Frame Design

D. Thrusters

Leviathan operates with six reliable SeaBotix thrusters, with one horizontally mounted thruster on each of the four corners of the frame and two vertically mounted thrusters at the center of buoyancy. Each thruster provides a maximum of 28.4 Newtons of thrust with a sustainable thrust of 21.5 Newtons. With an operating voltage of 19.1VDC and a current draw of 4.25A, each thruster fits well within *Leviathan*'s power budget (Appendix VII-C). To keep the vertical thrust in line with the center of buoyancy, the two vertical SeaBotix thrusters are mounted on adjustable guide-rails. Grates mounted in front of each thruster's intake prevent cabling, foreign objects and fingers from getting sucked into the props.

E. Connectors

Rovotics designed and manufactured two different styles of proprietary waterproof connectors with the purpose of creating a robust system that is easy to manufacture and cost effective. With production and operational field testing completed this year, the use of expensive SubConn connectors is mitigated on *Leviathan*.

The Type I connector (Figures 6 and 8) is fully detachable and is capable of supporting up to nine electrical contacts, consisting of a base that has the female contacts and a hood with the male contacts. The 3.5mm and 4mm bullet connectors are used to make a reliable, yet compact, connection. Surface sealing O-rings are used between the base and hood, making the connector waterproof to great depths. Within the hood and base, all of the contacts are potted using a 3M 3422 potting compound to prevent leakage if the O-ring seal seeps or an unmated connector is submerged. After consulting with a 3M adhesive application consultant, the company selected this potting compound for its ability to bond to many materials, its low viscosity and its dielectric properties.

Figure 6: Type I Connector

The Type II model (Figure 7) is a non-detachable connector that is cheaper and easier to produce. Electrical wires are soldered to a brass tube which is then potted with PC-11 two-part epoxy within a custom bulkhead connector. The bulkhead connector is manufactured by machining a brass bolt, milling a brass washer with an O-ring groove, and cutting a hood from a brass tube. These three components are soldered together making a single rugged unit. To protect the wires from wear and tear, they are passed through a rubber boot and wrapped in a polyester sheathing.

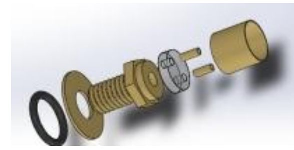


Figure 7: Type II Connector

The Type I and Type II connectors have proven to be very reliable and deliver significant cost savings over commercially available waterproof connectors. The Type I connectors require approximately $35 of raw materials with over three work hours of manufacturing time for each side, while the Type II connectors require simple raw components at trivial cost and approximately two work hours to manufacture per side.

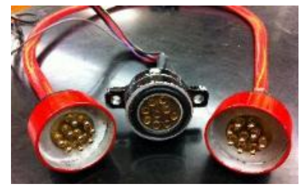


Figure 8: Type I Connector

F. Buoyancy

Leviathan is equipped with a buoyancy float (Figure 9) specifically designed to give the ROV positive buoyancy. The weight in water of the ROV, before the addition of the float, was 3.4kg. The float, made of Styrofoam covered by a durable fiberglass shell, provides 4.5kg of buoyancy, compensating for any late additions to the vehicle which could add weight.

Figure 9: Buoyancy Float

The float provides a smooth, curved top for the ROV with beveled corners, to prevent snags on cabling. Final dimensions were adjusted in SolidWorks to achieve the desired buoyancy. To fabricate, our engineers made simple wooden guides with the contour profile, then carefully cut a Styrofoam block with an electrically heated wire guided by the jig. The foam block was then fiber glassed using an epoxy resin, sanded smooth and painted bright yellow for safety. Once installed, buoyancy was fine-tuned with small weights where necessary.

For the tether, adjustable floats were installed at regular intervals to ensure it maintains buoyancy, providing easy tether management and better operational stability.

G. Housing

Pressure Vessel

In past years, Rovotics has used several electronics canisters connected by a series of wires and tubes. However, the company learned that this system has many flaws including an increased number of connection locations that could leak, an increase in complexity of the design, and an added difficulty in maintenance. This year, a single pressure vessel was used to house all electronics and connections inside an aluminum canister for each half of the vehicle. The top housing consists of a large aluminum tube with a vertical "outhouse" upon which connectors are attached. The cylindrical portion is made up of a 15.2cm outer diameter aluminum tube, measuring 45.2cm in length. Aluminum rings crafted on the lathe with an outer diameter of 17.8cm and an inner diameter of 15.2cm are welded on to the end of the tube to form two flanges. The flanges hold O-rings, creating a reliable face seal with a polycarbonate window at each end. The five-piece outhouse is added to the bottom of the cylinder, enabling the installation of waterproof connectors, adding an easy-access maintenance panel and creating a sump to mitigate possible problems caused by small leaks. The welding was outsourced due to resource constraints. By using formulas from "Design Curves for Oceanographic Pressure-Resistant Housing" (Reference 4), Rovotics' engineers calculated the crush depth of *Leviathan*'s pressure vessel.

6" OD x 0.125" WALL x 5.75" ID 6061 T6 TUBE	150 meters

Accessory Pod

The accessory pod contains all electronics operating the mission-specific tools. The pod, mounted directly to the bottom half of the frame, consists of an aluminum rectangular extrusion sealed by polycarbonate end caps. A circular camera view-port manufactured in the middle of the downward facing side gives the crew a perfect view of *Leviathan*'s Scientific Interface Assembly (SIA) Drop mechanism. This view-port has an O-ring groove crafted on the CNC mill and welded onto the pod. Custom O-rings were made and installed at each end cap, as well as the view-port's window, to prevent leakage.

Camera Housings

There are two independent camera housings on the ROV in addition to the four internally mounted cameras. One housing contains a camera for the gripper hand and the other contains a camera for the secondary node leveling accessory. The housings consist of aluminum tubes with face plates glued to the tube with PC-11 epoxy. To both waterproof the enclosures and ensure the cameras are easy to maintain, polycarbonate windows create face seals with the O-rings located on the flanges (Figure 10).

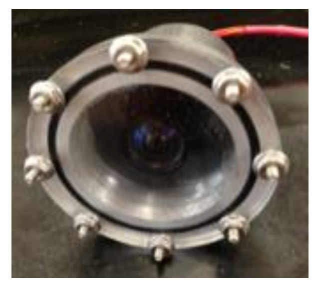


Figure 10: Camera Housings

Motor Housing

The Rovotics standard motor housing design consists of two mechanical double shaft seals for improved reliability (Figure 11). The housing is filled with silicon dive gel through a sealable screw hole which increases the ability of the shaft seal to prevent external fluids from entering the internal motor housing.

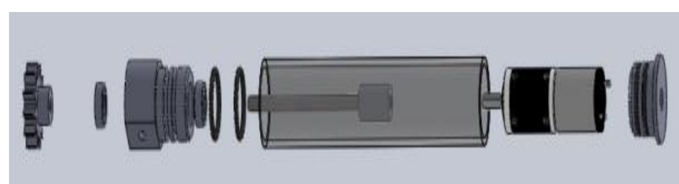


Figure 11: Motor Casing

H. Electronics

Tether Control Unit/Tether

The tether control unit (TCU) controls power, communications, and video distribution for the ROV system (Figure 12). To activate the ROV, the 20A circuit breaker must be closed and the main power switch, with a removable key, must be turned on. The removable power key is a safety feature preventing accidental activations. In addition to the 20A circuit breaker (Figure 13) and the main power switch, there is a 3A breaker with a separate switch which turns on the remote turbidity sensor, nicknamed WALL-E. Voltage and current meters alert the co-pilot to power issues, such as discharged batteries and short circuits.

Figure 12: The TCU Dashboard

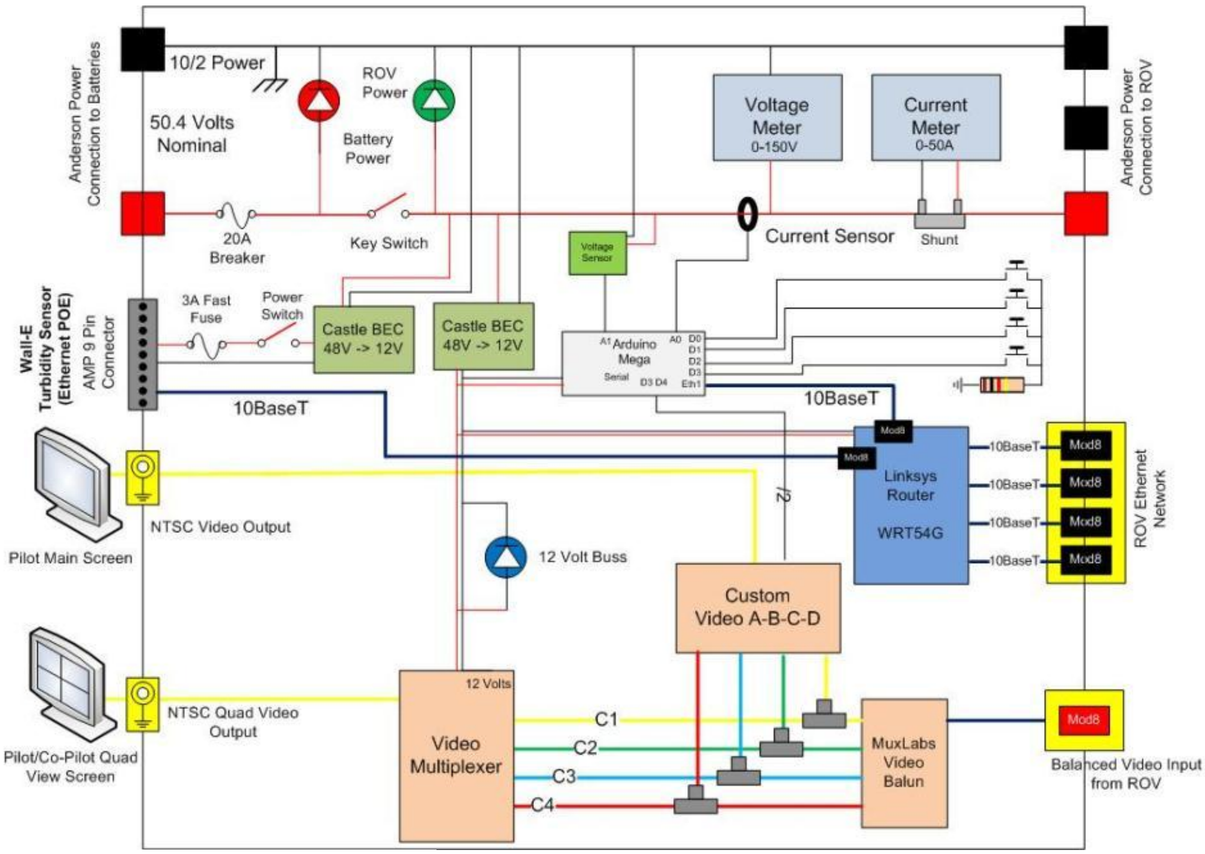


Figure 13: TCU Electrical Schematic

Each of the video signals from *Leviathan* is split into two signals, with one going to a video multiplexer and the other going to a custom-designed and built quad video switching circuit board. The multiplexer allows the pilot to see the video feed from four of the cameras onboard the ROV on a single monitor, improving situational awareness, and the switcher allows the pilot to direct a single camera feed to a second monitor for a more detailed and enlarged view.

The TCU contains two Castle Creations Battery Elimination Circuits (BECs) that step down 48VDC to 12VDC for most embedded electrical components while the Arduino microprocessor drops 12VDC down to 5VDC to power the remaining components. Custom PCBs were designed to minimize wiring, increasing product longevity and durability.

The tether consists of two CAT5e data lines, and one 12AWG DC power line. One of the CAT5e cables carries data packets to and from the microprocessors onboard *Leviathan*, while the second transmits NTSC/Composite video with video baluns at each end. The power cable is sized to double our normal operating current to ensure crew safety in the event of a short circuit or other electrical issue.

Main Electronics Module

Leviathan's main electronics module (Figure 14) contains the electronics necessary to control all primary aspects of the ROV and it serves as a hub to the accessory pod. The module was implemented for ease of maintenance as all of *Leviathan*'s electrical components can be quickly removed from the pressure vessel and worked on from any angle. Dockable

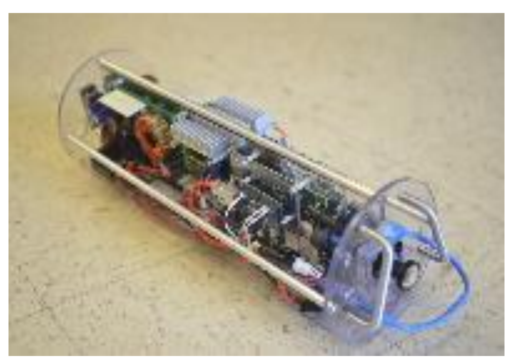
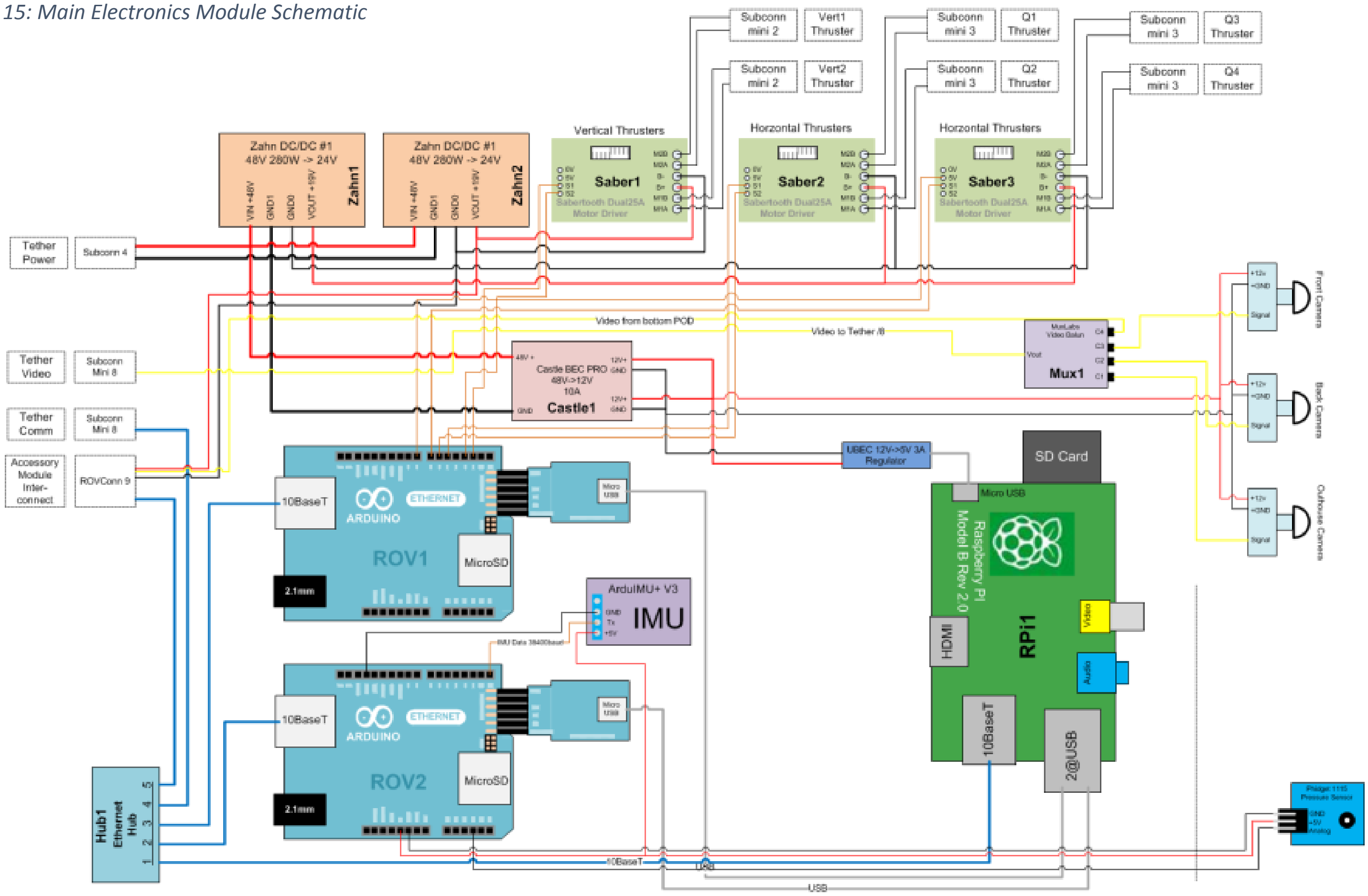


Figure 14: Electronics shelving

connectors (V.35 connectors) mounted on a bulkhead allow for easy plugging and unplugging of the entire electronics module. The vehicle side of the V.35 connectors is wired directly to the waterproof connectors that penetrate the “Outhouse”. A wiring "basement" on the module keeps the wiring organized and elevates the circuit boards above the floor of the pressure vessel to prevent water damage in the event of a small leak.

Figure 15: Main Electronics Module Schematic



For power regulation in the electronics module, two Zahn 48VDC to 24VDC switching power converters drop the 48VDC input to 19.1VDC (limited by the SeaBotix thruster voltage rating) while two battery eliminating circuits (BEC) steadily regulate 12VDC and 5VDC buses. The SeaBotix thrusters and Accessory Pod run on the 19.1VDC bus while the networking hub runs on the 12VDC bus. The microcontrollers and sensors run on the 5VDC bus. A complete schematic is shown in Figure 15.

To be able to reprogram the Arduino microcontrollers without opening the pressure vessel, a Raspberry Pi computer was installed in the electronics module. It is connected to the microcontrollers via USB, which enables the software to be updated while *Leviathan* is running with only a momentary pause.

Accessory Pod

A multilayer rack of polycarbonate holds all electronics of the accessory pod, which can be easily serviced by pulling out the rack, similar to the main can. It contains the ROV3 Arduino Ethernet controller, which controls the custom-made video switching board, Phidgets dual solid state relay board, DROX L289N dual bidirectional H-bridge controller and a Cytron 10A motor controller (Figure 16). The relay board was chosen as the most reliable way to energize the electromagnet used for the ADCP Drop while the motor controller was selected for the high current needs of the F150 linear actuator. The DROX L289N controllers provide dependable bidirectional control of the gripper hand and ADCP winch motors. The custom video switching board controls the video feeds from one internally and three externally-mounted cameras.

Video Switcher PCB

Rovotics engineers designed a custom video switcher printed circuit board (PCB) to control *Leviathan*'s camera feeds (Figures 16 and 17). The board is based on the Maxim Integrated MAX455 series of video multiplexors which have the ability to take in up to eight different camera signals, and select any of the eight to be output on one video line. The custom video board uses a surface mount technology (SMT) version of the integrated circuit (IC), enabling the utilization of a space efficient and modular PCB.

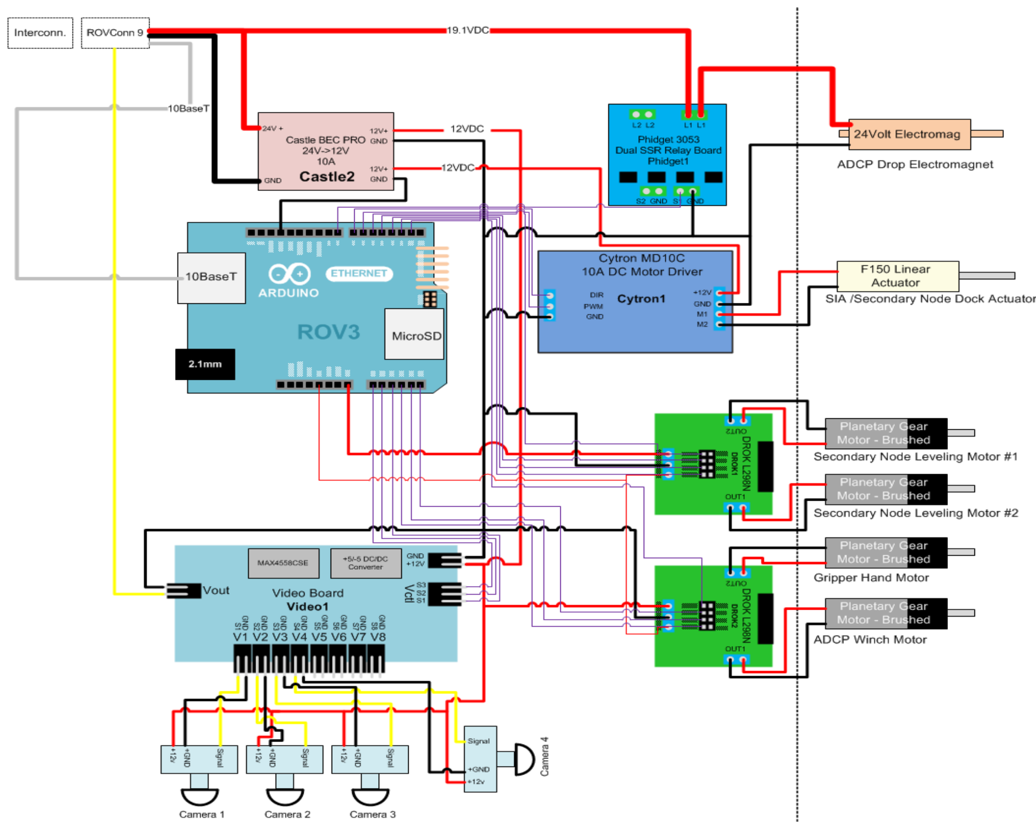


Figure 16: Accessory Pod Schematic

An impedance shifting transformer from Texas Instruments bridges the regular 75 Ohm output from the MAX4558 IC to the higher 100 Ohm impedance of a twisted pair CAT5 cable. For optimum serviceability and reliability, Molex locking connectors were chosen to connect both the input and output video feeds.

Sensors

The accurate sensors onboard *Leviathan* are used to gather pertinent real time information at 20 hertz which is displayed by the top-side control application, Nautilus, for the pilot and co-pilot. An inertial measurement unit (IMU) records the current

Figure 17: Video Switcher PCB

attitude of *Leviathan*, which Nautilus displays on an artificial horizon. This display alerts the pilot to possible snags, enables precise tuning of both buoyancy and motor placement, and assists in docking procedures vital to many aspects of the mission.

An accurate depth sensor comprised of an air pressure sensor and long capillary tube, in conjunction with a depth-holding PID algorithm, is used to assist the pilot in leveling the secondary node by automatically holding *Leviathan* at a specific depth.

The embedded Raspberry Pi sends its central processing unit (CPU) temperature to Nautilus so that the operating crew can ensure that the Raspberry Pi is not overheating.

Speed controllers

Leviathan's six SeaBotix thrusters are controlled by three Sabertooth, Dual 25A Brushed Speed Controllers. These speed controllers feature both over-current and thermal protection, while handling up to 50A spikes in power draw. These speed controllers can be controlled using various communications protocols, including analog, R/C, and serial. The R/C communications protocol is used because the microprocessors can easily interface with that established standard. These speed controllers also allow for precise control and fast response of the thrusters, so *Leviathan*'s movements are quick and efficient.

I. Programming

Top-Side Code

Leviathan is controlled via a laptop running a C++ application, "Nautilus," written in Qt Creator (Figures 18 and 19). Nautilus is controlled through a Graphical User Interface (GUI) and a joystick. The goal during development was to give the pilot and co-pilot complete and intuitive control over *Leviathan*. This freedom of movement was accomplished by Rovotics vector drive algorithm (Appendix VII-B) and state-of-the-art control system. A proportional-integral-derivative (PID) algorithm maintains the *Leviathan*'s depth within two centimeters based on readings from *Leviathan*'s precise depth sensor. This depth hold feature assists the pilot in leveling the node on the sea floor as *Leviathan* will keep itself positioned on the secondary node, while the pilot levels the node. Nautilus has a GUI to display information from the ROV's communication network and to accept commands from the co-pilot. Nautilus was developed from the ground up to be user friendly and easy to debug, reducing required training time and expediting the development cycle. In the case of a communication loss or joystick disconnect, Nautilus promptly alerts the user with red warning lights so the user always knows the status of the entire control system. The warning-light-based error system is designed to quickly but

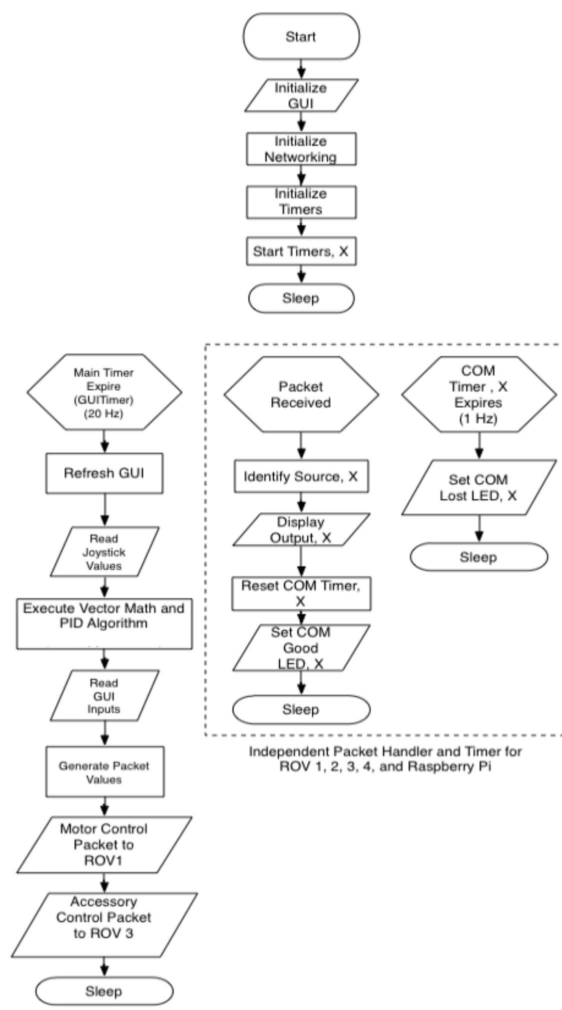


Figure 18: Nautilus Flowchart

unobtrusively alert the user of any errors, similar to the cockpit of modern airplanes.

Figure 19: Nautilus GUI

Bottom-Side Code

Leviathan has three Arduino microprocessors, known as ROV1, ROV2 and ROV3, onboard to handle motor outputs, telemetry data and accessory control. All data sent to and from the ROV is transferred over the simple and reliable User Datagram Protocol (UDP) at roughly 20 hertz to ensure a smooth and seamless operation. To confirm that communication is present, each Arduino echoes its software version number to Nautilus upon receiving a packet. In the case of lost communication, the ROV puts itself into a safe state to prevent it from damaging itself, the mission field or personnel.

ROV1, located in the main electronics can, manages only *Leviathan*'s six thrusters to ensure maximum reliability. Upon receiving thruster control values from Nautilus, ROV1 checks their integrity to prevent corrupted values from damaging the thrusters or speed controllers. Once the check is passed, ROV1 sends the commands to the thrusters. If ROV1 does not receive any control packets for one second, it puts *Leviathan* into the safe-state by sending the thrusters a neutral value. ROV1 resumes normal operation when communication is re-established. See Appendix VII-D for flowchart.

ROV2, also located in the main electronics can, reads and returns the data from various onboard sensors in a continuous loop. Since ROV2 does not directly control any physical aspect of the ROV, it does not participate in the ROV safe-state. See Appendix VII-E for flowchart.

ROV3, located in the accessory can, controls the motors and solenoids used to actuate *Leviathan*'s tools. Like ROV1, ROV3 enters the safe-state, in which solenoids and motors are turned off, when it does not receive any control packets for one second. When communication is regained, normal operation resumes. See Appendix VII-G for flowchart.

Vector Thrust Control

Leviathan's motor layout, with four horizontal thrusters mounted at 45 degree angles on each corner, lends itself to using a vector thrust control. The joystick's x, y and z axes are read and then mathematically rotated 45 degrees to match the layout of the motors. By using vectored thrust, *Leviathan* has an incredible amount of maneuverability as it can rotate in place, strafe in all directions, and reliably execute complex combinations of rotational and lateral shifts. 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. The work behind creating the vector thrust control is described in depth in Appendix VII-B.

Source Code Management

To better manage concurrent development of software, CADD models and other computer files, Git was adopted this year as the company's Version Control System (VCS). By using a VCS, the company can keep track of every change made to every file, from Nautilus' source code to *Leviathan*'s CADD files. 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 revisions. Also, by making detailed commit messages standard, everyone on the team can easily see the progress that each division is making, which is critical in Rovotics' parallel development environment. Git provides a DVCS that excels at branching and merging, which is an important feature when multiple people are working on the same file or interdependent files.

J. Mission-specific

Payload Description

The ROV contains many accessories which support the completion of the mission tasks. These accessories, their related control systems, and the bottom half of the frame of the ROV are referred to as the "mission-specific" aspect of the vehicle.

Task 1 involves transferring the Scientific Interface Assembly (SIA) into the Backbone Interface Assembly (BIA), inserting the Cable Termination Assembly (CTA) into the BIA bulkhead connector, transferring the secondary node to the sea floor and leveling it, removing the secondary node connector from the elevator and installing it, and opening the door of the BIA. To transfer the SIA and the secondary node, a dropping mechanism is utilized on the bottom ROV. To level the secondary node, two "Roman gears" rotate the handles on the node. A gripper hand is used to insert the CTA into the bulkhead connector on the BIA. The gripper hand is also used to move the secondary node connector.

Task 2 consists of designing and utilizing an optical beam transmissometer to measure water opacity, also known as turbidity. The turbidity sensor measures the clarity of the water. The turbidity is displayed on a graph on the Nautilus application on the co-pilot's laptop.

Task 3 entails removing and replacing an ADCP located on a suspended mooring platform. Rovotics utilizes a neodymium winch to remove and transfer the ADCP. The versatile gripper hand is used to open and close the mooring platform latch.

Task 4 involves removing biofouling from any structure or instrument within the observatory area. The removal of biofouling is completed by utilizing the gripper hand.

Figure 20: WALL-E

Turbidity Sensor

To measure the opacity of the water, the turbidity sensor, nicknamed "WALL-E," uses three super-bright white light-emitting diodes (LEDs) and a photoresistor (Figure 20). The LED and photoresistor components are housed in clear acrylic tubes spaced about fifteen centimeters apart from each other. The two tubes act as feet for the turbidity sensor, letting it stand up on its own. The LEDs are wired to an Arduino Mini microcontroller with an Ethernet module (Figure 21). The photoresistor receives the diluted light from the LEDs and the microprocessor analyzes how much light is diluted as a result of the opacity of the water. WALL-E sends UDP packets over an independent tether to transfer the value of the photoresistor (a value of 0 to 100) to Nautilus. The topside software then graphs the opacity values over time.

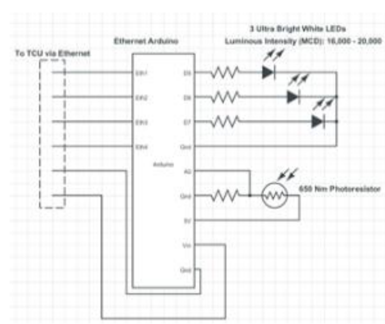


Figure 21: Opacity Sensor Circuit

Neodymium Winch

A winch is utilized to raise the ADCP into the ROV (Figure 22). It is equipped with an 18 RPM motor to spool up or down a composite ribbon, attached to a polycarbonate alignment cup with a neodymium magnet. At the desired time, the polycarbonate cup lowers out of a tube and aligns itself onto the ADCP U-bolt. The magnet clings to the ADCP U-bolt and the winch retracts, drawing the ADCP into the polycarbonate tube and locking it into the ROV. A magnetic limit switch automatically stops the winch once it has fully spooled back into the ROV, preventing damage to the ROV due to over-retraction. A diode bridging the limit switch allows current to flow in the reverse direction, allowing the winch to be deployed again if necessary (Figure 23).

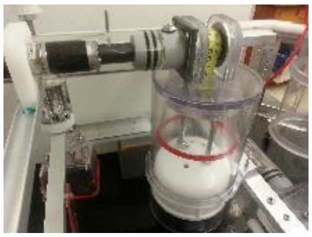


Figure 22: Neodymium Winch

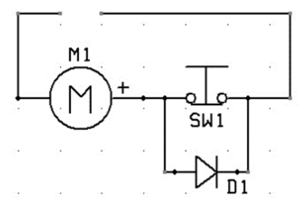


Figure 23: ADCP Winch Limit Switch

SIA/Secondary Node Pickup and Movement

A linear actuator on the bottom of the ROV is used to move a rod which locks through the U-bolt of the SIA and secondary node. In order to allow the pilot to secure the SIA and Secondary Node with ease and in the least time possible, two guide rails are mounted in a V shape to create a “hit box” area for docking with the node (Figure 24). Once successfully aligned, both the SIA and Secondary Node are secured with a linear actuator and pin that allow for precise pickup and release.

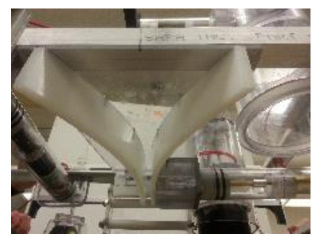


Figure 24: SIA Drop

Roman Gears

To quickly and precisely level the secondary node, two rotating cups were mounted to the rear of the ROV. Springs, located on the shafts upon which the cups are mounted, make docking to the secondary node easier by automatically adjusting for any discrepancies in height of the secondary node handles (Figure 25). The cups are driven by Roman gears attached via belts to independently controlled bidirectional motors.


Figure 25: Roman Gears

Gripper Hand

The gripper hand consists of a metal frame, high density plastic arms, and a motor (Figure 26). The metal frame is a piece of a square aluminum extrusion machined into a slotted aluminum block with a raised lip using the CNC mill. The raised lip guides the arms, made out of black high-density-polyethylene (HDPE), to slide back and forth. A 5 RPM planetary gear motor provides enough torque to grip anything within the mission parameters. From SolidWorks to the mill, the entire gripper was machined, assembled, tested, and fine-tuned in just over three work days. The friction of opening and closing the gripper hand was reduced with the application of dive gel and spacers.

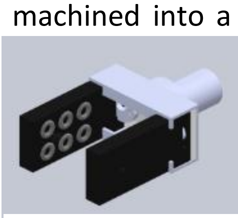


Figure 26: Gripper Hand

The gripper uses a dual diode proximity switch to limit the two horizontal movements of the gripper to a safe range (Figure 27). Once the gripper is fully opened, the limit switch and diode prevent current from flowing in the circuit. By

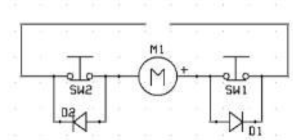


Figure 27: Gripper Dual Diode Proximity Switch Layout

reversing the polarity of the circuit, the same diode will cause current to flow in the opposite direction, allowing the gripper to close.

ADCP Drop

The ADCP Drop tube transports the ADCP to the mooring platform by a simple linear actuator function (Figure 28). The ADCP is fitted into a clear polycarbonate tube secured by an actuator rod at the start of the mission. At the desired time, controlled by Nautilus, an electromagnet will draw the actuator rod out of the ADCP U-bolt releasing the ADCP into the mooring platform. The simplicity of the linear actuator allows for efficient transfer of the ADCP.

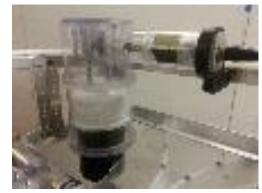


Figure 28: ADCP Drop

Odometer

The linear rolling measurement device is an odometer in a custom waterproof housing connected to a rubber wheel (Figure 29). When the ROV lowers to the bottom of the pool, the wheel will spin as the ROV moves. The odometer tracks the movements of the wheel and expresses them in inches to the tenth of an inch. The versatility of the odometer allows for reading of movement both forwards and backwards and it is easy to read from *Leviathan*'s cameras.

Figure 29: Odometer

III. Safety

A. Company Safety Philosophy

Rovotics emphasizes safety above all other priorities. The company's safety procedures are among the most rigorous in the industry. Strict guidelines and protocols are enforced in the lab and when handling or operating the ROV or any equipment. These procedures allow for a safe working environment with minimal risk for injuries.

B. Training

Rovotics highly values its peer-to-peer training system. Newcomers to the company spend their first few meetings watching and learning from veteran members using equipment in the lab. They also take lessons, typically PowerPoint presentations provided by the experienced members, on each set of equipment and tools. Finally, they get to use lab equipment, with the supervision of a veteran member to correct any mistakes and to ensure they follow safety procedures (Figure 30). This combination of direct exposure, lessons, and hands-on training proved to be very effective in teaching employees proper adherence to safety protocols.

Figure 30: Following safety procedures at the CNC mill

C. Lab Protocols

To ensure safety when servicing, constructing, and using the ROV, Rovotics has set up lab protocols for all workers. Proper precautions must always be taken to avoid accidents that could be dangerous to staff or cost the company time and money. The company requires safety glasses to be worn at all times when in the lab or when using tools. Cords are always kept in a localized area and away from aisles to prevent tripping. Closed toed shoes are required and worn at all times in the lab for safety. Gloves may not be worn while using any machine, especially the belt sander, to prevent hands from getting caught in dangerous moving machinery. Proper shields and enclosures surround all machinery that could throw chips, for the safety of others around the machines and for cleanliness.

D. ROV Safety Features

Leviathan has numerous safety features implemented in order to keep the crew and ROV safe while operating. In addition to the previously mentioned fuses, software safe modes and key switches, mesh netting covers the motors to protect them from any cabling at mission sites. Motor shrouds cover the blades of the thrusters to prevent any damage to the thrusters or injury to company members. Handles are installed on the ROV for ease of moving the ROV, and to prevent injury to company members during ROV handling. Various waterproofing techniques ensure all electronics are dry, which keeps them operational and protects both personnel and equipment from short circuits.

E. Safety Checklist

Leviathan must pass a company-built safety inspection protocol before the crew attempts any practice run or mission. The safety inspection involves ensuring that electronics and thrusters function properly, that *Leviathan* is leak-free, and that all Rovotics employees and the working environments are free from potential harm. The safety checklist is located in Appendix VII-A.

IV. Logistics

A. Schedule and Company Structure

To ensure that *Leviathan* was fully prepared for the MATE competition, the Rovotics leadership used a Gantt chart (Figure 31) to guide their decisions regarding allocation of resources and time. The CEO delegated responsibility for the construction of specific components, such as custom video boards, software, and connectors to the heads of each department, who in turn led new members in the development of each part. A similar approach was taken with the development of both the poster and the technical report, as each had their own employee responsible for their completion who delegated specific sections and tasks to other members of the team. While mentors were there for technical guidance along the way, they did not work on the vehicle or components of the vehicle.

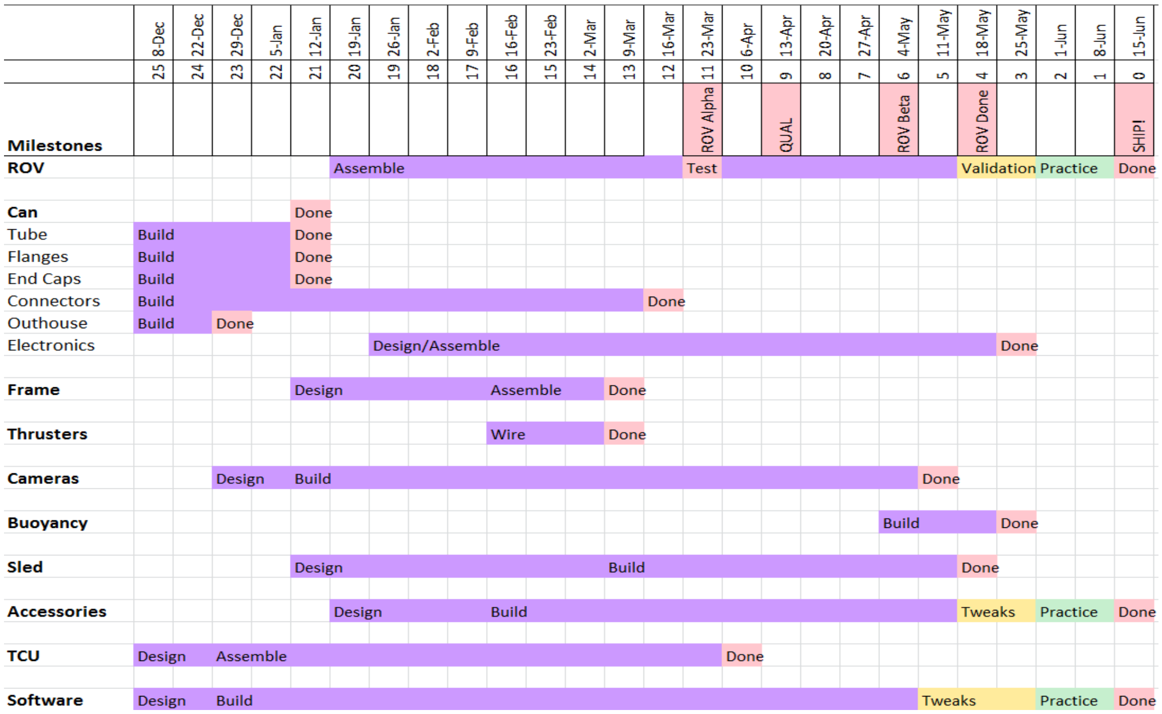


Figure 31: Gantt Chart

B. Budget

As a high school company, Rovotics must operate on a limited budget. The majority of funding comes from Jesuit High School and school-run fundraisers, along with donations of services or equipment (Figure 32). To cut down on the cost, expensive components such as thrusters and microcontrollers are reused from previous years' ROVs. Including the value of reused parts and resources used in research and development, the total cost of *Leviathan* is $8,451 (Appendix VII-H). The majority of this cost comes from the six SeaBotix thrusters which account for almost half the overall expenditures. Beyond the money that went into developing *Leviathan*, the Rovotics' budget must also provide for many other expenditures such as travel, tool purchases and replacements, and general maintenance of the workshop.

	Expenses This Year	Expense	Donated	Carry-Over
Operational Expenses	Airfare (coach/faculty)	$ 1,050		
	Competition Expenses (est.)	$ 3,500		
	Hotel	$ 4,146		
	Lab Supplies	$ 10		
	Printing (est.)	$ 250		
	Props	$ 368		
	Qualification Trip	$ 291		
	ROV Components*	$ 2,707	$ 350	$ 5,394
	Shipping		$ 1,500	
	Tools/Consumables	$ 770		
Capital Expenses	Mill Turntable	$ 887		
	Oscilloscope		$ 400	
	Tooling (miscellaneous)	$ 71		
	Total Expense:	$14,050		
	Budget:	$14,600		
	Surplus:	$ 550		

*see appendix for explanation

Figure 32: Rovotics' 2013 Operating Budget

V. Conclusion

A. Challenges

This year's biggest challenge in the development of *Leviathan* was the complexity inherent in a modular design. To help overcome the challenge, CADD was used extensively for the first time in the development of custom made parts, such as Rovotics' new underwater connectors. After designing and building parts, it was sometimes discovered that they did not function properly because of some small error in their dimensions in the CADD files. Designs with small errors, which would have taken only seconds to fix on the original CADD files, took hours to redo after they had been run through the extensive manufacturing process to the point that the simple mistakes were noticeable. An example of this lies in the production of the custom connectors, where the first set of the connectors manufactured had a failure rate of 50% due to small mistakes in the depth of some cuts. Once the errors were discovered, they were quickly fixed in the engineering drawings, but remaking the complicated parts with the correct measurements took weeks of effort and extra work days. Now, to prevent any further delays caused by small design errors, extra time and care is taken to inspect CADD drawings before they go to production.

Rovotics faced challenges beyond the technical issues of developing an ROV. Being a company of engineers, all employees would rather spend their time building *Leviathan* than writing sections of the technical report. The employee in charge of the technical report faced issues regarding people not turning in requested sections. Through working together with the other members of Rovotics' leadership team, the technical report lead author was able to pull the company together in time to complete the report.

B. Troubleshooting Techniques

For *Leviathan* to function, its electronics must be kept dry by its electronics containers. Checking for leaks used to entail dropping the ROV, unpowered, to the bottom of the pool and checking for water once it was pulled back up. Now an innovative and efficient leak check technique has been developed by Rovotics' engineers. After sealing all openings, the ROV's containers are pressurized to double the operational depth's pressure before being sprayed with soapy water, forming bubbles over any leaks. This is done in the workshop during each pre-mission ROV test, reducing the time needed for leak checks. If leaks are discovered, they are quickly fixed by Rovotics' engineers.

C. Lessons Learned and Skills Gained

Rovotics always seeks to learn and improve from its failures and successes. A critical component of the company's consistent success is actively applying lessons from each previous year and adding them to a continuously growing base of knowledge.

This year, Rovotics added the skill of building its own connectors, saving hundreds of dollars on key components. A strict assembly process and innovative design method developed over many years helped accomplish the tough task of creating viable connectors capable of transmitting communications and power while preventing leakage. Improvements in technique were also developed in the manufacturing of small pressure vessels, by learning from mistakes made this year.

Rovotics' employees also learned a valuable communication lesson after the pinouts of some connectors were not written down, requiring extra time to rewire another connector. Now, all important design information is written down in documents accessible to every employee.

D. Future Improvements

Within two years Rovotics seeks to custom manufacture all subsystems on its ROV. To reach this goal, the company will develop its own custom microcontroller boards, as opposed to using commercially available Arduino boards, to streamline future ROVs' electronics, and also will return to building its own thrusters. In previous years, the company had attempted to make its own thrusters, but stopped producing them because they had a high failure rate. Now that Rovotics owns a CNC mill, the company has the precision tools necessary to create quality thrusters.

E. Senior Reflections

Spencer Breining-Aday

Looking back on my experience, I would like to thank the Marine Advanced Technology Education society. My time as part of the explorer class ROV competition has been one of the most educational experiences of my life. Starting on the team as a sophomore, I learned the intricacies of precision machining, working on the lathe and mill, and the careful process of creation and revision while learning to be a mechanical engineer. In later years managing the team, I learned valuable leadership skills and management techniques. Beyond just the technical, I have gained many cherished memories as a part of this team. I especially want to thank the coaches and the members of Jesuit Robotics.

Chris Konstad

I'd like to thank MATE for putting on this fantastic competition and Jesuit High School for hosting our team. I really appreciate my teammates and their parents and I'd like to thank them for making this program what it is today. I have learned so much about leadership, presenting, machining, CADD, electronics and programming through this competition. I was introduced to programming through the MATE competition. It has become my favorite hobby and I now want to major in computer science. I have countless fond memories of writing code during cold winter nights and testing our ROV in the pool during warm summer nights. My time in high school has been defined by my participation on Jesuit Robotics, and I know that my experiences will help me as I move on into the future.

Jesse Tambornini

I would like to thank MATE for giving me the chance to compete in their ROV competition. MATE has provided us the opportunity to compete at the collegiate level against colleges like Purdue, Georgia Tech, and many others. I have gained so many skills, from machining to programing. The experience I have gained as a result of MATE has and will continue to help me throughout college and beyond.

F. Acknowledgements

Rovotics' outstanding season this year could not have been possible without the help of these generous supporters:

- MATE- For organizing this excellent competition
- Jesuit High School- For its generous donation of funding and lab space
- Rolf Konstad, Head Coach- For the countless hours of time, wisdom, and patience that he has put into the team over the past three years
- Jay Isaacs, Senior Assistant Coach- For all of the time, creativity, and energy that he has generously put into the team over the past eight years
- Brian Honnold, Mentor- For sharing his expertise at the lab for the past two years
- Andrea Konstad – For handling a multitude of administrative tasks behind the scene
- Lisa Schneider- For organizing the lunches for each work day
- Christina Woollgar – For keeping track of the team finances all year
- Tim Kenneally- For organizing and booking the company's travel, hotel, and meals
- Mark Standriff - For sharing his expertise in public speaking with us
- Julia Yang - For coordinating the company's needs with the school
- James Claybrook- For donating his time to weld the electronics can at no cost
- Helen and Neil Zinn- For donating an oscilloscope and general support
- Fish Eye Scuba- for providing SCUBA tanks for in-pool sessions at a reduced rate
- All My Best- For generously providing shirts and logo items at a reduced cost
- SeaBotix- For providing thrusters and maintenance at a discounted rate
- Anonymous- for the generous donation of Fed Ex shipping of our crate
- To all the parents for doing all the things for the team that are too numerous to mention here, including but not limited to meals, transportation, love and support!

G. References

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3. "PID Controller." *Wikipedia*. Wikimedia Foundation. Web. <http://en.wikipedia.org/wiki/PID_controller>.
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VII. Appendices

A. Safety Checklist

Rovotics Pre-Mission Checklist

Pre-Power
- Safety glasses on
- Area safe (trip hazards, standing water, etc.)
- Verify power switches and circuit breakers on TCU are "Off"
- Tether connected to TCU
- WALL-E connected to TCU
- ROV connected to tether
- Thrusters connected to pressure vessel
- Thrusters free of obstructions
- Electronics pods connectors flush, covered over
- O-ring seal nuts tight
- O-ring seal flush against surface

Power Up
- Power source connected to TCU
- TCU receiving 48VDC
- Control computer booted and Nautilus launched
- Call out "Powering On"
- Ensure team members are clear/attentive
- Power on with key switch
- WALL-E on
- ROV status LEDs verified
  - Pressure Vessel
  - Accessory Pod
- Thruster test
  - Call out "Testing Thrusters. Remain Clear!"
  - Operate joystick
  - Confirm no vibrations
  - Disable thrusters
- Verify all video feeds
- SIA Drop working
- Gripper working
- Roman gears working

Launch
- Call our "Prepare to Launch"
- 2 deck crew handling vehicle call "Ready"
- Call "Launch"

In Water
- Bubble Check
- 5 minutes submerged, then leak check
- Engage thrusters and begin operations

B. Calculations for Vector Thrust Control

The strategy for this year's vector thrust system was to use the superposition method to determine the contribution of each x, y, z of the joystick to each motor independently, then normalize the resulting motor vectors to match the magnitude of the joystick vector. This method should greatly simplify the math. Results should be a seamless control regardless of direction or mixing and allow full power in any direction.

Theory

The joystick provides input for forward, lateral, and rotation. The motors are assumed as follows, where the positive direction is defined as water being ejected by the motor from the impeller over the motor casing, resulting in thrust where the impeller is forward.

This table that shows the impact of a full scale deflection of the joy stick and impact on the motor command:

	Joy stick input (full deflection)			Motor Command, % of full power			
Vector	X	Y	Z	Motor1	Motor2	Motor3	Motor4
Forward	0	500	0	-100	-100	100	100
Backward	0	-500	0	100	100	-100	-100
Trans R	500	0	0	-100	100	100	-100
Trans L	-500	0	0	100	-100	-100	100
Rot L	0	0	500	100	-100	100	-100
Rot R	0	0	-500	-100	100	-100	100

Or, another way to look at is how each motor direction relates to the stick direction:

	X	Y	Z
Motor1	Inverse	Inverse	Same
Motor2	Same	Inverse	Inverse
Motor3	Same	Same	Same
Motor4	Inverse	Same	Inverse

Knowing how each motor contributes to a basic motion, more complex motions can be calculated simply by adding up the contribution of each direction. For example, to go diagonal (forward, left), the "Forward" and "Trans L" motor commands are added for each motor:

Motor 1 = -100 (F) + 100 (L) = 0
Motor 2 = -100 (F) - 100 (L) = -200
Motor 3 = 0
Motor 4 = 200

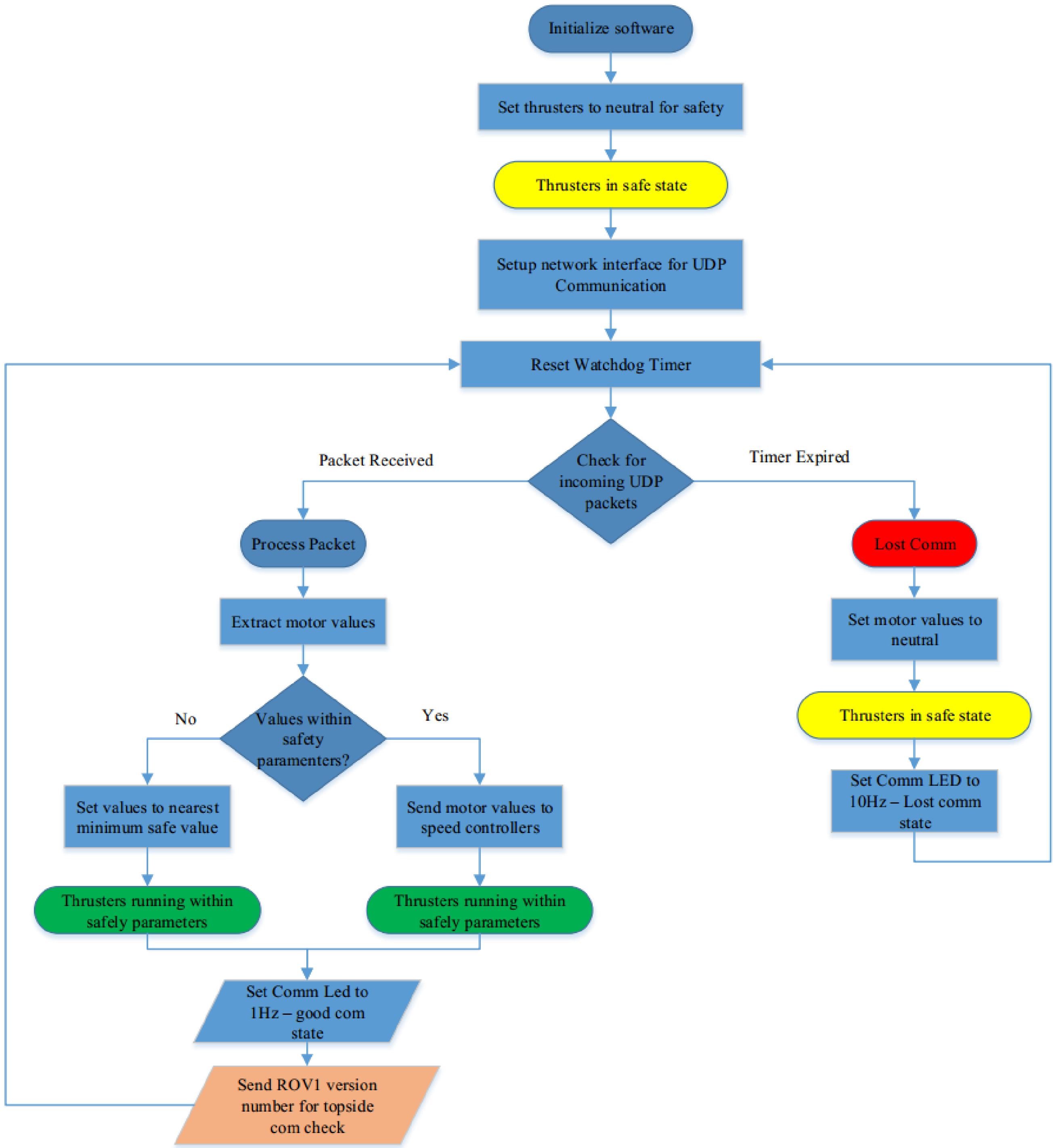
From the ROV diagram, the results make sense in terms of direction, but the magnitude is too large; motors cannot be run at 200%. Therefore, values must be "normalized", where all the motors are scaled to fall with their capability range. The highest percentage motor should match the highest percentage of full scale on the stick.

For each motor i, Motor(i) = Motor(i) * (% highest stick deflection)/(% highest motor).

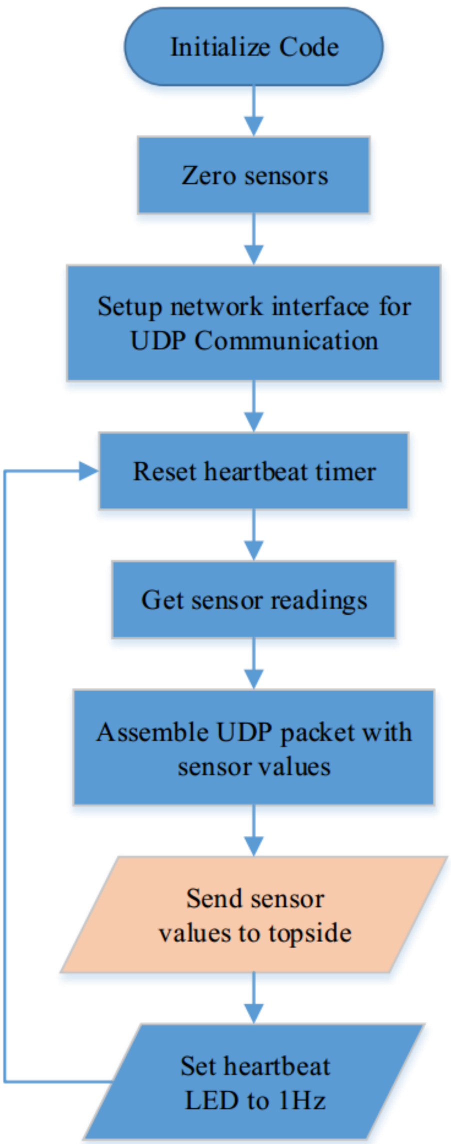
C. Power Budget

Power Budget						
Section:	Unit	Current, A	Volts, V	Power/Unit,	Quantity	Max Power, W
Top Half:	Thruster	4.20	19	79.80	6	479
	Camera	0.75	12	9.00	3	27
	Arduino	0.75	12	9.00	2	18
	Rasberry Pi	1.20	5	6.00	1	6
Bottom Half:	Motor	1.50	12	18.00	4	72
	Solenoid	1.10	19	20.90	2	42
	Camera	0.75	12	9.00	1	9
	Arduino	0.75	12	9.00	1	9
Peak Power, ROV, W (Total)						662
Regulator Efficiency, % (Estimated)						85
Power Loss, W (Peak Power/Efficiency)						99
Peak Power Load, Tether, W						761
Peak Power Available (20A * 48V)						960

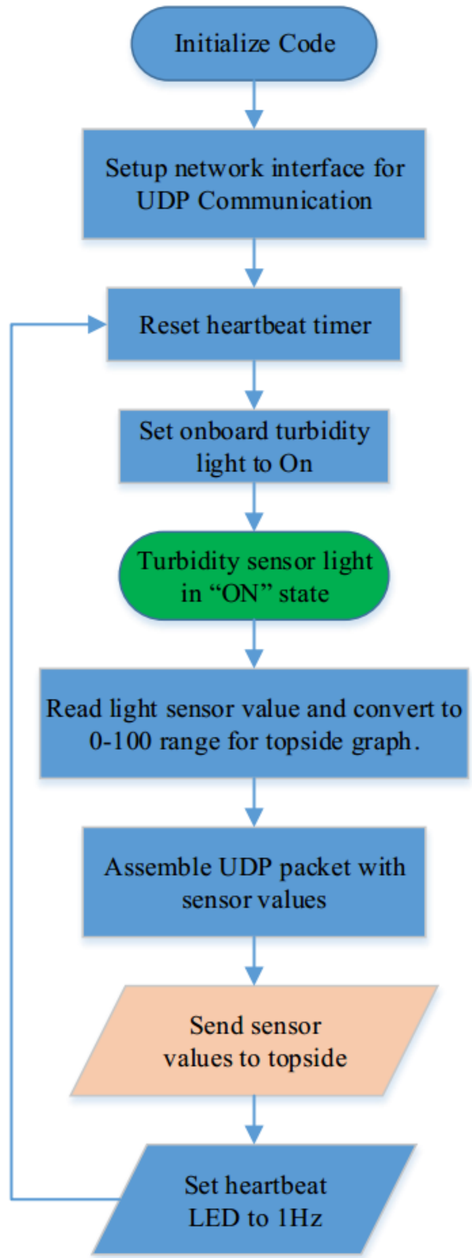
D. ROV1 Flowchart



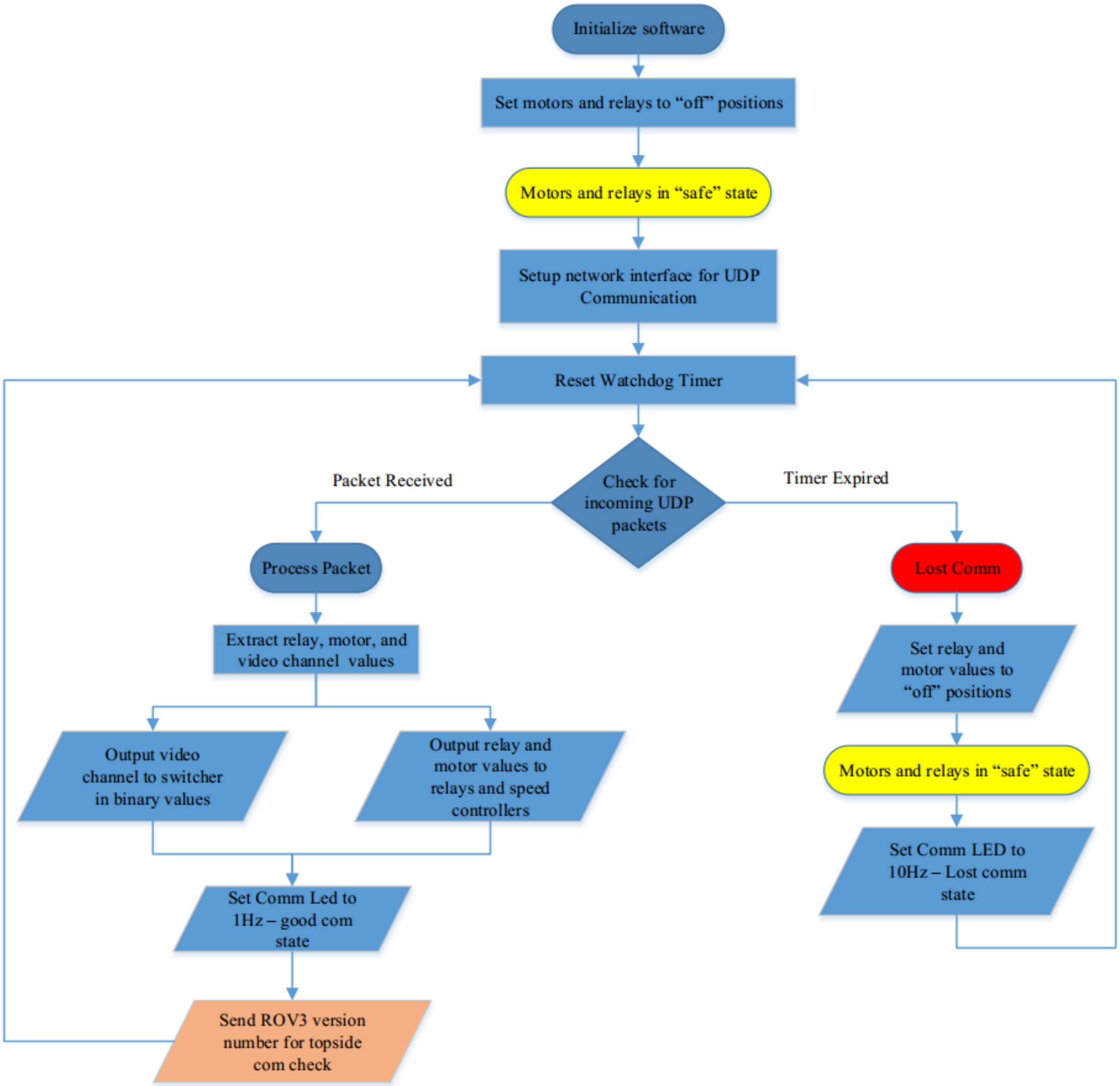
E. ROV2 Flowchart



F. WALL-E Flowchart



G. ROV3 Flowchart



H. ROV, TCU and WALL-E Cost Breakdown

ROV, TCU, and WALL-E Cost Breakdown						
	Part	Quantity	Price	Total	Donated?	Carry-Over?
Electronics	Ammeter	1	$ 10	$ 10		Yes
	Arduino Ethernet	4	$ 52	$ 208		Yes
	Camera	6	$ 55	$ 330		
	Castle Creations BEC Pro	4	$ 45	$ 180		
	Custom Connector (Type I)	2	$ 35	$ 70		
	Interial Measurement Unit	1	$ 80	$ 80		
	Miscellaneous Electronics	1	$ 150	$ 150		
	Motors	4	$ 47	$ 188		
	Motor Controllers	2	$ 15	$ 30		
	Motor Controller - Cytron	1	$ 17	$ 17		
	Muxlab Video Baluns	2	$ 50	$ 100		Yes
	Networking Hub	1	$ 30	$ 30		
	PCB (Custom)	1	$ 65	$ 65		
	Phidgets P1115 Sensor	1	$ 20	$ 20		Yes
	Power Switch	1	$ 30	$ 30		Yes
	Quad Display	1	$ 100	$ 100		Yes
	Raspberry Pi	1	$ 35	$ 35		
	Relay Board	1	$ 20	$ 20		
	Router	1	$ 45	$ 45		Yes
	Sabertooth ESC	3	$ 125	$ 375		
	Screen	1	$ 45	$ 45		Yes
	Solenoids	2	$ 15	$ 30		
	SubConn (pair)	9	$ 100	$ 900		Yes
	Tether Cabling	1	$ 110	$ 110		Yes
	HobbyWing UBEC	1	$ 11	$ 11		
	V.35 Connectors	8	$ 2	$ 16		
	V.35Pins	160	$ 0.4	$ 64		
	Volt Meter	1	$ 10	$ 10		Yes
	Zahn Voltage Converter	2	$ 100	$ 200		
Hardware	Acrylic Stock	1	$ 25	$ 25		
	Aluminum Stock	1	$ 400	$ 400		
	Aluminum Tube	1	$ 70	$ 70		
	HDPE Stock	1	$ 100	$ 100	Yes	
	Magnets	10	$ 0.1	$ 1		
	O-rings	1	$ 20	$ 20		
	Case	1	$ 150	$ 150		Yes
	Polycarbonate	1	$ 300	$ 300		
Services	Welding	1	$ 250	$ 250	Yes	
Thrusters	SeaBotix Thrusters	6	$ 611	$ 3,666		Yes
		Grand Total:		$ 8,451		
		Cost This Year:		$ 2,707		