# PREDATOR

rovotics

**Jesuit High School**
**Carmichael, CA**
**MATE 2014**

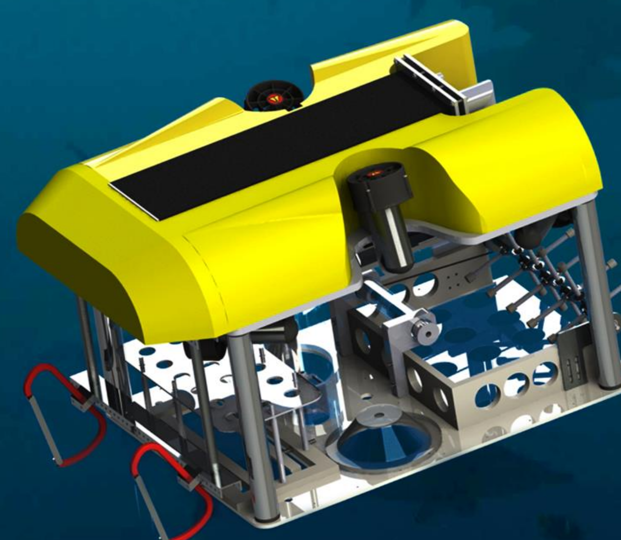
*Company Members*

**Amirali Akhavi '14 - Electronics**
**Charles Fries '14 – Programmer**
**Tyler Honnold '14 – Research & Development**
**Nolan Schneider '14 – Research & Development**
**Nicholas Sopwith '14 – Head of Control Systems**

**Alexander Aprea '15 – CEO**
**Jared Borg '15 – Mill Operator**
**James Guidry '15 – Engineer**
**Ryan Kenneally '15 - Engineer**
**Matthew Woollgar '15 – Head of Manufacturing**

**Benjamin Byers '16 - Electronics**
**Patrick Horan '16 – Lathe Operator**
**Collin Meissner '16 - CADD**
**Killian Randle '16 - CADD**
**Riley Unter '16 – Engineer**

**Carson Black '17 – Graphic Design**
**Jake Honnold '17 – Technical Writer**
**Matthew Kiyama '17 - Engineer**
**Sam Kriefels '17 - Engineer**
**Cassidy Nguyen '17 - Electronics**



*Mentors*

**Rolf Konstad – Head Coach**
**Jay Isaacs –Senior Assistant Coach**

# I. Introduction

## A. Abstract

Throughout history, humankind has used earth's waterways for travel and trade. However, water travel is often perilous, with heavy storms and icy waters overwhelming ships. If conditions are right, such as those in Thunder Bay, these shipwrecks are remarkably well preserved with their contents intact. Exploration of these wrecks helps to support ocean research of the chemical and physical conditions found around the Great Lakes affecting archaeological sites.

Rovotics has the capability and technology to explore shipwrecks of all types. A twenty person company, Rovotics has the people, the experience, and the ability to deliver state-of-the-art customized Remotely Operated Vehicles (ROV), designed to meet the mission requirements. Efficiently organized into departments, including design, control systems, and manufacturing, Rovotics utilizes program management methods and source code management systems to streamline the 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 presents its newest ROV, *Predator*. *Predator* is designed for serviceability, safety, and performance including compact and fully accessible electronics, an active buoyancy heavy lift device, and custom video subsystem.

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


**Figure 1 Rovotics with Predator**

## Table of Contents

# II. Design Rationale

## A. Mechanical Design Process

In order to maximize the efficiency of the design process, we use a multi-step approach, which allows the team to earlier envision the end result. This reduces the number of design iterations. The first step is to sketch out the concept on a whiteboard during the brainstorming phase (Figure 2). For more complicated pieces, where dimensions and shape are significant, cardboard mock-ups are built to create a physical representation. During this step, various ideas are shared and discussed while necessary changes are incorporated until the desired configuration is achieved.

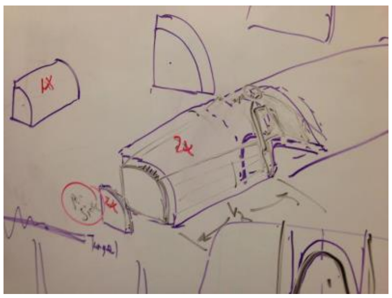


**Figure 2 Whiteboard Design for Buoyancy**

**Figure 3 Buoyancy Design Review**

Once the design team has validated the concepts through sketches and mock-ups, a detailed Computer-Aided Design and Drafting (CADD) model in either 2D or 3D, based on need, is fashioned utilizing Draftsight or SolidWorks, respectively (Figure 3). For parts targeted for production on the CNC mill, the CADD models are converted in 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 Cutting Buoyancy with hot wire**

For some custom parts, CADD drawings are printed 1:1 as templates for jigs. For example, the side buoyancy profile was printed and glued to a piece of plywood which in turn was used as a hot wire form cutting template (Figure 4).

## B. Vehicle Systems

*Predator* is a completely new ROV and an original design. Our experience told us that producing our own thrusters and connectors would divert us from the primary purpose of building the ROV and its mission accessories. Therefore, Rovotics has carefully balanced the use of original and commercially sourced components in *Predator*. Details of each subsystem will be discussed in the document.

**C. Frame**

Based upon multiple years of design experience, Rovotics understands the value of a sturdy and versatile frame. This year's design focuses on safety, serviceability and functionality.

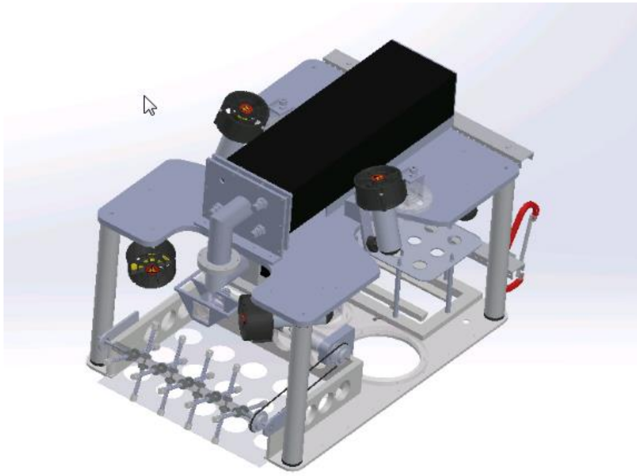


Figure 5 Predator Open Frame Design

The frame (Figure 5) is constructed from a combination of aluminum, high density polyethylene (HDPE) and clear polycarbonate. The design calls for an open frame which provides reduced drag and minimal obstructions to thrust. Two flat working areas provide easy access to accessories and electronics. The bottom and top sections of the frame are capable of being separated for easy serviceability during testing, practice, and competition.

The bottom half of the frame is clear to enable unimpeded visibility for the pilot through downward looking cameras during the mission.  Accessories are positioned on the lower frame for functionality and easy access for serviceability.

A dramatic new feature is that the electronics can, positioned on top of the ROV, is completely detachable without having to disconnect any of the electronics or tether. This feature allows the electronics to be tested and observed with full visibility while the ROV is powered on in mission configuration. See section F, for more details.

**D. Thrusters**

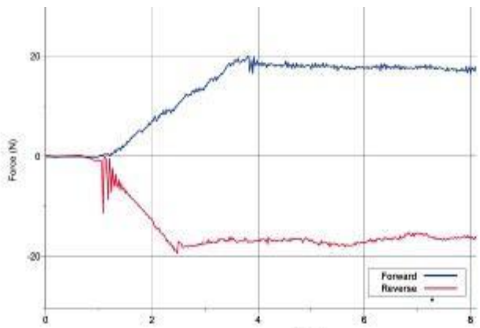



Figure 6 Forward and Reverse Thrust

*Predator* operates with six reliable SeaBotix BTD150 thrusters, with one horizontally mounted thruster on each of the four corners of the frame to allow more space for accessories and minimize thruster wash interference and two vertically mounted thrusters at approximately the center of the buoyancy. Each thruster provides a maximum of 28.4 Newtons (6.38 lbf) of thrust with a sustainable thrust of 20 Newtons (4.49 lbf) (Figure 6). With an operating voltage of 19V DC and a maximum operating current of 4.2AMPS, each thruster fits well within *Predator*'s power budget (Figure 11). For safety and equipment protection, grates mounted in front of each thruster's intake prevent cabling, foreign objects and appendages from getting sucked into the thrusters.

**E. Buoyancy**

*Predator* is outfitted with a buoyancy float system specifically designed to neutralize the ROV buoyancy. The weight in water of the ROV, before the addition of the float, was 42.6 Newtons (9.58 lbf). The float, made of Styrofoam® coated by a durable fiberglass shell, provides 44.1 Newtons (9.91 lbf) of buoyancy, compensating for the vehicle wet weight and adjusted so the vehicle floats in a level attitude.

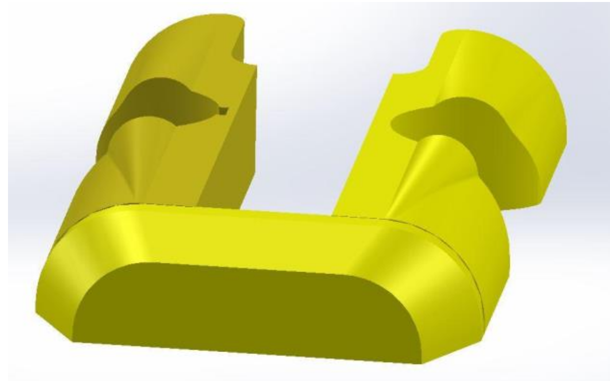


Figure 7 Three Part Buoyancy

The three piece design (Figure 7) provides a sleek, lofted curve, with rounded corners to prevent snags on cabling, and raised sections around the thrusters to provide a safe zone to prevent injuries or thruster damage during operation. The two side pieces on the ROV provide primary buoyancy while the third removable front piece can be filled with air to lift the Danforth anchor from the seafloor (See Danforth Anchor Recovery for more information).

Final dimensions were adjusted in SolidWorks to achieve the appropriate amount of buoyancy. To fabricate, our engineers made simple wooden guides with the contour profile, then carefully cut the Styrofoam® block with an electrically heated wire guided by the jig. The foam block was then fiberglassed using an epoxy resin, sanded smooth and painted bright yellow for safety. Once mounted, the buoyancy float was fine-tuned with small weights where necessary to achieve neutral buoyancy and level attitude.

For the tether, adjustable floats were fitted at regular intervals to insure it maintains proper buoyancy, providing easy tether management and increasing operational stability. The section of tether closest to the ROV was made neutrally buoyant in order to avoid snagging on the ship and threatening the success of the mission.

**F. Housing**

*Predator*'s innovative cuboid welded aluminum pressure housing was specifically designed to allow for better volumetric efficiency, a more compact ROV for maneuvering in shipwrecks, and to allow unimpeded access to vehicle electronics for excellent serviceability. Electronic components tend to be cuboid therefore they can be more densely packed into a cuboid enclosure than a typical cylindrical enclosure, minimizing the size of the housing. In previous year models, the electronics were removable from a fixed housing but could not be tested while installed in the vehicle. To address this limitation, our electronics are now fixed to the vehicle while the upper housing is removable to allow full access for testing (Figure 8).

The bottom pressure vessel serves as a hub for all vehicle connectors. Its cuboid shape allows for many connectors and its position below the main electronics can provides addition reliability in case of a leak from a connector penetration.  The under-vehicle location eliminates any cabling from the top of the vehicle that could impede access to the electronics during servicing.

The two pressure vessels are connected via an interconnect tube and all sections are sealed using a 3.175mm (0.125 in) O-ring in a face seal configuration.  Welding was outsourced to a commercial service as we do not have the capability or equipment in-house.

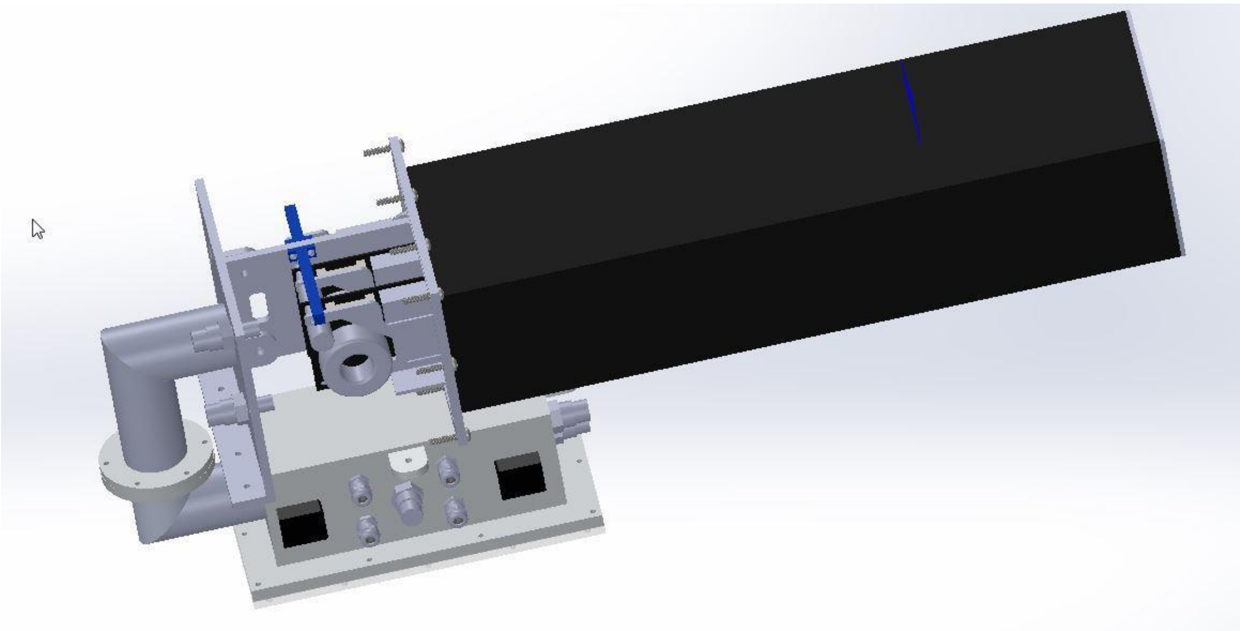


**Figure 8 Two Part Pressure Hull**

### G. Electronics

This section describes Rovotics' Predator overall electrical design including a Tether Control Unit (TCU) on deck, tether connecting to the ROV, and onboard electronics.

*Tether Control Unit*

The Tether Control Unit (TCU) controls power, communications, pneumatics and video distribution for the entire ROV system and is a key element of our overall system safety (Figure 9).

**Figure 9 Tether Control Unit**

To activate the ROV, the 30A circuit breaker on the TCU must be closed and the main power switch, turned on. The power switch is a safety feature insuring no accidental operation of the ROV. In addition to the circuit breaker and the main power switch, there is a power toggle button for all major networking components inside the TCU. One high capacity step down power regulator (48VDC to 12VDC) is used to power the embedded

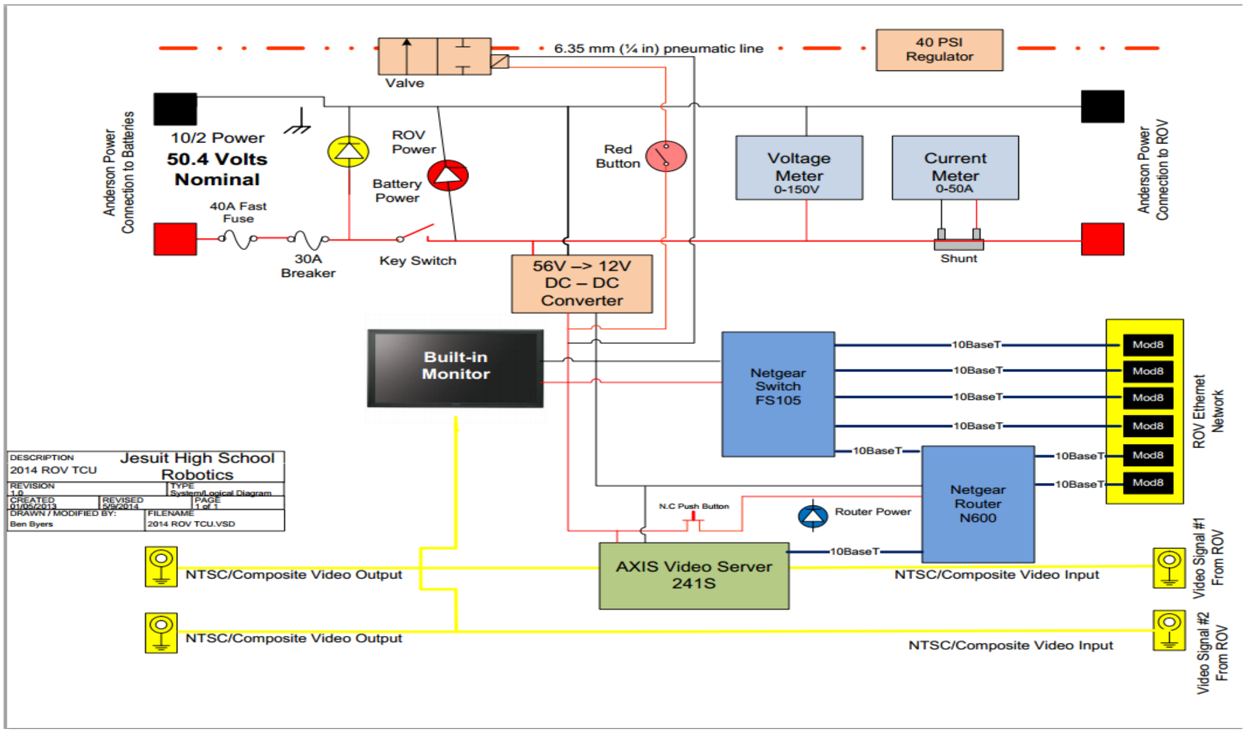



Figure 10 TCU Electrical Schematic

electrical components (Figure 10). Voltage and current meters allow the co-pilot to monitor for power issues, such as discharged batteries and short circuits.

Of the two video signals from *Predator,* one goes to an internet protocol (IP) video server (AXIS 241S) and the other goes to an integrated monitor. Two video signals allow for multiple camera feeds to be displayed at once and increased situational awareness. The IP video feed is displayed on the control laptop so pixel measurement software image analysis can be performed on the shipwreck.
The TCU's integrated monitor allows the co-pilot to view video without looking away from critical safety components. This video feed may also be viewed on a secondary monitor if necessary.

All networking with the ROV is handled by a Netgear router and switch, providing Ethernet ports for the ROV's tether and command laptop.

Our pneumatics are operated by a simple push button on the TCU which activates a solenoid connected to a pneumatics line. This design allows for easy use during the mission.

Our TCU is built in a convenient robust carrying case for portability. The top lid opens exposing the integrated monitor and the controls described. All electronics are housed in a pull out drawer for easy servicing.

*Tether*

Our tether connects the ROV and TCU together, carrying all power, data, video signals and pneumatics. The tether consists of a single CAT5e Ethernet cable for data, dual 12 AWG conductors for power and ground, two Belden 735A coaxial cables for video and a 6.35mm pneumatics line for certain accessories. All lines are wrapped in a polyethene sheath for safety, abrasion resistance and ease of handling. The tether is connected to the ROV via Subconn waterproof connectors and is strain relieved to allow unpowered vehicle recovery.

The Ethernet cable was selected due to the ability to carry signals more than 90m. The Belden video cables were selected due to their 75 ohm impedance for video quality, reduced interference, flexibility and small diameter (3.5 mm). The pneumatics tubing is rated at 1379 kPa, well above the operational pressure of 275 kPa, and has proven to provide sufficient airflow by in water testing.

To ensure robust power delivery, our tether conductors were sized using an online calculator[4], to ensure we maintained sufficient voltage at the ROV power converters during maximum power operation to avoid brown outs. The calculations predicted a total resistance of 0.16 Ohm, which would result in a minor 4.8V voltage drop at the maximum circuit breaker rating of our system of 30A per Ohm's Law. This would result in a supply voltage of approximately 43V at the ROV power converters, well above the minimum 36V input voltage required[6].

| ROV Power Budget | | | | | |
|---|---|---|---|---|---|
| Unit | Current, A | Volts, V | Power/Unit | Quantaty | Max Power, W |
| Thrusters | 4.2 | 19 | 79.8 | 6 | 478.80 |
| Cameras | 0.75 | 12 | 9 | 6 | 54.00 |
| Arduino Ethernet | 0.75 | 12 | 9 | 2 | 18.00 |
| Plate Motor | 1.5 | 12 | 18 | 1 | 18.00 |
| Hi Beam Ligth Bar | 0.31 | 12 | 3.72 | 1 | 3.72 |
| Video Control Boards | 0.68 | 12 | 8.16 | 2 | 16.32 |
| Peak Power, ROV, W (Total) | | | | | 588.84 |
| Regulator Efficiency, % (Estimated) | | | | | 85.00 |
| Power Loss, W (Peak Power/Efficiency) | | | | | 677.17 |
| Peak Power Available at Top of Tether (30A * 48V) | | | | | 1440.00 |
| Power Loss Due to Tether Resistance (30A^2 * 0.16Ohm) | | | | | 144.00 |
| Peak Power Avaiable a ROV end of Tether | | | | | 1296.00 |
| Power After Conversion on ROV (3@Zahn 280W each) | | | | | 840.00 |

**Figure 11 Predator Power Budget**

*Electronics:*

When Rovotics designed the electronics system, the main goals were safety, functionality, serviceability, compactness, video quality, and robust power. Safety is always our first priority in all of our systems at Rovotics to insure employee and work environment safety. We used CADD to optimize wire layout, routing, and to efficiently utilize stacking volume. Video quality was enhanced by utilizing shielded coaxial cable to match impedance and reduce interference. This year we added a third power convertor to accommodate our six thrusters and numerous accessories.

The main vehicle electronics assembly has three stages of power conversion. The primary 48 volt to 19 volt power conversion is done by three 280 watt Zahn DC to DC power converters (Zahn Model DCDC48/24/280). Each power converter supplies one of the three dual channel Sabertooth speed controllers that control the six Seabotix thrusters. Each Zahn power converter also provides a power source for a portion of the secondary control systems. The secondary power conversion of 19 volt supply from the Zahn is dropped down again to 12v, which is our standard supply voltage for our logic control system (Figure 15).

Our primary control electronics consists of three Arduino microcontrollers (designated ROV1, ROV2, and ROV3) and a Netgear Ethernet switch. The Arduinos each controls certain aspects of our communications, sensors, and control systems. The 5 port Netgear switch provides Ethernet ports to ROV1, ROV2, and the topside system via the tether.

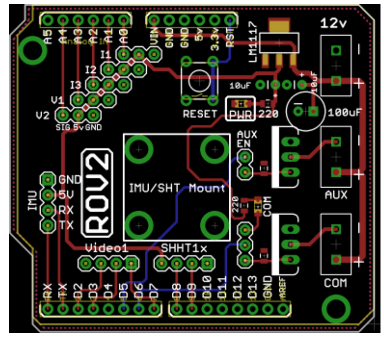


Figure 12 ROV2 Custom Shield

ROV1, an Arduino Ethernet, controls the motors and video switchers and communicates with the topside software via Ethernet. It also acts to relay commands to ROV3 via a serial bus link.


Figure 13 Etched Lead Detection Board

ROV2, another Arduino Ethernet, gathers all the sensor data, including voltage, current, salinity, and leak detection. Two dual Phidgets SSR relays are used to control our accessories.

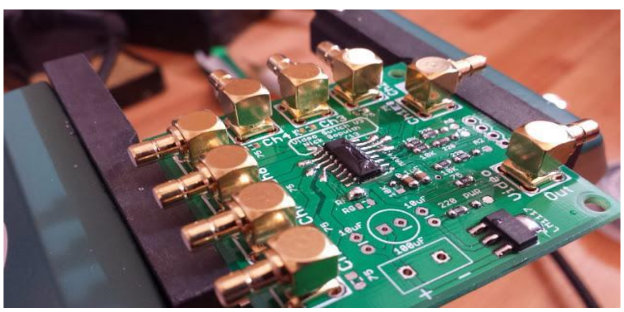


Figure 14 Rovotics Designed Custom 8 Channel Video Board[2]

ROV3, an Arduino Mini Pro, controls all mission accessories through packets sent from the topside through a serial bus link with ROV1.

ROV1 and ROV2 are each fitted with Rovotics custom designed and built breakout shields, which streamlines the wiring of the control system (Figure 12).

The leak detector connected to ROV2 was fabricated in-house using CADD and a laser printer pattern which was then transferred to a copper clad board, etched, and cleaned (Figure 13). The etched copper fingers act as a variable resistor in a voltage divider with a 10MΩ pullup resistor to 5V. ROV2 can sense the voltage in the middle of the divider which will vary if the copper finger are wet or dry. ROV2 sends the voltage reading to *Torpedo* which will alert the co-pilot to a leak if the value is outside of a certain range. For example, if the detector is dry the voltage reading sent to the topside would be 5V. If moisture results in a 10MΩ resistance across the copper fingers, then the voltage reading sent to the topside is 2.5V.

The two 8 channel Rovotics custom video switch boards controlled by ROV1 change the camera feed sent to the topside to allow for multiple views of mission specific accessories. On *Predator* three cameras are attached to each board. Each board utilizes shielded coaxial cable connections to match impedance and reduce interference as well as power filtering in order to protect sensitive video electronics (Figure 14).

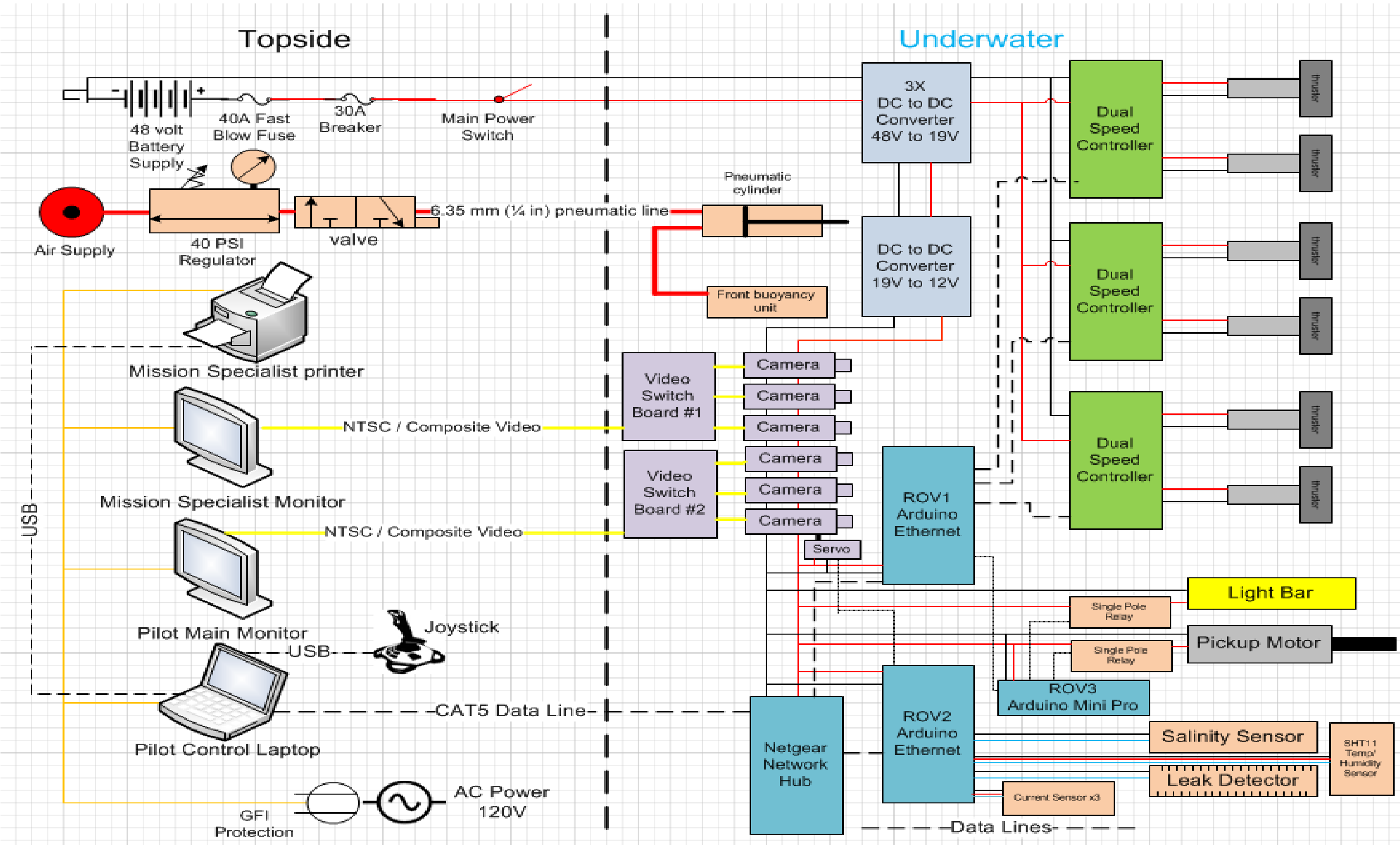



**Figure 15 Main ROV System Interconnect Diagram**

Internally all components are wired with silicon coated wire for its current carrying capability and its flexibility, making it easy to route through the chassis. This year all of our video lines are RG 179 Coaxial to provide noise immunity from the speed controllers in the ROV.

### H. Programming

Rovotics uses a dedicated topside laptop for joystick and co-pilot inputs, embedded controller on board the ROV, and User Datagram Protocol (UDP) packets for communication. UDP broadcasting keeps the control system simple and robust with no end point IP address, so any team device can view the status of the ROV's main systems as listeners on the network.

*Top-Side Code*

*Predator* is controlled via a laptop running a C++ application, "*Torpedo*," written in Qt Creator. *Torpedo* is controlled through a Graphical User Interface (GUI) and a joystick (Figure 16). The goal during development was to give the pilot and co-pilot complete and intuitive control over *Predator*. This freedom of movement was accomplished by a unique vector drive algorithm and state-of-the-art control system. *Torpedo* has a GUI to display information from the ROV's communication network and to accept commands from the co-pilot. *Torpedo* 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, *Torpedo* promptly alerts the co-pilot with an alert message, so the co-pilot always knows the status of the entire control system.

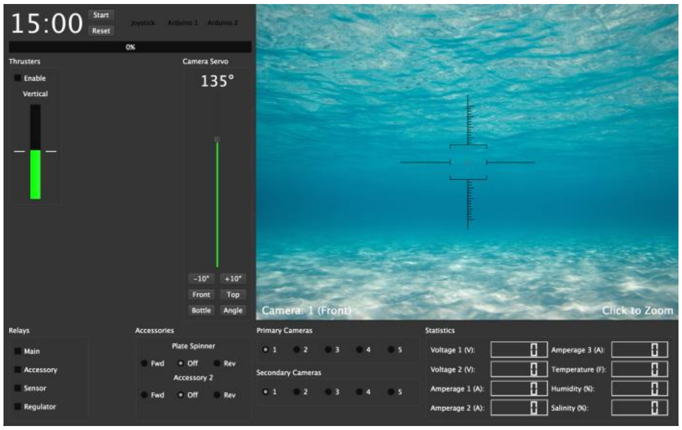



Figure 16 Command Program GUI

*Vector Thrust Control*

*Predator*'s motor layout, with four horizontal thrusters mounted at 45 degree 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 degrees to match the layout of the motors. By using vectored thrust, *Predator* 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.

*Bottom-Side Code*

The processing of the bottom-side code is completed by three Arduino microcontrollers: ROV1, ROV2, and ROV3. The firmware is written in the Arduino variant of C++.

ROV1 controls the thruster speed controllers, relays commands to and from ROV3, and controls the video switching circuit boards. ROV1 receives the UDP packet with the motor values for the six thrusters, the desired video channels for each board, and the accessory values. Before outputting the thruster values received from the topside, the ROV1 software first checks those values to make sure they are within the safety parameters of the thrusters, then outputs them as PWM (Pulse Width Modulation) signals. To switch video channels, the ROV1 software first takes the desired video channel it receives from the topside, and determines which board the desired channel is on. A three bit binary pattern is decoded to determine which of the 8 channels to enable.

ROV2 is the primary telemetry system on the ROV, and reads and returns the data from the onboard sensors. ROV2 is capable of taking data from an inertial measurement unit reporting in real time the ROV's attitude in the X, Y or Z direction. Additionally *Predator* has the capability to measure internal temperature and humidity, detect leaks, and take current readings from each of the main power converters.

ROV3 is a serial bus slave off of ROV1 and controls *Predator'*s existing mission specific tools with room to grow. All commands are originally sent to ROV1 and then transmitted via a serial link to ROV3. ROV3 has the capability to trigger two 12V 9A relays, two 19V 9A relays, and one 5A dual channel bidirectional Sabertooth motor controller.

For safety, ROV1, ROV2, and ROV3 disable all thrusters and accessories if communications are lost with the topside, but resume operation if communications are restored. Another safety feature includes, our leak detector indicator, which can alert the co pilot to the presence of moisture in the electronics can.

**I. Mission Specific**

Rovotics' *Predator* is a custom-built ROV uniquely suited for the exploration of shipwrecks, scientific analysis of the surroundings and site conservation jobs. *Predator*'s mission will be divided into three separate tasks.  Task 1: Measure the length, width, and height of the shipwreck; correctly scan the shipwreck at three target locations; create a photomosaic from five locations; determine the type of ship; determine shipwreck's cargo; enter the shipwreck; locate and determine the ship's build date; recover a dinner plate with port of call; and ultimately, identify the ship using *Predator*'s vision, sonar, and remote sensing systems. Task 2: Measure the conductivity of the ground water, retrieve a microbial mat sample, recover and replace a sensor string, and estimate the number of zebra mussels on the wreck. Task 3: Remove two bottles, an anchor line, and the Danforth anchor from the seafloor. Details of *Predator*'s mission specific tools, set forth below, describe how each of these tasks will be completed.

*Measuring the Length, Width, and Height of Ship*

Underwater measurements will be determined by scaling screen shots of the underwater shipwreck.  On the screen shot, a pixel dimension will be taken of a known object, followed by a pixel measurement of an unknown object using a software package called "PixelStick"[5] (Figure 17). By using a known dimension, the unknown dimension can be solved quickly using an algebraic formula. To calculate the length and height of the ship we are using the 75cm by 75 cm hole on the side of the ship as the known measurement. For the width, we are using our custom zebra mussel grid for the known measurement.

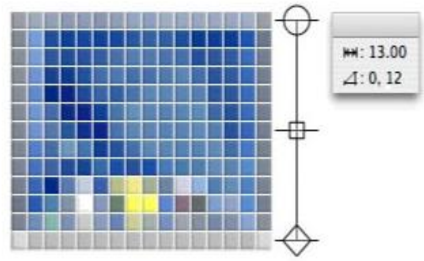



Figure 17 Measuring Pixels

For example, calculating the ship width by using the known size of the hole in the side of the ship.

$$\frac{325\ pixels\ (porthole)}{75\ cm\ (porthole\ known)} = \frac{1275\ pixels\ (ship\ width)}{x\ cm\ (unknown\ ship\ width)}$$

$$\frac{1275\ pixels\ x\ 75\ cm}{325\ pixels} = 294.23\ cm\ ship\ width$$

*Scanning Ship Target Locations*

To complete the scanning of the ship target locations the ROV will traverse the ship from the aft to the bow. To insure a uniform visual of the black rings at each of the target locations, via the onboard cameras, the pilot will maintain a constant depth while traversing the ship. This will also position the ROV to take the five pictures needed to create a photomosaic of the ship. *Predator* is equipped with a light bar for better picture quality.

*Estimation of Number of Zebra Mussels on Shipwreck*

By counting the number of mussels present in the area encompassed by a premeasured grid that we will place on the shipwreck, we are able to estimate the total number zebra mussels on the entire ship using mathematical ratios.

*Plate Recovery*

To retrieve the plate on the seafloor, a gear-rotating motor spins a rod towards the ROV. This rod is comprised of spokes made from plastic tipped springs which move the plate toward and into the basket. When the motor is off, these fingers prevent the plate from falling out of the basket. Through testing we discovered that, by using an opposing spiral pattern of fingers instead of a continuous spiral, we greatly improved the speed and reliability of the plate acquisition (Figure 18). The co-pilot activates the motor through *Torpedo*.

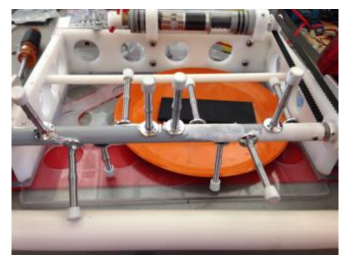


Figure 18 Plate Pickup

*Measuring Groundwater Conductivity*

A salinity sensor is mounted on a cone made of clear polycarbonate for pilot visibility and easy alignment (Figure 19). The salinity sensor uses two prongs on the end of the probe which send electrical signals to each other to measure the conductivity of the water. A voltage divider circuit which includes the conductivity sensor and a 10kΩ resistor is energized by setting a digital output to HIGH. The voltage from the divide is sensed by ROV2 and transmitted to *Torpedo* for display on the

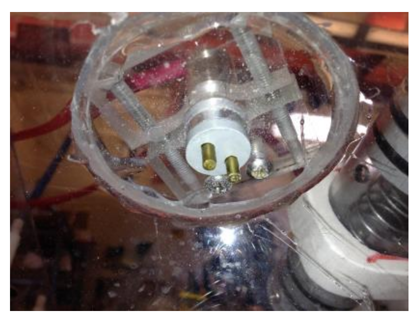


Figure 19 Conductivity Sensor

GUI. A portion of the 5V from the digital output is dropped across the conductivity sensor, and the remainder is dropped across the 10kΩ resistor: $\Delta V_{conductivity\ sensor} + \Delta V_{10k\Omega\ resistor} = 5\ volts$

*Microbial Mat Sampling*

Using a cylindrical tube with a wire across the opening to cut and retain the sample from the cup, we land on top of the microbial mat sample and rotate the ROV. This rotation allows the wire to cut the base of the sample which is then retained in the tube for transportation to the surface.

*Sensor Line Recovery*

To recover the sensor line, our ROV features a hook with a tapered notch for ease of retrieval (Figure 20). This simple attachment is made from smoked polycarbonate to allow for pilot visibility in clear water. This device is attached to the Danforth anchor recovery assembly to utilize active buoyancy for assistance in lifting the sensor from the seafloor.

**Figure 20 Sensor Line Recovery**

*Bottle Recovery*

Our bottle retrieval device is located on the bottom of our ROV. This tool features a mechanical design comprised of a spring loaded bottom side gate, which opens from pressure caused by the ROV landing on the bottle, without the need for electrical or pneumatic actuators (Figure 21).

**Figure 21 Bottle Recovery Device**

*Danforth Anchor Recovery*

In assessing the mission requirements, we determined that the retrieval and recovery of the Danforth anchor was going to be one of the most difficult tasks. In order to accomplish this, we designed a fully removable module with active buoyancy to neutralize the weight of the 3.6 kg anchor. This module consists of a custom, rigid "lift bag" matching the volume required to lift the anchor, which is attached to the top of a removable frame on the face of the ROV (Figure 22). Two carabineers are located on the bottom of the frame which lock securely to the main support of the anchor. Once the anchor is acquired, the "lift bag", which is centered over the lift points to avoid destabilizing the ROV, is then inflated with compressed air from the surface. Small holes in the top of the "lift bag" allow for venting of excess air. When the ROV returns to the surface, the entire module, including the anchor, can be quickly removed so that the ROV can immediately return to the work site. This design was chosen over a traditional lift bag to simplify vehicle operation and poolside retrieval.

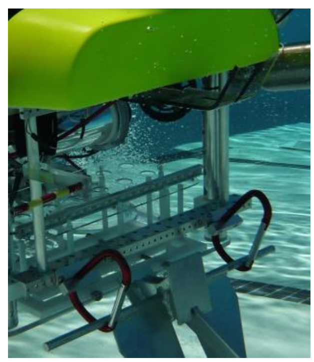


**Figure 22 Danforth Anchor Recovery Accessory**

*Anchor Line Recovery*

*Predator* has multiple capture devices and, depending on the orientation of the debris and ROV, the pilot can select the best tool to retrieve the anchor line and return it to the surface. *Predator* is also capable of handling multiple retrieval tasks at once thereby minimizing the number of surface trips required. For example, the sensor line retrieval can be completed in conjunction with the anchor line recovery.

*Ship Identification*

*Predator* utilizes a high beam light bar and a wide angle, pannable camera, which allow the pilot to identify the manufacture date inside the hull, determine the nature of the cargo, and thoroughly scan the debris field for additional identifying artifacts.

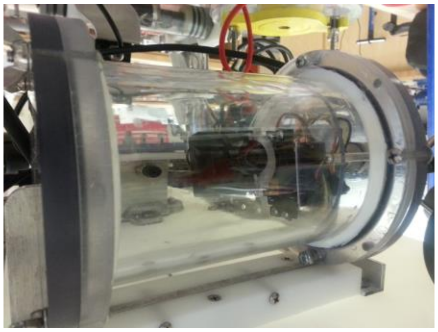


**Figure 23 Forward Pannable Camera Pod**

*Mission Specific Cameras and Vision System*

*Predator* is equipped with multiple camera and vision systems making it uniquely fitted for recording and analyzing archaeological sites. The front main 140 degree wide angle camera is mounted on a digital servo making the camera vertically pannable 180 degrees (Figure 23). The servo responds to either joystick hat buttons or preset values depending on mission tasks selected from the command software. The benefit of a pannable camera is that it provides the same functionality of 4 static cameras. The camera modules are sealed with clear acrylic housings with bayonet O-ring seals for easy accessibility. The main camera is linked to an IP video server streaming real time video. This video stream can be picked up by any standard web browser, allowing the mission specialist to take screenshots and generate the printed mosaic of the shipwreck. Along with pixel analysis software, ship dimensions can be determined easily.

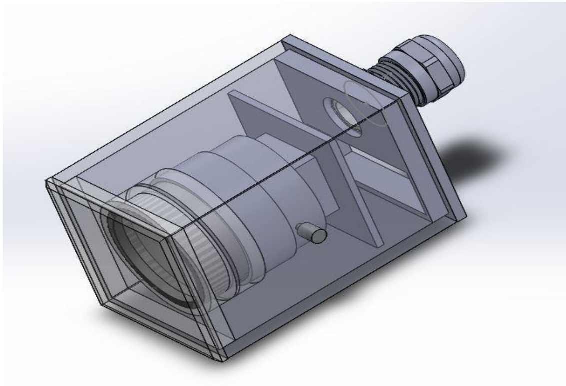


**Figure 24 Potted Camera CADD**

Our static system is comprised of four wide angle, 120 degree cameras, each contained within a custom aluminum housing with a polycarbonate front panel and a strain relief back, and potted with a clear compound to prevent leakage (Figure 24). The four cameras are strategically placed on the ROV to provide the maximum amount of visibility. NTSC cables link the cameras to the video display system. An additional advantage of our custom system is its cost benefit to the customer, as our system is less expensive than commercially-produced cameras.

# III. Safety

### A. Safety Philosophy

Safety is the highest priority for Rovotics. Through our rigorous safety procedures and requirements, we were able to remain accident free this year.


Figure 25 Cutting Bulk Aluminum

### B. Lab Protocols

To insure the utmost safety while operating in the lab and on the ROV, specific safety procedures were implemented. Safety glasses and closed toe shoes must be worn at all times in the lab. Cords are kept out of aisles and walkways to keep the area neat and prevent tripping. When operating machinery, especially the belt sander, where hands could be caught in dangerous rapidly moving parts, team members are prohibited from wearing gloves. Proper shields and enclosures are in place around all machines that could throw chips during operation. Our new lab facilities include a chemical vent hood, so all soldering can be completed with minimal fume exposure.

### C. Training

Rovotics trains through a peer-to-peer system. New employees are required to spend their first meetings observing veteran members operate the machines. Thereafter, they are able to start operating the machines under the supervision of senior members who will guide them and assure that they comply with safety procedures (Figure 25). This culmination of observation, training, and practice has proven to be an effective method in teaching new employees proper adherence to safety protocols.

In addition all members are responsible for policing each other to make sure everyone is complying with company standards. An example of an incident this year was when a member neglected to wear safety glasses while soldering a wire connection. Company members who observed this breach jointly agreed to make him write, “I will not take off my safety glasses” 50 times on the whiteboard insuring the mistake was never made again.

### D. ROV Safety Features

With soft skids and smooth edges, *Predator* 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 buoyancy float which was formed to protect the vertical thrusters from impact further protects people near the ROV from the spinning blades. The four aluminum supports for the unique frame act as handles for ease of moving the ROV and to prevent injury to company members during ROV transportation. Various waterproofing techniques insure all electronics remain dry, keeping them operational and protecting both personnel and equipment from short circuits. In the event of leakage, a leak detector monitored by one of our Arduinos detects moisture in the main electronics can and alerts the pilot to shut down and return to the surface.

**E. Safety Checklist**

*Predator* must pass a company-drafted safety inspection protocol before the crew may attempt to operate the ROV. The safety inspection involves insuring that the electronics and thrusters function properly, that *Predator* is leak-free, and that all Rovotics employees and the working environments are free from potential harm. The safety checklist is located in the Appendices section (VI-A).

# IV. Logistics

**A. Schedule and Company Structure**

To insure that *Predator* was fully prepared for the MATE competition, the Rovotics leadership used a Gantt chart (Figure 26) 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 and software, to the heads of each department who, in turn, led new members in the development of each part. Leads were also chosen to oversee the completion of the technical report and poster who, in turn, delegated specific sections to members in the


Figure 26 Gantt Chart

respective departments. Every workday began with a kickoff meeting during which we went over the tasks scheduled for completion that day. Midday progress reports were given from each department to track task completion. Closing meetings identified the tasks that had been completed and those that would be carried over to the next week. If parts were not completed on time, company members would work throughout the week to complete the parts. As our company meets only once a week, we viewed weeks as days to insure that all departments remain productive all year. While mentors were present for technical guidance along the way, they did not work on the vehicle or its components.

### *B. Source Code Management*

To better manage concurrent development of software, CADD models and other computer files, Git is used 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 *Predator*'s source code to *Predator*'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. Git has proven especially useful when multiple people are working on the same document and allows us to revert to the last working copy in the event an error is made in a flowchart or CADD. Detailed commit messages help us to insure that all departments are making progress. By using Git, we have been able to simplify file management and version control this year.

### C. Budget

As a high school company, Rovotics must operate on a limited budget. The majority of our funding comes from Jesuit High School, school-run fundraisers, and the donations of services or equipment. Including the value of reused parts and resources used in research and development, *Predator* came to a total of $7,485. The six SeaBotix thrusters themselves account for almost half of the overall expenditures. In addition to the money we spent developing *Predator*, Rovotics' budget is required to provide for travel, tool purchases and replacements, and general maintenance of the workshop. The full budget is located in the Appendices section (VI-B).

## V. Conclusion

### A. Challenges

One of Rovotics' main challenges this year was relocating to a new lab facility during the peak of our build season. The decision was made to completely shut down for a three day period and devote our energy to the move. The goal was to do a major house cleaning, move and reorganize our equipment, and be fully operational for the following weekend.

A second challenge Rovotics faced was improving our video quality. In the past, we have always been plagued with a high degree of video interference from electronics components, particularly the electronic speed controllers. Our video signal would have ghosting, reflections or interference lines from noise. This year we completely rebuilt our video systems with a new video board and ground shielding, and all coaxial cable from camera to monitor. Early production testing has resulted in excellent video quality this year.

### B. Troubleshooting Techniques

For *Predator* to remain operational, its electronics must be kept dry. Previously we would leak check by dropping the ROV, unpowered, to the bottom of the pool and inspect for water once it was retrieved. Now, Rovotics' engineers have developed an innovative and efficient technique.

After sealing all openings, the ROV's containers are pressurized to double the operational depth's pressure and then sprayed with soapy water, which produces bubbles at leak points. We do this in the workshop during each pre-mission ROV test, thereby reducing the overall time needed to waterproof the housing. This check is performed using a special sealing window fitted with a Schrader valve. If leaks are discovered, Rovotics' engineers quickly fix them and identify any manufacturing issues.

**C. Lessons Learned and Skills Gained**

Rovotics always strives to learn from its failures and improve on its successes. A critical component of the company's consistent success is actively applying lessons learned in previous years and adding them to a continuously growing knowledge base.
Each year we start with a preseason project that addresses a deficiency that we select from the previous year. This year, we chose to upgrade our video transmission system. We consulted with a professional video engineer who demonstrated the benefits of using shielded cable to protect video signals and made a number of recommendations for cabling and connectors that we integrated into this year's design process.

In the days leading up to the competition, we learned that no one person can complete all mission preparations, so we relied on each other to make the vehicle ready for competition.

**D. Future Improvements**

Rovotics will continue to reduce the complexity of interconnections between electronic devices. This year, Rovotics developed two Arduino daughter boards and a custom video board. Next year, Rovotics plans on developing and manufacturing a single board containing bi-directional motor controllers and solid state relays for accessory control. With the successful integration of an IP video server with very low frame latency, Rovotics plans to continue researching and implementing IP Video to reduce video hardware components.

**E. Senior Reflections**

*I would like to thank MATE for allowing us to compete in their ROV competition. I would also like to thank Jesuit High School for the opportunity to join a team where I can participate in such a prestigious event. This experience on the robotics team has taught me many technical skills such as machining, public speaking, CADD, and programming along with meeting some great people, so I would like thank the coaches and fellow teammates I have met over the years. Through my experience here, I have decided to major in mechanical engineering. In a sense, my high school experience has been partially defined by my presence in the robotics program. I will take all the skills that I have learned and apply them to college and my future.*
-Amirali Akhavi

*Looking back on my experience, I would like to thank Jesuit Robotics for giving me the opportunity to participate in this amazing program. It is not customary for a high school junior to*

*join the team, and I am incredibly appreciative for the chance to prove my skills. Starting on the team as a junior, I learned the intricacies of CNC milling, working on large software applications, and the careful process of creation and revision while learning to be a computer scientist. Managing the topside software aspect of the team, I learned valuable efficiency skills and code management. Beyond just the technical skills, I have gained many cherished memories as a part of this team. I especially want to thank the coaches and the members of the Jesuit Robotics Team.*
-Charles Fries

*I would like to thank the MATE Center and all those who dedicate their time to this competition. The environment and experience that has been created and cared for by the MATE Center has provided me with rewarding experiences that challenged me and gave me some of the most rewarding memories of my life. Since I started with the team sophomore year, I have learned many skills involved in producing a complex ROV in a team environment. Leaving the team, I realize that I have learned more than just the physical engineering lessons. I have gained many great memories working with my team members and interacting with the other teams at the MATE competition.*
-Ty Honnold

*Thanks to all my teammates, coaches, parents, and MATE. My time on the Jesuit Robotics Team has been great. I have gained many skills and experiences and my participation has been one of the most educational and rewarding experiences of my life. This involvement has influenced me and pushed me in a certain direction for my career. With all these skills and lessons learned in the last three years, I will continue to learn and be interested in robotics and engineering.*
-Nolan Schneider

*Thanks to all the students, parents, coaches, and especially MATE for making the robotics program at Jesuit possible. As a fourth year member, I've been given the opportunity and motivation to further a dream into something that will remain a lifelong passion. With the skills that have developed in me, I have insured a successful future in the electronics industry, and I plan to stay within the robotics field as well. I plan to major in electrical engineering as a result of the interest that I have further worked on in  MATE competitions.*
-Nick Sopwith

**F. Acknowledgments**

Rovotics' would like to thank the following benefactors:

- MATE and Marine Technology Society's ROV Committee - For sponsoring this year's ROV competition
- Jesuit High School - For the generous donation of a new lab space and support

- Rolf Konstad, Head Coach - For his countless hours of wisdom, time, and patience for the past four years
- Jay Isaacs, Senior Asst. Coach - For the time, creativity, and knowledge he has shared with the team for the past nine years
- In-lab mentors: Brian Honnold, Steve Kayama, and David Unter
- Marc Aprea - Presentation Coach and Team Lobbyist
- Sharon Aprea – Administrative support
- Andrea Konstad- Administrative support
- Lisa Schneider - For organizing team lunches and presentation coaching
- Christina Woollgar – For managing our finances
- Meissner Sewing Machine Company, Inc.- For donating team shirts to give to fellow competitors
- Cindy Meissner - For managing our company clothing
- Tim Kenneally – For organizing our complicated team travel logistics
- Justin Hall - Jesuit High School Activities Coordinator
- Jim Claybrook, "Weldmasters" - For welding our electronics pressure vessel
- Laurie and Jim Sopwith – For donating our 48V power supply
- Fish Eye Scuba - For providing SCUBA tanks for in-pool sessions at a reduced rate
- TAP Plastics, Sacramento – For donated stock plastic
- Zahn Electronics, Inc. – For providing power converters at a discounted rate
- Byers Family – For providing a TCU monitor and video board
- MacArtney Underwater Technology Group - For providing SubConn connectors at a discounted rate.
- FedEx - For assistance in shipping our crate to competition
- Jamey Sanger - For providing expert consulting with our video systems
- All My Best – For providing shirts at a reduced rate


**G. References**


1. "Mission & Specs." ROV Education and Resources. MATE Center, 2014. Web. 28 Apr. 2014. < http://www.marinetech.org/missions-specs--scoring/>.
2. Maxim Integrated Circuit Application note for MAX4312: http://www.maximintegrated.com/datasheet/index.mvp/id/1892
3. Moore, Steven W. *Underwater Robotics: Science, Design & Fabrication*. Monterey, CA: Marine Advanced Technology Education (MATE) Center, 2010.
4. The Engineers Toolbox website: http://www.engineeringtoolbox.com/
5. PixelStick: http://plumamazing.com/mac/pixelstick
6. Zahn DCDC48/24/280 Data Sheet: http://www.zahninc.com/sd1xspec4824280.html

# VI. Appendices

## A. Safety 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
- Tether connected to ROV
- Thruster free of obstruction
- Electronics can sealed
- O-ring nuts tight
- Verify air supply is properly regulated to 40PSI
- Connect air supply to TCU
- Attach printer to main ROV control computer

**Power Up**
- Power source connected to TCU
- TCU receiving 48 volts nominal
- Control computers booted and ROV control system launched
- Ensure team members are attentive
- Call out "Powering On"
- Power on with TCU key switch
- ROV status lights verified
- Thruster / Systems test
- Call out "Testing Thrusters"
- Operate Joystick
- Confirm no unusual vibration
- Verify video feeds
- Active buoyancy test
- Send 5 second burst of air to ROV
- Plate paddle wheel test

**Launch**
- Call out "Prepare to Launch"
- 2 deck crew members handling vehicle call "Ready"
- Call "Launch"

**In Water**
- Bubble check
- 5 minute submerged, then leak detector check
- Engage thrusters and begin operation

**ROV Retrieval**
- ROV pilot calls out "ROV surfacing"
- Deck crew calls out "ROV on surface"
- ROV pilot calls out "Power down ROV"
- Operation technician calls out "ROV power off / safe to retrieve ROV"
- Deck crew calls out " ROV secured on deck"

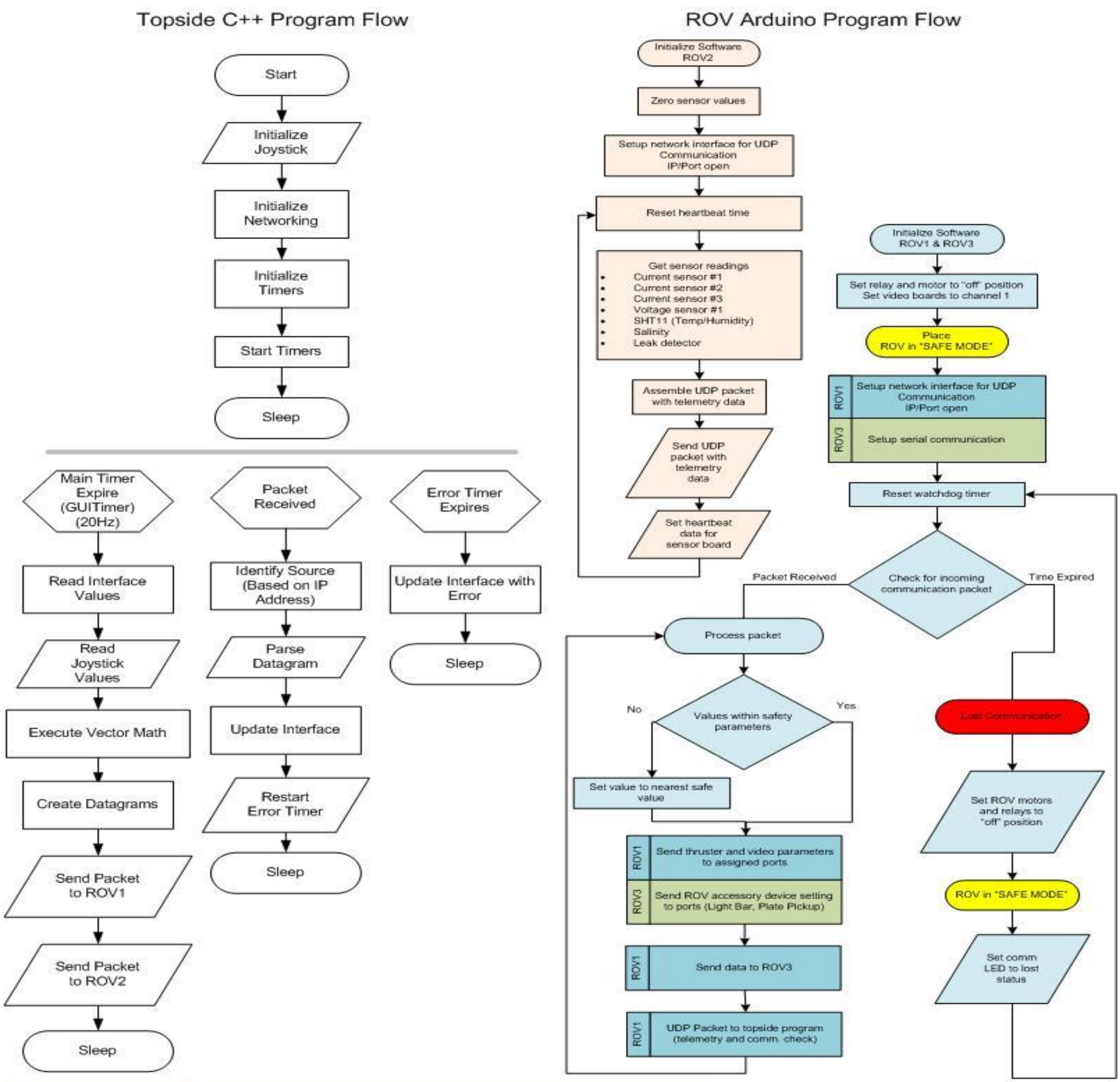
**Leak Detection Warning**
- Surface immediately
- Power down TCU
- Retrieve with tether
- Inspect

**Lost Communication**
- Cycle power switch to reboot ROV
- If no communication
  - -Power down ROV
  - -Retrieve with tether
- If communication restored
  - -Confirm no leak detection
  - -Resume normal operation

## B. Budget

| ROV, TCU, PSU, Consumables, and Services Cost Breakdown | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Expense | Description | | # | Amount | Donatior | Total |
| Predator ROV | Arduino Ethernet | | Purchased New | 2 | $56 | | $112 |
| | Zahn Power Converters | 56V to 24V DC to DC Power Converter | Purchased New | 2 | $95 | | $190 |
| | NTSC Cameras | | Purchased New | 6 | $42 | | $252 |
| | Inertial Measurment Unit (IMU) | | Purchased New | 1 | $81 | | $81 |
| | Seabotics BT150 Thrusters | | Purchased New | 6 | $495 | | $2,970 |
| | Motor Controllers | | Purchased New | 1 | $16 | | $16 |
| | Networking Hub | | Purchased Used | 1 | $15 | | $15 |
| | Custom ROV1 & ROV2 Boards | | Purchased New | 2 | $20 | | $40 |
| | ROV1 & ROV2 Descrete Compone | Resistors, Capacitors, LEDs, Connectors (2 sets) | Purchased New | 2 | $18 | | $36 |
| | Custom PCB | Video Switching Board | Purchased New | 2 | $19 | | $38 |
| | Video Switching Board Componets | Resistors, Capacitors, LEDs, Connectors (2 sets) | Purchased New | 2 | $26 | | $52 |
| | Silicon Relay Board | | Purchased New | 2 | $20 | | $40 |
| | Sabertooth Speed Controller | | Purchased New | 3 | $125 | | $375 |
| | Subconn Connectors | | Purchased New | 12 | $55 | | $660 |
| | Front Camera POD | NTSC Camera, Servo, Clear Acrylic Housing | Purchased New | 1 | $122 | | $122 |
| | Tether Cabling | 100 Feet (12/2 wire, 1/4" Pneumatic Line) 2 @ 75 ohm videc | Purchased New | 1 | $250 | | $250 |
| Tether Control Unit | TCU Case | Dewalt Modular Toolbox | Purchased New | 1 | $71 | | $71 |
| | Netgear Router | | Purchased Used | 1 | $62 | | $62 |
| | Netgear Switch | | Purchased Used | 1 | $25 | | $25 |
| | Axis IP Video Server | | Purchased Used | 1 | $125 | | $125 |
| | DC-DC Power Converter | 56V-12V | Purchased New | 1 | $16 | | $16 |
| | Ethernet Connectors | Nutric Panel Mount Mod 8 Pass Through | Purchased New | 8 | $7 | | $56 |
| | BNC Video Connectors | | Purchased New | 4 | $6 | | $24 |
| | LED Panel Lights | | Purchased New | 5 | $5 | | $25 |
| | Main Power Switch | | Purchased New | 1 | $28 | | $28 |
| | Amp Meter | | Purchased New | 1 | $11 | | $11 |
| | Air Button | | Purchased New | 1 | $4 | | $4 |
| | Pneumatic Relay | | Purchased New | 1 | $12 | | $12 |
| | Laptop LCD Display | Laptop LCD and Video Converter Board | Purchased Used | 1 | | $130 | $130 |
| RAW Stock | Acrylic Stock | | Donated | 1 | | $125 | $125 |
| | Aluminum Stock | Tubing, Channel, Plate | Purchased New | 1 | $200 | | $200 |
| | HDPE Stock | | Purchased New | 1 | $150 | | $150 |
| | Polycarbonate | Discounted | Purchased New | 1 | $300 | | $300 |
| 1KW Power Supp | Craftsman Toolbox | | Donated | 1 | | $15 | $15 |
| | Meanwell Power Supply | 1000 Watt | Donated | 1 | | $275 | $275 |
| | Volt Meter | | Donated | 1 | | $6 | $6 |
| | Current Meter | | Donated | 1 | | $11 | $11 |
| | Emergency Power Off Button (EPO) | | Donated | 1 | | $6 | $6 |
| | Miscellaneous Components | Wire, Terminals, Connectors, LEDs | Donated | 1 | | $18 | $18 |
| | Custom 3D Printing | Student Work at Public Library Design Spot | Donated | 1 | | $341 | $341 |
| Services | Welding | Upper and Mid Can and Mounting Plate | Purchased Services | 1 | | $200 | $200 |
| | Large Format Printing | | Purchased New | 1 | $42 | | $42 |
| Capitol Expenses | Shop Tools | Craftsman 14" Bandsaw | Purchased New | 1 | $750 | | $750 |
| Travel | Lodging | Team Housing ( Students and Teachers) | Purchased New | 1 | $4,146 | | $4,146 |
| | Team On Locatioin Travel | Rental Vhecals for Competition | Purchased New (estimated | 4 | $450 | | $1,800 |
| Funding | QSP Magazine Sales | $ 3,000.00 | | | | | |
| | School Funding | $ 14,000.00 | | | | | |
| | Donations | $ 1,500.00 | | | | | |
| | Consumables | Drill Bits, Sand Paper, Glue, Epoxy, Solder, Saw Blades Mi | Purchased New | 1 | $375 | | $375 |
| | | Total Expenses | | | | | $14,598 |
| | | ROV Total Cost (ROV Cost, TCU, RAW Stock, Welding, Power Supply) | | | $7,485 | | |

## C. Software Flowcharts




| | |
|---|---|
| ROV3 SerialPacket Structure | SERIAL HEADER, motor1, moter2, relay1, relay2, relay3, relay4, servo1 |
| ROV2 UDP Packet Structure | UDP HEADER, voltage1, voltage2, amperage1, amperage2, amperage3, temperature, humidity, salinity |
| ROV1 UDP Packet Structure | UDP HEADER, thruster1, thruster2, thruster3, thruster4, thruster5, thruster6, videoA, videoB, accessory1, accessory2, relay1, relay2, relay3, relay4 |