Palos Verdes Institute of Technology ROV

The *Nautilus*

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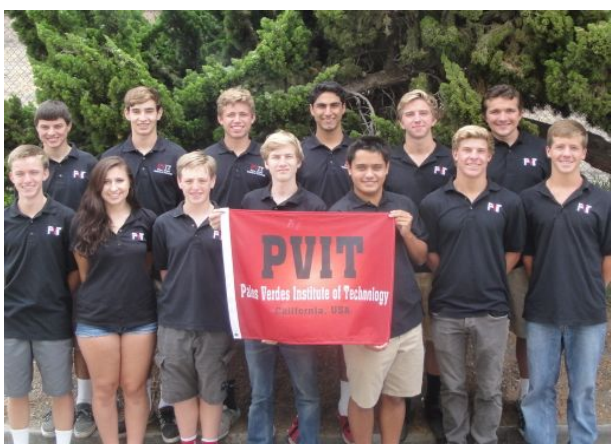
"High quality underwater engineering at its best."



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Abstract

Palos Verdes Institute of Technology (PVIT) ROV is dedicated to providing state-of-the-art Remotely Operated Vehicles (ROV) for underwater exploration. At PVIT, we specialize in data collection and surveying of underwater shipwrecks. Our latest ROV, the *Nautilus*, was created to specifically address the unique needs of the Thunder Bay National Marine Sanctuary (TBNMS) and MATE missions.

Nautilus is designed to work in tight quarters and is able to maneuver around delicate structures. *Nautilus* distinguishes itself from other ROVs with the following features such as a fore facing and aft-facing cameras, servo tiltable rear camera, a durable, rigid, buoyant, corrosion-resistant polypropylene frame, and five orthogonally oriented SeaBotix brushed BTD150 motors to optimize maneuverability. The innovative 2014 *TriRex Claw*, designed and built by PVIT, uses a Firgelli electric linear actuator. PVIT *Nautilus* uses a PC laptop, PlayStation 2 Controller, Arduino Mega microprocessors and Pololu high power simple motor controllers to control the SeaBotix thrusters, tiltable aft-camera and *TriRex Claw*.

We custom fabricated a collection device to retrieve bacterial samples. To identify karst formation ground water, we designed an Arduino Mega-based electrical conductivity meter. PVIT engineered a custom flexible tether to minimize voltage drop, weight and tether steer. With the most innovative equipment and technical expertise, the *Nautilus* satisfies the requirements of TBNMS and MATE to conduct shipwreck surveillance, scientific research and conservation.

Backed by six years of underwater ROV experience, PVIT *Nautilus* is the best choice for TBNMS and MATE.

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Introduction

Palos Verdes Institute of Technology (PVIT) appreciates the opportunity to present the capabilities and features of our underwater ROV, *Nautilus,* to the National Oceanic and Atmospheric Administration's (NOAA), Thunder Bay National Marine Sanctuary (TBNMS). This Technical Report will describe our innovative data collection, surveillance and conservation techniques. At PVIT, we understand TBMNS is in charge of protecting one of America's best-preserved and nationally significant collections of shipwrecks. The unique environment of Lake Huron and its cold, deep, fresh waters have preserved hundreds of sunken ships, nearly intact. The schooner *Defiance* sank in 1854 after a collision with the brig *John J Audubon* (Gandulla). The TBNMS is known worldwide for its maritime heritage and excellent recreational diving opportunities, bringing welcome tourism to the Northern Michigan region. The experienced PVIT team will provide clear video, scientific samples, and a means to retrieve artifacts and debris from the lake bottom ("MATE - Marine Advanced Technology Education :: Home" , "Thunder Bay National Marine Sanctuary | Home,").

Design Rationale

Mechanical

Frame

The *Nautilus* frame is composed of 0.93 cm thick polypropylene sheeting. Over the years at PVIT, we have evaluated a variety of materials such as aluminum, steel, PVC, HDPE, LDPE, and polypropylene. We found polypropylene to be ideal due to its non-reactivity, ability to insulate, and low mass. Other attributes such as its durability, low price, and slight positive buoyancy, were necessary qualities for our company's design. Polypropylene is cut easily using our company's Universal Laser Systems laser-cutter. The frame was designed so that each thruster has unrestricted access to water to optimize each motors thrust. The compact size of the *Nautilus* allows us to maneuver in tight quarters.

Custom Fabricated Components

Laser Cut Components

All of the onboard electronics for the *Nautilus* are located within the electronics tube, see Electronics Housing section on page 4. The biggest difficulty with having a single tube to hold the electronics is getting the electronics to fit nicely and neatly. To solve this problem, we designed an acrylic frame to organize our Pololu motor controllers (see figure 1).

Figure 1. Laser Cut Acrylic Frame for Motor Controllers

The *Nautilus* requires five Pololu Motor Controllers. In order to mount them, we used a Universal Systems laser cutter to cut acrylic mounts, which were then glued together to easily fit the Pololu Motor Controllers into a compact, neat module. Each Pololu has a distinct location on the module where it can slide into and attach to custom-built, seven-pin RX to TX sockets as well as Power-in/out sockets. The sockets are connected to the ROV Arduino Mega inside the electronics tube. The framework allows us to fit the majority of the onboard electronics into a compact space while remaining sufficiently cooled, to allow us more room in the tube for the cameras and other necessary electronics. The development of the framework went through many versions because of the required volume limitations. After many different models we finally developed the final product, perfect for the *Nautilus*.

The polypropylene frame for *Nautilus* was laser cut. The mounting components for the SeaBotix thrusters, *TriRex Claw*, electrical conductivity meter and bacterial mat sampler were all cut from acrylic using the laser cutter. The laser cutter allows us to rapidly prototype components with high accuracy and precision. For this reason it is our favorite tool.

3D Printed Components

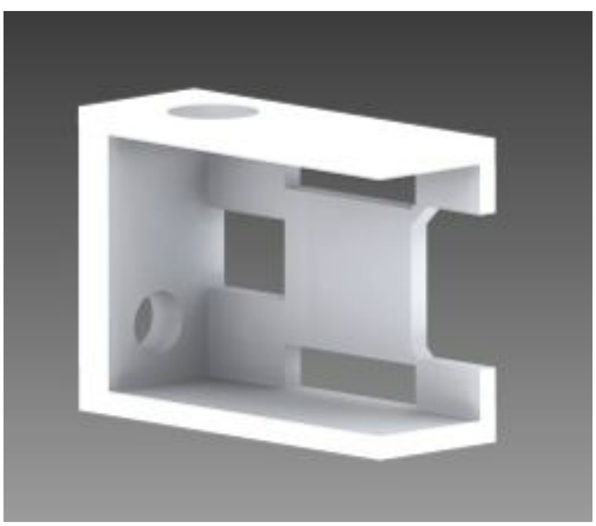


Figure 2. Autodesk Inventor 3D Camera

For the 2014 season, the company updated our camera system to help conserve space and increase the picture quality. Using the new GoPro Hero 3 cameras we had to design a mounting system using Autodesk Inventor Professional 2014 to create a 3-D design modeled around a computer generated GoPro, see figure 2. Once the 3-D file was created and suited our needs, the company printed the camera mount using a Dimension BST1200 3-D printer that was provided by the Palos Verdes Unified School District in conjunction with Peninsula Education Foundation, see figure 3.

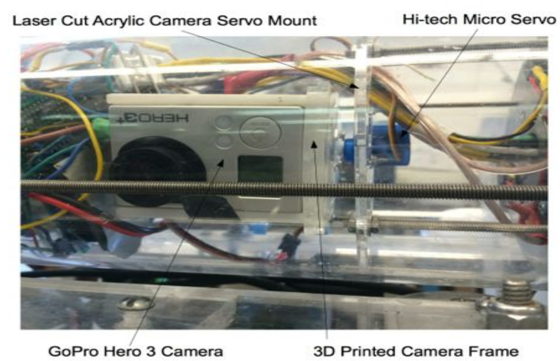


Figure 3. 3D printed camera frame.

Electronics Housing

The 0.64 cm thick acrylic tube, 11.43 cm i.d. proved a superior shape to house onboard electronics, see figure 4. It is sealed on each end with 6061 T6 aluminum side plates. The side plates were machined from aluminum and made watertight with O-rings using approximately 40% compression to ensure an adequate sealing force. This allows us to easily disassemble and reconfigure the electronics for updates and improvements. One side plate connects to our tether using the Glenair waterproof tether connector and two 2.05 mm diameter power wires connected to two PTFE coated 10-32 feed-thru terminals, waterproofed with countersunk O-rings. The other plate has PTFE coated 10-32 feed-thru terminals waterproofed with countersunk O-rings that are connected to the SeaBotix motors, *TriRex Claw*, and electrical conductivity probe using Deutsch DT waterproof connectors.

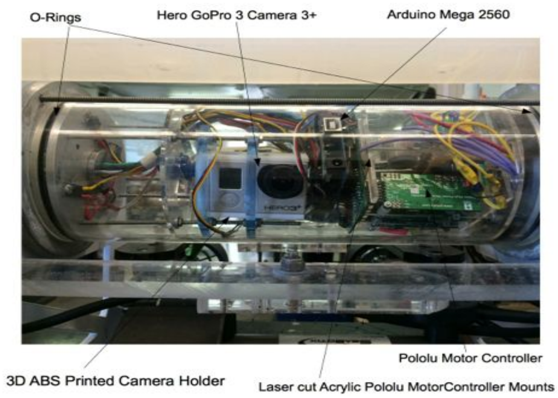


Figure 4. Electronics housing with Arduino Mega, fore-facing GoPro Camera, Pololu motor controllers

Tether

A custom tether was constructed for the *Nautilus* to optimize its performance, allowing it to successfully maneuver through and around ships at TBNMS. The tether is fabricated from a standard 15.24-meter Ethernet cable to carry serial communications between the deck and ROV Ardunio Megas, video signals from both cameras, and signal from the electrical conductivity sensor. Power is supplied through two 2.05 mm diameter stranded copper wires to minimize the voltage drop. The tether is held together using a polyester expandable sleeve. A bright orange color was selected due to its visibility and safety. The tether was made neutrally buoyant by using closed cell foam floats .

Thrusters

The *Nautilus* is equipped with five SeaBotix BTD150 brushed motors that are oriented orthogonally to maximize mobility and efficiency as well as drivability. Each SeaBotix motor develops a continuous thrust of 14 Newtons at 12V, 1.5A.

The forward and backwards thrusters are located near the aft of the *Nautilus*. By individually controlling the port and starboard thrusters we can pivot rapidly. The strafe thruster is located near the center of gravity of the ROV on the underside of the *Nautilus*. The vertical thrusters are on the outside of the frame on the ROV in line with the center of gravity, thus keeping the ROV level during up and down operations. To create a streamlined outer profile, safety guide bars were added to prevent the snagging of the motors on underwater objects. The positioning of the thrusters allows the *Nautilus* to easily maneuver through the fragile environment of the shipwrecks at the TBNMS without disruption.

After each fifty hours of underwater use, SeaBotix protocol calls for the motors to be re-greased. The SeaBotix thrusters are each connected to waterproof Deutsch DT detachable plugs that facilitate a quick exchange of thrusters for maintenance and repair, see figure 5 (SeaBotix).

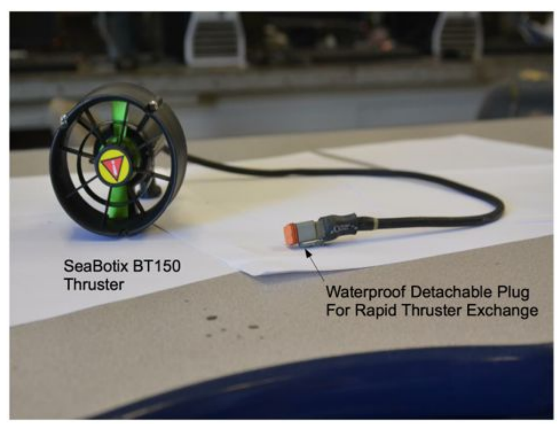


Figure 5. SeaBotix BT150 with rapid exchange connector.

TriRex Claw

A unique development used for the first time on the *Nautilus* is the new *TriRex Claw*. The claw is designed around a single non-waterproof Firgelli L12 electrical linear actuator, 50:1 with limit switches, see figure 6. This gives the

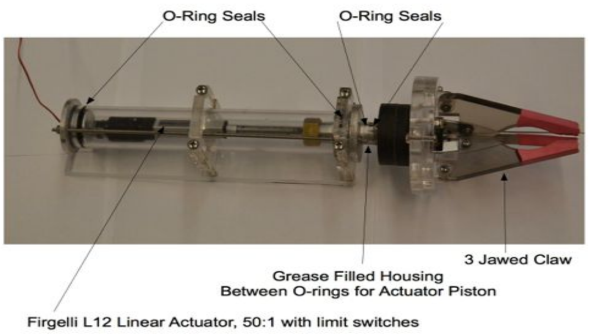


Figure 6. Acrylic 3 Jawed *TriRex Claw* with rubber tips

TriRex Claw a 12 Newton grabbing force at 12V. The electric linear actuator eliminated the need for a separate pneumatic system that had the disadvantages of stiffening the tether due to the rigid, non-compliant pneumatic air hose.

We designed and custom built a waterproof enclosure to protect the actuator that was based upon the electrical tube design. The end caps were machined out of 6061 T6 aluminum with O-ring grooves using a lathe, creating approximately 40% compression to ensure an adequate sealing force. The actuator is housed inside a 3.81 cm diameter acrylic tube, see figure 6. The end of the waterproof enclosure has a grease-filled chamber tightly machined to .0127 mm and over 5.08 cm long slip fit. This slip fit, grease-filled chamber provides high surface tension creating a watertight seal between two O-rings on each end.

The *TriRex claw* was designed with three acrylic fingers to eliminate the need for a rotating wrist joint. The fingers are encased with rubber grips to increase friction with objects and reduce the possibility of defacement to artifacts collected in TBNMS. The fingers open and close as the linear actuator extends and retracts. They were laser cut to reduce the width at the ends in order to be able to precisely pick up artifacts such as ceramic plates in an underwater environment. The interior of the claw was widened to allow the pick up of cylindrical objects from many angles. The *TriRex Claw* is one of the main payload tools on the *Nautilus* because of its ability to complete many of the tasks with ease and efficiency.

Bacterial Mat Sampler

The low oxygen, high sulfur, high salinity water found in the sinkholes of Lake Huron provide a unique environment that supports the growth of unique, primitive microbes similar to what existed early in earth's history (Nature, "Submerged Sinkholes"). These bacteria have been the source of intense research. In order to gather more complete data about the TBNMS the *Nautilus* is equipped to take samples from the bacterial mats in and near the sinkholes.

The *Nautilus* has onboard a custom designed bacterial mat sampling device, see figure 7. The sampler consists of a plastic bottle with a cylindrical tube cut from sheet metal. The leading edge of the sheet metal is serrated to increase the contact force of the sampler to break the surface of the bacterial mat. This allows the sampler to slice through the bacterial mat to take a large sample. A one-way valve, from a snorkel, is placed at the top end of the plastic bottle. As the sampler is driven into the bacterial mat

Figure 7. Bacterial mat sampling device

retained air in the botte is displaced out of the plastic bottle via the valve. The reduced volume of air creates a vacuum between the top section of the bottle and the bacterial sample as the sampler is retracted from inside the bacterial sample. This helps to remove the sample and to retain it during its transfer to the surface.

We came to this version of the bacterial sampler after several previous prototypes failed. We used agar to simulate a bacterial mat in our prototyping since we did not have easy access to actual bacterial mats. We started out using a plastic bottle with a one-way valve at the cap end and the bottom cut off. This did not cut very deeply into the agar. In the next version, we sharpened the plastic but the sampler did not get reliably retain the sample. Next, we tried a core-catcher, which is an industry standard for retaining sediment samples underwater. This was added in hopes of keeping the sample, but it failed to penetrate well and obtained small sample sizes, see figure 8. Our final version incorporated a sheet metal section which provided the smallest cross section and greatest stiffness to cut through the bacterial.

Figure 8. Core catcher prototype.

Basket

To minimize the number of times the *Nautilus* needs to resurface for each dive mission, we designed a special basket that can be carried to the shipwreck site and left on the lake bottom while the *Nautilus* completes its tasks. The basket was fabricated from ½" PVC with dimensions 53.34cm X 44.85cm X 9.35cm. The basket has a specially designed float system for easy retrieval and a net bottom to lower the resistance of moving through the water.

The basket can be loaded with artifacts, bottles or other debris near the shipwreck, and then brought to the surface after the other tasks have been finished. Without a basket we would have to take multiple trips to the surface to bring each item up one at a time.

Electronics &Programming

Command and Control System

The *Nautilus* command and control system makes use of a PlayStation2 (PS2) controller, two Arduino Mega 2560's, five Pololu Simple High-Power 24v23 Motor Controllers and a HiTEC micro servo, which tilts the aft-facing camera. The PS2 controller communicates with the on-deck control box Arduino Mega using the PS2 library. ("Tutorial: Vixeno"). The Arduino Mega was chosen because it has four serial UART ports, two of which we use for serial communication. The control box Arduino communicates this data to the on-board Arduino inside the electronics tube using serial communication via two of the wires in the tether Ethernet cable. A second UART port is then used to communicate between the on-board Arduino and the Pololu motor controllers. The electrical connections are detailed in the electrical schematic below (Pololu)

In past ROV models we used two of the Arduino Mega digital pins to communicate between the on-deck Arduino Mega and the on-board Arduino Mega using SoftSerial and EasyTransfer libraries ("Arduino-SoftwareSerial," "Tutorial: Vixeno"). A software interrupt that is part of the SoftSerial library interfered with the timing function necessary to control the micro servo. For this reason the Arduino Mega, with its multiple serial connections, offers a communication advantage over the Arduino Uno, which has only one serial port .

The ROV Arduino Mega connected to the Pololu motor controllers provides both variable speed and bi-directional motor control. The PS2 joysticks and buttons are used to control forward, reverse, strafing, upward and downward motion as labeled in figure 9. The opening and closing of the *TriRex Claw* is controlled in a similar fashion using buttons on the PS2 and a Pololu motor controller. The aft-facing camera tilt position is controlled by buttons on the PS2 controller via the Arduinos and a HiTEC micro servo in the electronics housing.

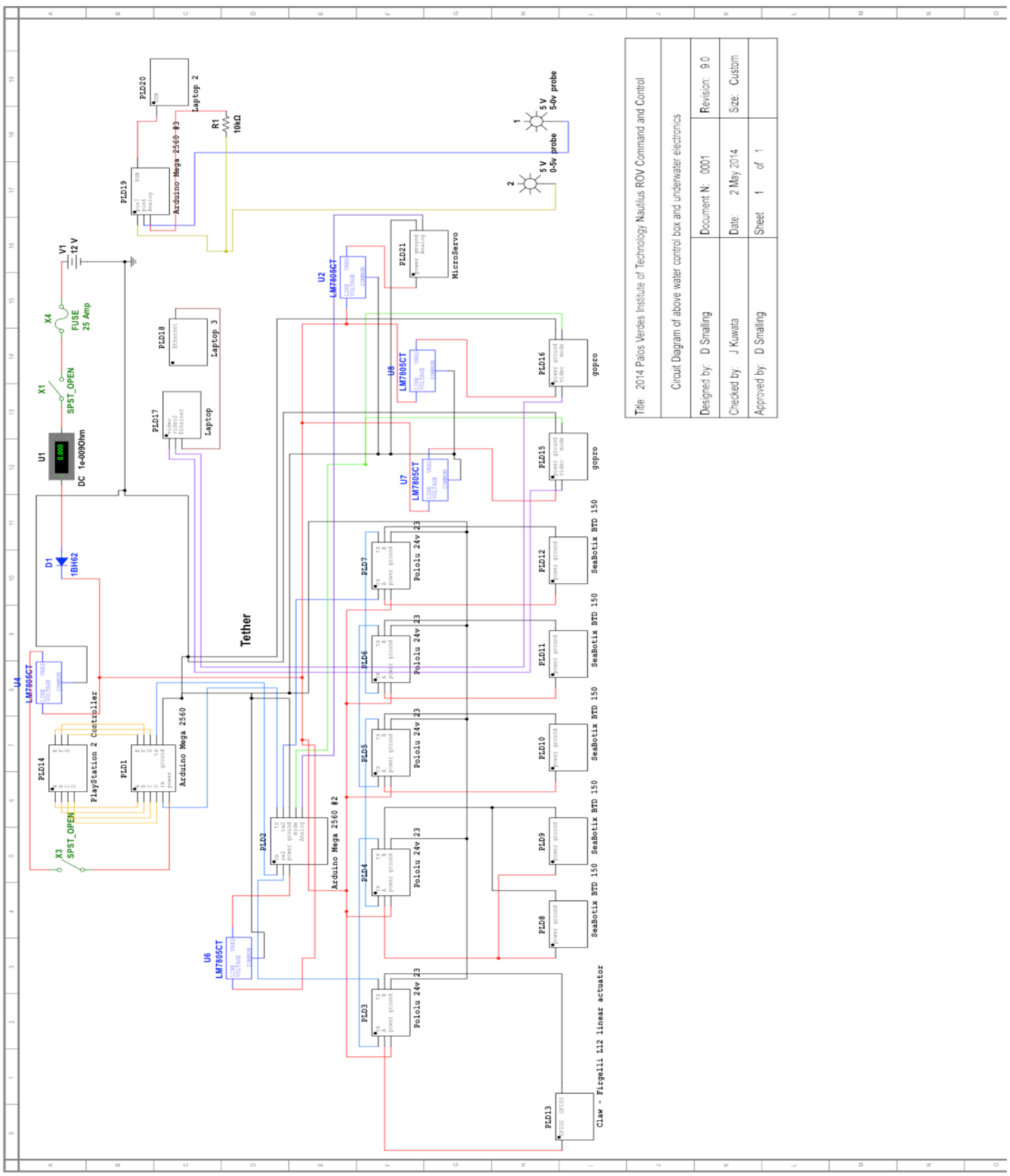
Figure 9. PlayStation 2 Controller

The chain of communication is easy to follow and all of the components in the on-board electronics tube unplug in order to facilitate troubleshooting and upgrades.

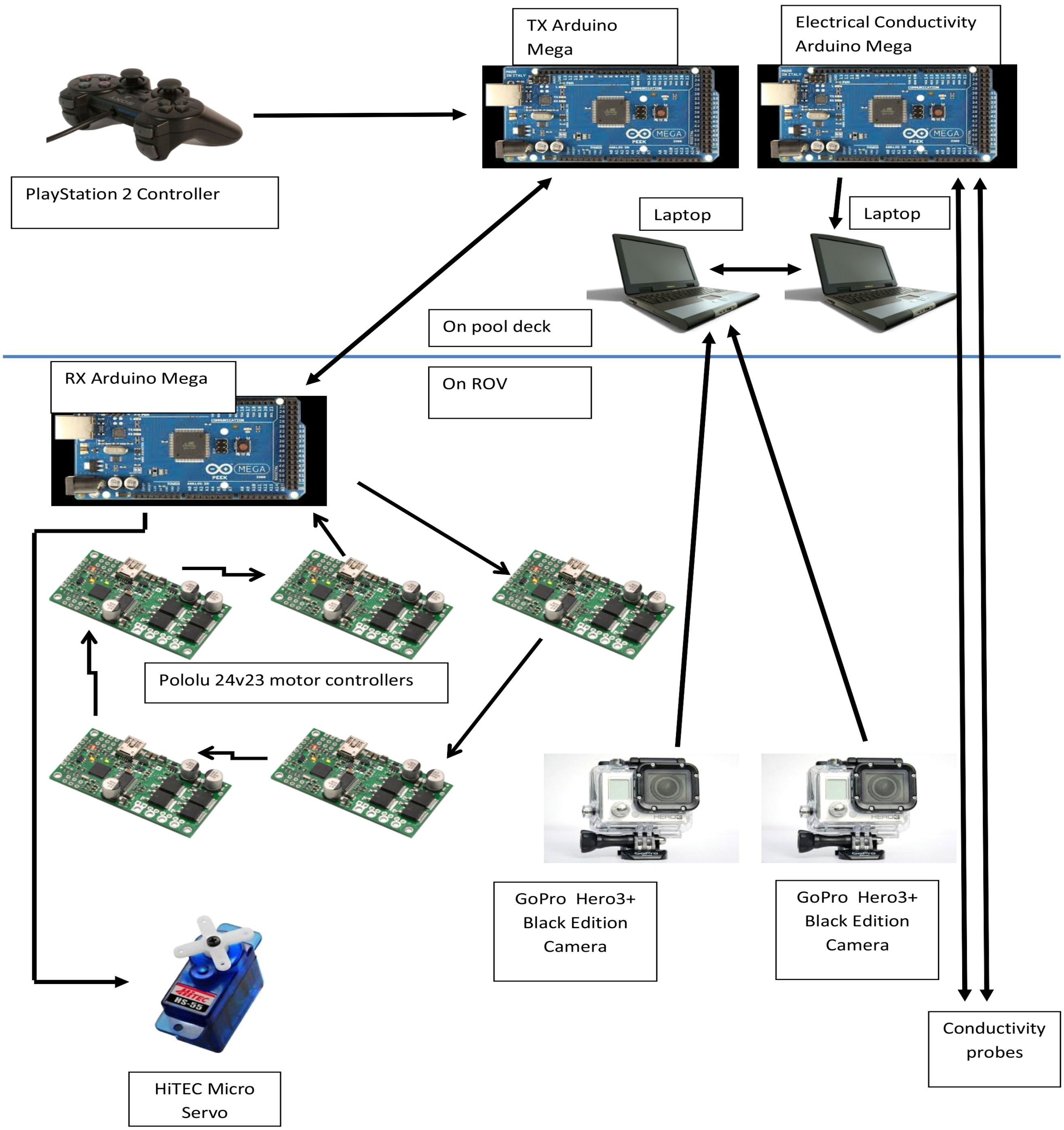
On the next four pages we show the details of the electrical system and the software that controls them. The electrical diagram, on page 9, shows the wiring details of the electrical circuits that we used. This is followed by a Block Diagram that provides a generalized overview of the interconnections between the major electrical components, page 10. This is followed by three software flowcharts that show the programming for the "On Deck Control Box Arduino Mega" page 11, the "Underwater ROV Arduino Mega" page 12, and the "Arduino Mega to Electrical Conductivity Probe" page 13.

Electrical Schematic

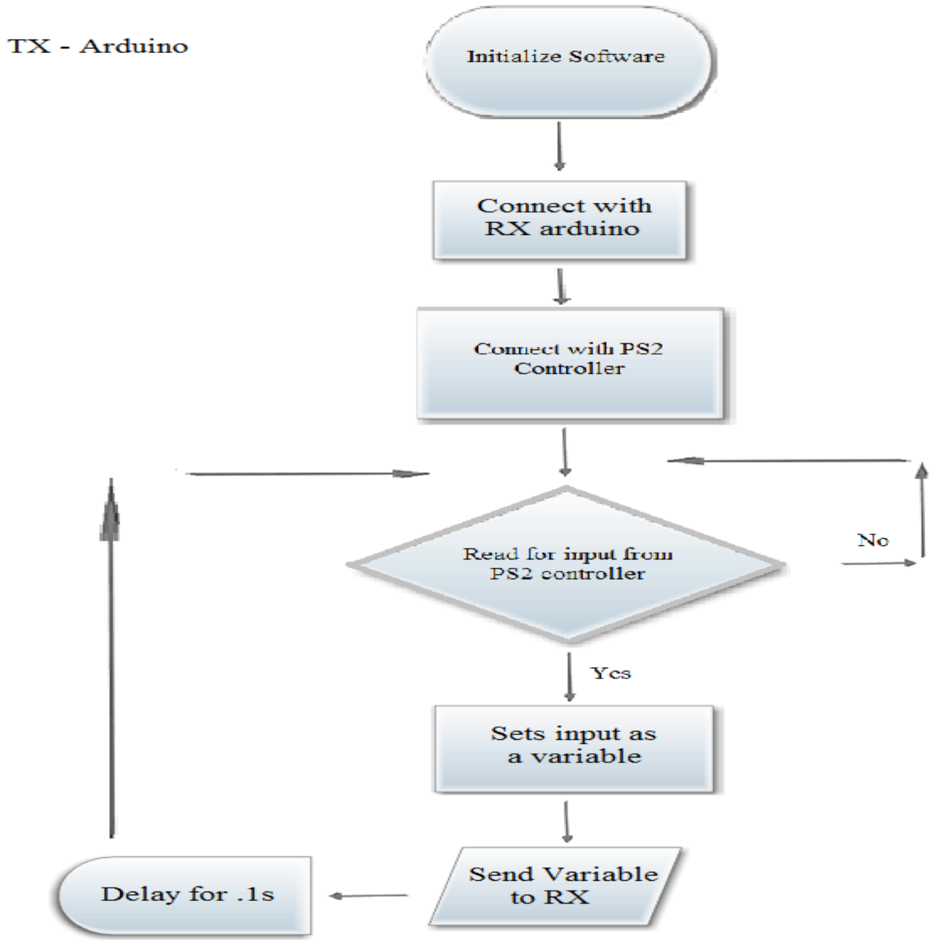
****Please see High Resolution Electrical Schematic PVIT.pdf attached for legibility”**



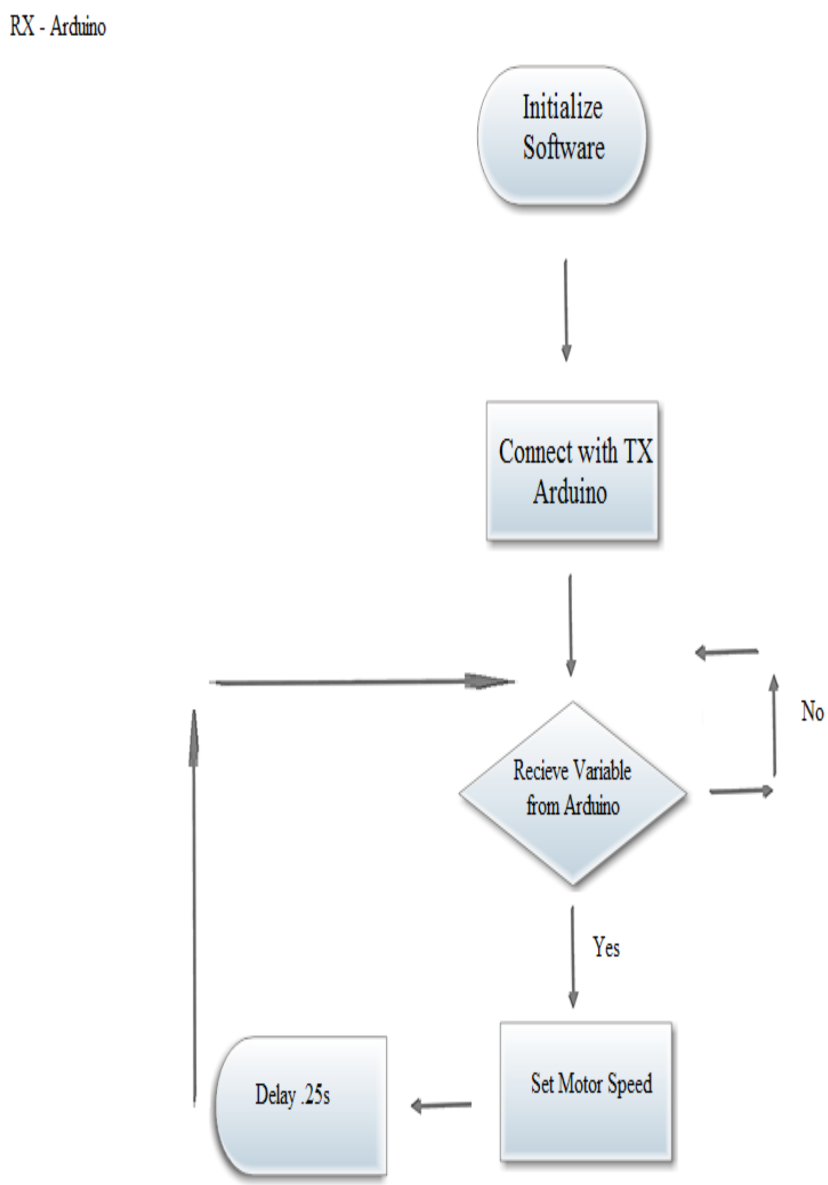
Block Diagram: Electrical Components Interconnections



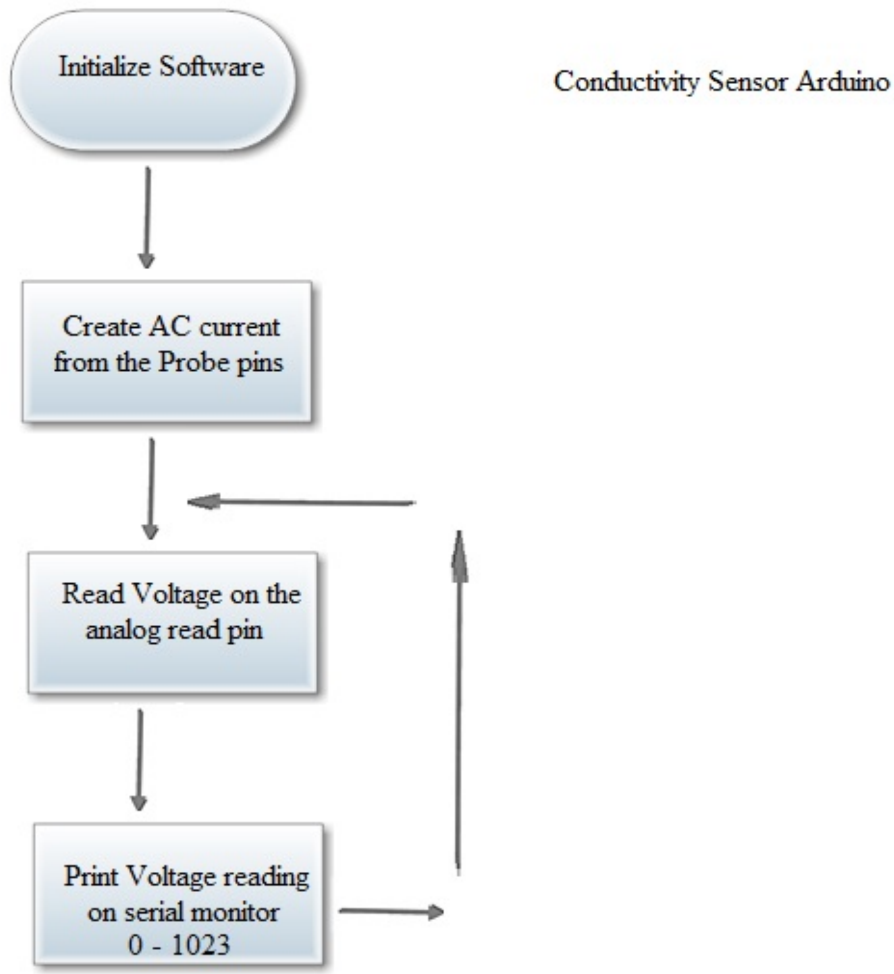
On Deck Control Box Arduino Mega software flowchart



Underwater ROV Arduino Mega software flowchart.



Arduino Mega to Electrical Conductivity Probe software flowchart



Electrical Conductivity

The bottom of Lake Huron contains limestone, dolomite and gypsum, ("Submerged Sinkhole Ecosystem"). Over millions of years groundwater dissolved salts in the bedrock at the lake bottom and created karst formations. When the ceilings of these caverns collapsed they formed sinkholes. The groundwater arising from these sinkholes forms a layer on the bottom of Lake Huron that has a higher salt content and higher electrical conductivity then the surface lake water, (Nature.com). The *Nautilus* has been tasked with identifying and locating these sinkholes. To find the location of the venting groundwater, the *Nautilus* includes a custom-built electrical conductivity meter.

The electrical conductivity sensor on the *Nautilus* is connected to a third Arduino Mega in the on-deck control box. The conductivity probe is mounted to the front of the *Nautilus*. Its electrodes are connected to a voltage divider and Arduino Mega 2560, which are in the on-deck control box, see figure 10. We generate an AC

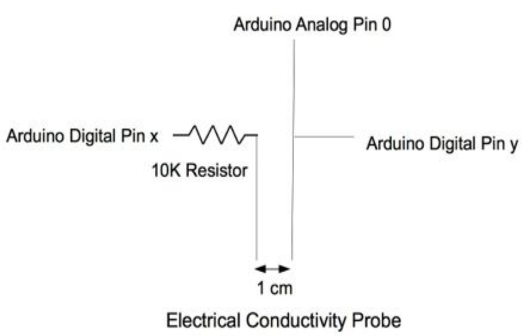


Figure 10. Schematic Electrical Conductivity with Arduino pin connections

current by alternating which probe is positive relative to ground to minimize electrolysis ("A Cheap Soil Moisture Sensor - GardenBot").

The electrodes are positioned 1cm apart and mounted to the front of the *Nautilus* in view of the forward camera, see figure 11.

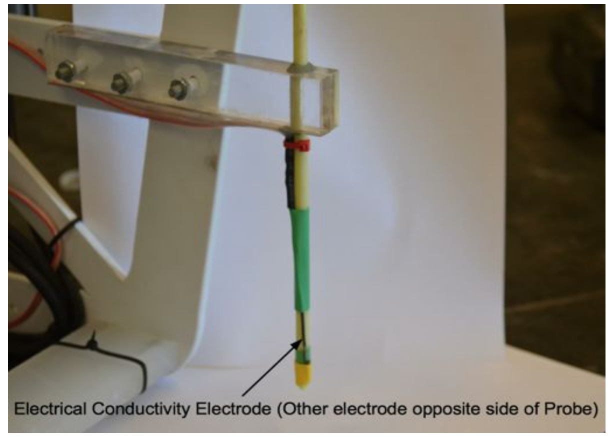


Figure 11. Electrical Conductivity Probe

The conductivity probe is calibrated with saline solutions of known concentration and electrical conductivity at 25 degrees C, see figure 12. The calibration graph demonstrates a linear correlation over the values measured. At very

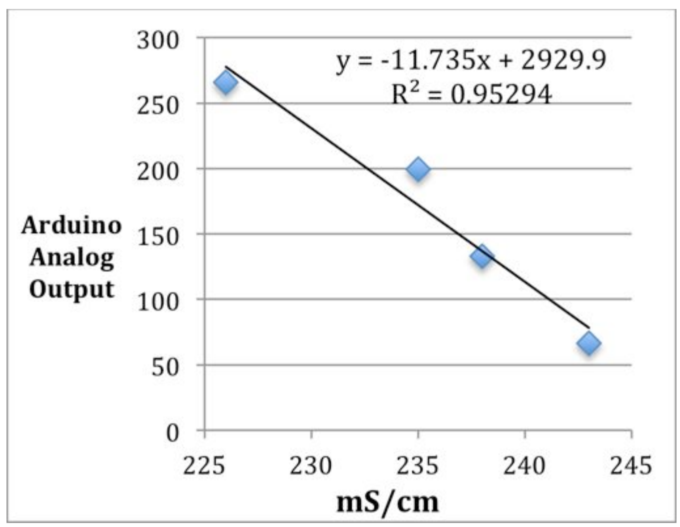


Figure 12. Saline Calibration of Arduino

dilute saline levels, the curve becomes non-linear. If we were measuring a series of dilute solutions we would use a diluted saline calibration curve. The TBNMS is specifically interested in ground water which requires that we use a more concentrated calibration standard. ("Category: Vinduino").

Cameras

The *Nautilus* uses two GoPro Hero 3 Plus Black Edition cameras to get a real-time, first person view of the pool and tools. Older ROV models used the SeaViewer camera, which is big and bulky. GoPros were chosen to be our new cameras because they are very compact, provide a super wide visual angle, and have an RCA composite video output feed through a USB port into an EasyCap converter attached to the computer. The GoPro visuals allow us to maneuver around the shipwrecks in the TBNMS and to perform the necessary tasks. Both GoPros are located in the electronics tube of the *Nautilus*. One GoPro is oriented to face forward to be able to drive and maneuver around the shipwreck. The *TriRex Claw*, bacterial mat sampler, and electrical conductivity probe are positioned so they can all be seen from the front facing GoPro. The aft-facing GoPro is mounted on a HiTEC micro servo, oriented to act as a rear view camera for the *Nautilus*. Due to the fact that batteries are not permitted on the ROV, we had to figure out a different way to power our GoPros. This required the use of a GoPro breakout board which allowed us to access the

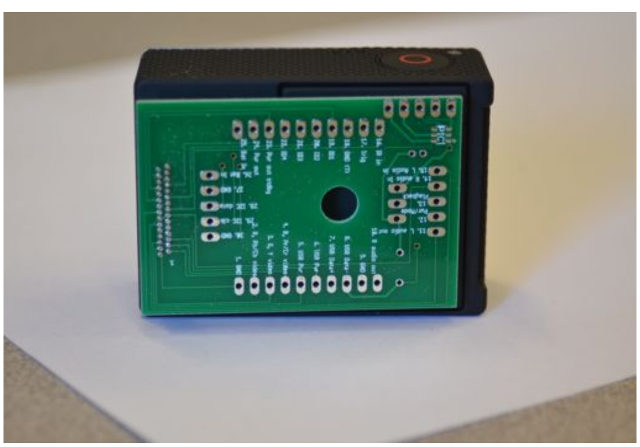


Figure 13. GoPro Hero3 Breakout Board for 5VDC power input.

GoPRO power directly without a battery, see figure 13. They are powered using 5V from a 12V to 5V DC LM7805 regulator which use the aluminum end plates as thermal sinks for heat management. Without the heat sink, the LM7805s will overheat and shut off. The 5V output is connected to a breakout board connected to the Hero Port of the GoPros.

Shipwreck Measurement Calculations

Zebra mussels are a non-native species artificially introduced to the Great Lakes in 1988. It is postulated that they were carried in the ballast tanks of ships from European ports, ("We Need Your Help!"). The zebra mussels have damaged the Great Lakes' ecosystem. They reproduce rapidly and have led to the depletion of fish stocks and clogging of pipes from power plants and water treatment facilities, ("Invasive Species Threaten Native Ecosystems"). For these reasons the zebra mussels' populations are being surveyed by the TBNMS in order to get an effective estimate of the extent of their spread.

In order to meet this requirement the PVIT Company measures the shipwreck dimensions using information from our high definition video cameras and pixel measurement software, *Analyzing Digital Images*. Using the *Analyzing Digital Images* program the company uses a video image of the shipwreck taken by the *Nautilus*' GoPro cameras to calculate the measurements of the shipwreck ("Software - Digital Earth Watch."). We utilize natural and environmental features of known dimensions as calibration factors. We then measure the width, height, and length of the shipwreck as outlined in this equation:

$$\frac{Reference\ cm}{Reference\ pixels} = \frac{ship\ measurement\ cm}{ship\ measurement\ in\ pixels}$$

Then, by taking a picture of the bow of the shipwreck and using the height from the first measurement as a calibration factor, the width can be determined. The company will then use these measurements to calculate the total surface area of the shipwreck.

In order to get an accurate estimate of the total number of zebra mussels on the shipwreck, the *Nautilus* will take down a 50 cm by 50 cm quadrat and the company will count the number of zebra mussels in that 0.25 sq. meter area. By entering these measurements and the total surface area of the shipwreck into a Microsoft Excel spreadsheet the zebra mussel burden on the shipwreck can be calculated. This will be reported to TBNMS to add to their zebra mussel database.

Safety

Here at PVIT safety is our number one priority. Whenever doing anything that is remotely dangerous, we make sure to use proper safety equipment. Our best way to make sure everyone is safe is to watch each other's back. When doing any physical portion of the project, we stress safety at all levels necessitating the use of proper equipment. Everyone in the shop is required to wear closed toed shoes and protective eye wear whenever they use tools. We use preventative measures such as thruster propeller guards, a 25A fuse in the positive power supply line within 30 cm of the attachment point, and caution warning labels. As a final fail-safe, we adjusted the buoyancy of the *Nautilus* to be slightly positive so it would return to the surface in the event of a major failure.

Safety Checklist

- Ensure all personnel have no loose hair, jewelry or earphones which can become entangled in the equipment. Everyone must wear closed toed shoes
- Safety glasses are required in the lab and on-deck
- Before working with the ROV, make sure there are no hazardous objects in the vicinity
- Ensure all electronics are far from the water
- Plug in the power with proper polarity from the source to the ROV tether's leads
- Communication is key
- Check that no wires are exposed
- Before powering on the control box, ensure that the box is plugged in correctly

Pre-Run Checklist

- Check connections
- Dry-run to make sure the *Nautilus*' thrusters, claw, and cameras are working properly
- Submersion test for 5 min. to make sure the waterproof seals are intact
- Check thrusters to make sure that nothing is interfering with the propellers

Post-Run Checklist

- Show judges the shipwreck's home town on the plate
- Show judges the bacterial agar sample
- Disconnect the tether from *Nautilus*
- Tether Protocol
- Disconnect all connections
- Dry ROV and safely set on cart

Tether Protocol

- Unroll the tether
- Safely plug the tether into the control box and ROV

- Make sure there is adequate slack to the control box so it will not be tugged when working with the tether
- Safely unplug the tether from the control box and *Nautilus*
- Roll the tether back up

Challenges

One of the most significant problems that the company faced occurred early on in the year. The *Nautilus* had been built, but we discovered that every time four or more of the motors on the *Nautilus* were run simultaneously, all of the motor controllers would cease to function. The motor controllers would have to be manually reset by cycling the power off and then on to the ROV. At first the problem was thought to be inadequate voltage to the motor controllers caused by running four of the motors simultaneously. Interrogation of each motor controller, with the proprietary Pololu motor controller software, revealed that a serial communications error was occurring and not inadequate voltage (Pololu). After more testing, it was eventually realized that the motors were indeed causing a voltage drop, but that the voltage drop was interfering with the function of the Arduino board which, in turn, caused a serial communications error. This was a deceptive problem that required in-depth trouble shooting, but was fixed with the creation of a new and much larger tether that caused much less resistance.

Another problem that we experienced in the past is transporting the ROV. The older models of our ROV had a pneumatic system for the claw that required an air compressor, which was often difficult to transport to remote sites. Also, the pneumatic hose caused the tether to be excessively stiff. This problem was overcome by replacing the pneumatic claw with one that uses a linear actuator, which allows easy transportation, and reduces the impact of the tether on the maneuverability of the ROV.

Troubleshooting Techniques

Motor Controller Problem

1. Turn off power, wait 10 seconds, turn power back on. This resets the Pololu motor controller boards.
2. Check the status of the LEDs on each of the controller boards
3. Check if the plugs are adequately attached to each Pololu controller
4. Check if the RX and TX wires are properly plugged into each Arduino
5. Check to see 12V is being produced from power supply

Electronics Problem

1. Check power supply and make sure it's providing at least12V
2. Check that the main power cables are connected with the correct polarity
3. Check on /off switch
4. Check 25A fuse
5. Turn power off, wait 10 seconds, turn power back on
6. Check to see if any plugs within the control system are not attached properly
7. Check for any wires that should be connected
8. Check the continuity of tether conductors
9. Check continuity of all plugs

Future Improvements

One future improvement would be better underwater motor connections. We have frequent problems with the detachable connectors leaking and corroding. The corrosion leads to the wires becoming brittle and breaking which causes an electrical failure and requires a lot of soldering. Even though we use quality connectors that have

O-rings and marine grade adhesive lined shrink tubing the connectors still leak. Recently we spoke with a Chief Technical Engineer from Glenair who told us that the square seals on our Deutsch connectors are not always water tight because of the square corners. He recommended using round plugs because the seal is uniformly tighter all the way around.

We think it would be beneficial to take advantage of the HDMI output capabilities of the cameras. The GoPro breakout board only provides composite RCA output. If we could figure out a way to obtain a high definition signal from the breakout board we would improve our video images. Long HDMI cables are not feasible at this time.

Lessons Learned

Our company greatly improved our understanding of the process necessary to build a functioning ROV. Last year we were less experienced and still learning. Some areas where we improved our understanding were:

1. We learned that our tether from last year was contributed to a voltage drop whenever we used more than two SeaBotix motors. We constructed a new tether with larger gauge power wires.
2. We had many problems with corrosion in our wires this year. We determined that the best course of action would be to dress each pin connection in Boeshield, a hydrophobic lubricant, and adhesive-lined heat shrink.
3. On past ROV models we have used two-pronged claws. We found that having three-jawed claws offered certain advantages. The three-jawed claws are able to grasp objects with less concern for their orientation. For example a vertically oriented rod would be difficult to grasp with a two-jawed claw designed to open and close in a vertical plane. In a similar fashion, a two-jawed claw oriented to open and close in a horizontal plane would have difficulty grasping a horizontally oriented rod. The three-jawed claw would work in both situations. In place of a pneumatics system for our *TriRex Claw,* we used an electric linear actuator so that we would not have to transport an air compressor. The absence of the rigid pneumatic tubing improved the flexibility of our new tether.
4. To increase efficiency we learned how to use Microsoft Excel. We used it to create a spreadsheet to calculate shipwreck dimensions. We would enter a known reference calibration measurement in pixels, the actual reference dimensions in cm, and the shipwreck's dimensions in pixels into Excel. In this way we only needed a few numbers and Excel would do the arithmetic and give us the shipwreck's dimensions quickly and accurately. We recorded the analog value measured by the the Arduino Mega. We entered this value into Excel. Excel then used the slope and intercept values that we had entered from our calibration measurements to calculate lake water electrical conductivity to identify sinkhole ground water.

Another important issue our team had to face was how we would work together if new people came or if teammates left. Regrettably, we did lose eight teammates from last year; however, in their place we added two completely new recruits to PVIT ROV team. Based on each team member's skill-set, we appointed each to a specific task and, as a team, worked efficiently to complete the *Nautilus.*

Reflections

It was a successful year for our company, PVIT. We designed and assembled a functioning ROV, the *Nautilus*. Through generous donors and many man-hours we were able to complete what turned out to be a large job. At the start of the year things were slow because we just returned from summer break, but after a while everyone knew what had to be accomplished so we could be able to finish on time. We grew a lot as a team this year and learned many new skills that will help us in the future. We hope to continue to learn and improve

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Budget Expense Report

Product	Source	Costs
Aluminum	Reused from previous years	$0
Acrylic	Reused from previous years	$0
50ft Ethernet cable	Donated by Kreiner family	$5
50ft 12 gauge wire		$20
8 pin underwater connector	Donated by Glenair	$0
Polypropylene		$28
Pelican case	Donated by Pelican in 2012	$0
Ps2 controller		$10
Arduino Mega 2560, r3 x 4	Reused from previous years	$0
Polulu motor controllers x 2	Replacements purchased in addition to last years	$100
SeaBotix motor x6	10% subsidized by SeaBotix Purchased in 2012	$0
Gopro Hero 3+ Black Edition x 3		$1,200
Hi-Tech Micro Servo		$9
Breakout Boards for GoPros x3		$130
	Total	**$1,502**

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