Nautilus II
Technical Report

"SeaKing Depth in Underwater Engineering"

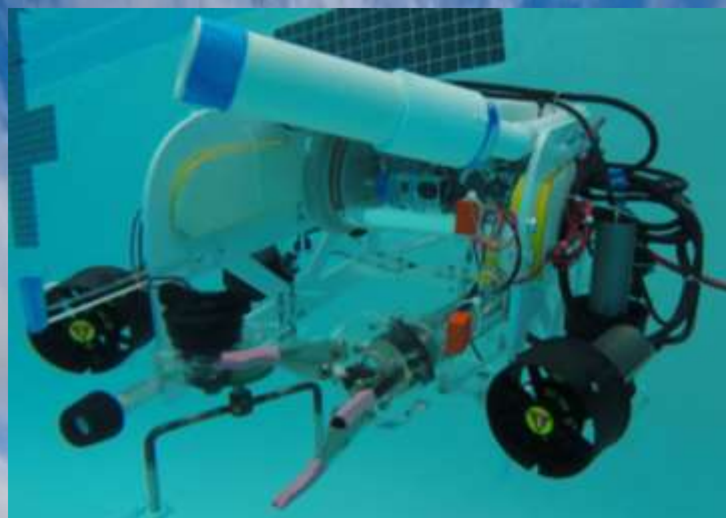

Fig. 1 *Nautilus II* in Action

Photo By: John Robertshaw

Mentors:
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2015 Ranger Team Organization

Kraig Kreiner, Chief Executive Officer, Pilot, 3rd yr., Class Of 2016
Dennis Smalling, Company President 4th yr., Class Of 2015
Mark Caropino, Chief Technical Officer 4th yr., Class Of 2015
Chandler Jones, Lead Mechanical Engineer 3rd yr., Class Of 2015
John Robertshaw, Lead Electrical Engineer 3rd yr. Class Of 2016
Nick Vlaco, Lead Communication Officer 3rd yr., Class Of 2015
Lucas Allen, Safety Engineer 3rd yr., Class Of 2016
Joshua Magid, Lead Software Engineer 2nd yr., Class Of 2017
Aaron Trell, Lead Mission Analyst 3rd yr., Class Of 2016
Grant Vanderdonck, Financial Officer 2nd yr., Class Of 2016
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Fig. 2 Ice and Clouds ©Michael Pollack & www.untamedimages.com

Abstract

For eight years, the ROV team at Palos Verdes Institute of Technology (PVIT) has operated under the mantra: ***Mission Safety, Mission Strategy, Mission Outcome***. Throughout our company's history, PVIT has successfully engineered and piloted safe and reliable underwater vehicles that handle the rigorous mission requirements put forth by Marine Advanced Technology Education (MATE) in adverse environments. With an untarnished company safety record, we have demonstrated the strength and design adaptability of our ROVs. Recent examples of our accomplishments include: providing ship wreck exploration (Thunder Bay, Michigan-2014), and supporting environmental studies by gathering underwater samples (Orlando Florida-2012). Our clients range from universities to international oil corporations.

Our highly talented team of engineers at PVIT is proud to unveil our latest model, *Nautilus II*—completely redesigned in 2015 to support offshore oilfield production and maintenance under the ice above the Arctic Circle as set forth by the MATE Request for Proposal (RFP). *Nautilus II's* polypropylene frame is smaller than last year's model to allow easy maneuvering through a 75cm x 75cm hole in the ice. *Nautilus II* is also equipped with specially designed tools that include our new claw, the *TriRex Claw v3*, an algae sampler, and a water mover engineered to test pipeline flow for pipeline maintenance and scientific data collection. Detailed technical information follows in this document. Summary information is contained in our company's specification sheet for your review.

PVIT looks forward to demonstrating our *Nautilus II's* unique design and capabilities in St. John's, Newfoundland & Labrador in June.

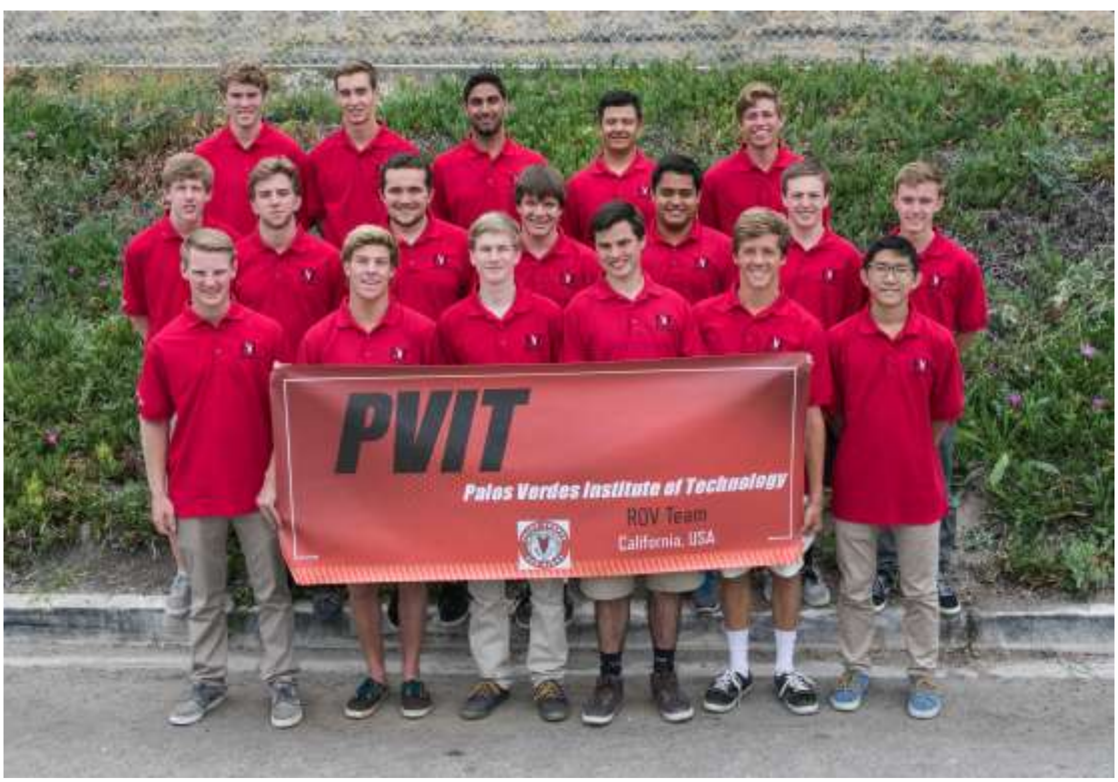

Fig. 3: Company Members Photo: Mary Diroll-Jones

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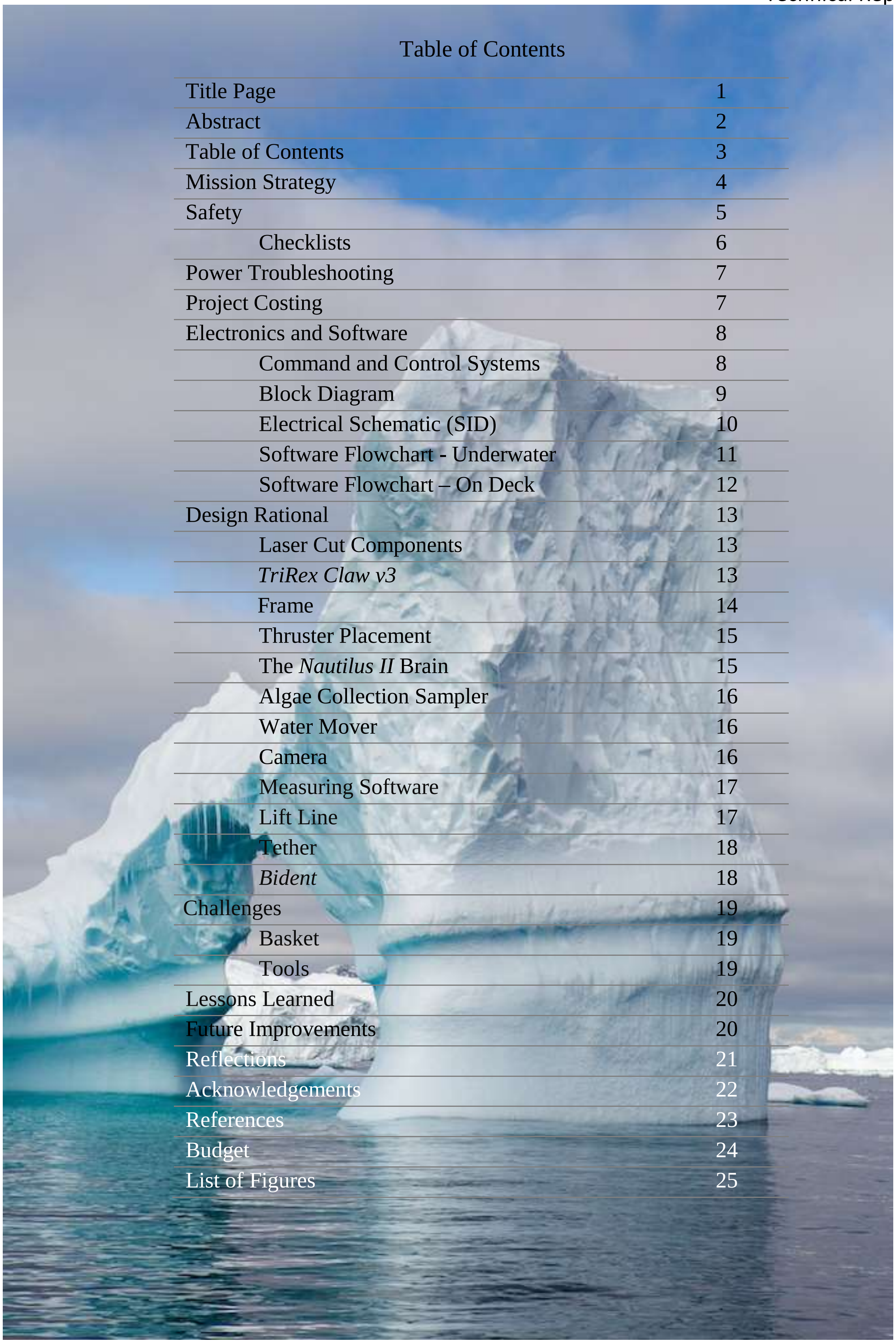


Fig. 4 Arching Iceberg ©Michael Pollack & www.untamedimages.com

Fig. 5

Nautilus II

Photo By:

Kraig Kreiner

Mission Strategy

PVIT is extremely excited for the opportunity to work in the Arctic. With past success working in the cold waters of Lake Huron in 2014, we have developed ROVs capable of functioning in frigid waters. We have equipped the *Nautilus II* with custom designed payload tools to complete the *Science Under the Ice* tasks. To collect the sea urchin and deploy a passive acoustic sensor, we will be using our *TriRex Claw v3.* We have developed a unique collection device for removing an algae sample from under the ice. For detailed iceberg surveys, we use pixel measurement software, *Analyzing Digital Images,* which reads the images of our GoPro video camera.

With previous years of experience providing maintenance on underwater pipelines in the Gulf of Mexico in 2011, we have been able to perfect our skills for *Subsea Pipeline Inspection and Repair* tasks. Our GoPro camera assists us in locating any corroded section of pipeline. Our custom designed *Bident* turning fork allows us to easily turn the valves to stop the flow of oil in the pipeline. Using the *Analyzing Digital Images* software enables us to measure the length of corroded pipe. Our custom engineered *TriRex Claw v3* is featured prominently throughout our assigned MATE demos. Its mission services, as per the RFP, include:

1) **SCIENCE UNDER THE ICE**
    - Collecting an urchin located on the sea floor.
    - Deploying a passive acoustic sensor in a designated area.
2) **SUBSEA PIPELINE INSPECTION AND REPAIR**
    - Attaching a lift line to the section of corroded pipeline.
    - Installing and securing an adapter flange over both cut ends of the pipeline.
    - Installing a gasket into a wellhead.
    - Inserting a hot stab to simulate injecting corrosion prohibiter into the wellhead.

Our time working on pipelines in the Gulf of Mexico in 2011 has given us ample experience to perform the *Offshore Oilfield Production and Maintenance* tasks. We have onboard devices capable of detecting corrosive situations on the four legs of the platform. Again, we use our modified *Analyzing Digital Images* software to perform measurements of the wellhead and use these measurements to calculate inclination angle. We have our custom designed *Bident* turning fork to allow the *Nautilus II* to easily turn valves to control oil flow. To test for flow through the pipeline, we have our *Water Mover*, which allows us to pump water through the pipeline.

Safety

As part of our company mantra: ***Mission Safety, Mission Strategy, Mission Outcome***- safety ranks as our first priority. All deck hands are trained to handle and operate the *Nautilus II* safely. While working on the *Nautilus II*, safety equipment is mandatory for all team members and safety precautions are taken while testing it. Safety glasses and close-toed shoes are always required while using any manufacturing tool.

In addition to using personal protective equipment, PVIT uses preventative safety measures such as motor guards, a 25A fuse in the positive power supply line within 30 cm of the attachment point, and warning labels. As a final fail-safe, we engineered the ROV to be slightly positive in buoyancy to ensure a safe return to the surface in the event of a major hardware or software failure. During manufacturing we smoothed all edges of the *Nautilus II* and eliminated any sharp points on the vehicle.

This year, we employed a new Safety Instruction and Observation Program. We use safety task analysis cards to outline all tasks and their safety hazards. The JSA explains tasks step by step and how to minimize risk of injury or illness in each step. We use the JSA to keep a safe environment and to emulate real off shore industry.

We rigorously follow safety checklists for every stage of production and operation for the *Nautilus II.* The following page exhibits our safety checklists.

Safety Checklist

- Ensure all personnel have no loose hair, jewelry or earphones, which can become entangled in the equipment.
- Ensure everyone is wearing closed toed shoes.
- Ensure safety glasses are worn in the lab and on deck.
- Ensure there are no hazardous objects in the vicinity before working with the *Nautilus II.*
- Ensure all electronics are located far from the water.
- Instill proper communication between all team members.
- Ensure no wires are exposed.
- Ensure the power connections and PS2 controller are plugged in correctly before powering on the control box.

Pre-Run Checklist

- Check electrical power connections.
- Dry-run to check the *Nautilus II* fork, bilge pump and cameras are working properly.
- Check to ensure waterproof seals are secure.
- Check thrusters to make sure they function and are clear of obstructions.
- Check *TriRex Claw v3* for proper functionality.

On Deck Checklist

- Follow Tether Protocol.
- Check all connections.
- Power up the *Nautilus II.*
- Test thrusters and *TriRex Claw v3* again.
- Prepare the basket (DEMO 2).
- Safely place the *Nautilus II* in water.
- Release trapped air pockets.
- Deck crew give “Ready” signal.
- Pilot calls “3, 2, 1, Launch.”

Post-Run Checklist

- Disconnect the tether from *Nautilus II.*
- Follow Tether Protocol.
- Disconnect all connections.
- Dry *Nautilus II* and safely set on cart.

Tether Protocol

- Unroll the tether.
- Safely plug the tether into the control box and *Nautilus II*.
- Secure the tether so the control box will not be pulled when working with the tether.
- Manage tether tripping hazard.
- Prohibit foot traffic on tether.
- Safely unplug the tether form the control box and *Nautilus II*.
- Roll up the tether.

Power Trouble Shooting

Trouble shooting on the *Nautilus II* has improved over the previous models. The trouble shooting begins in one of three areas: the craft, the tether, or the surface control box. We test the continuity of the system in each of the three areas to determine where any problem lies. Based on continuity, we start testing circuits to see if they are complete. If any circuits are open, we replace the broken component and retest for a complete circuit. Once all systems successfully function, we test the vehicle. If no further complications arise, the *Nautilus II* is ready to launch, otherwise, we repeat the trouble shooting process.

Project Costing

Table 1: *Nautilus II* 2015 Costs

Item	Quantity/Notes	Unit Price ($)*	Total ($)*
ROV Costs			$ 2,123
Acrylic Tube	3 feet		175
Aluminum Blanks	2	100	200
Electrical Connectors	2 eight, 3 four, 8 two pin	90	1076
Hardware	Nuts and bolts for the ROV, various mission props		79
Adhesive shrink tube	5 feet / unit price by foot	7	35
Pololu 24v23 Motor Controller	5	61	303
Acrylic Glue/Syringe			19
Polypropylene	Sheet		139
Wires/Boards			55
Pololu IC’s			42
Prop Costs			$ 454
PVC Pipes	Various for mission props	395	395

PVC Adhesive	1 can	6	6
Hub bushings	2	3	7
Oil Pans	2	2	4
Cement Mix	2 bags	21	42
Item	**Quantity/Notes**	**Unit Price ($)***	**Total ($)***
Tether Costs			$ 139
14 gauge speaker wire	100 foot spool	27	27
Ethernet cables	two 75-foot	46	91
Cable sleeve	100 feet	21	21
Miscellaneous Costs			$ 139
Soldering iron	1	29	29
Beesclover Voltmeter	1	10	10
MATE Registration Fee		100	100
ROV + Tether Total			**$ 2,262**
2015 Total Spending			**$ 2,855**
Re-Used			$ 3876
Hardware	Various screws, bolts, nuts		93
SeaBotix Thruster	6, Motors	450	2700
Shrink tubing	Various sizes and lengths		45
PS 2 controller	2 controllers	5	10
Polypropylene	sheet		60
Acrylic	sheet		70
PVC Pipe	various diameters and lengths		90
GoPro Hero3+ Black Edition	1	400	400
Arduino Mega 2560 r3 x 4	2	100	200
Breakout Board for GoPro	1	25	25
Pololu Motor Controller 24v23	3 Reused from last year.	61	183
Donated			$ 300
Pelican Case	2, large rolling cases	150	300

*Prices rounded to the nearest dollar (US)

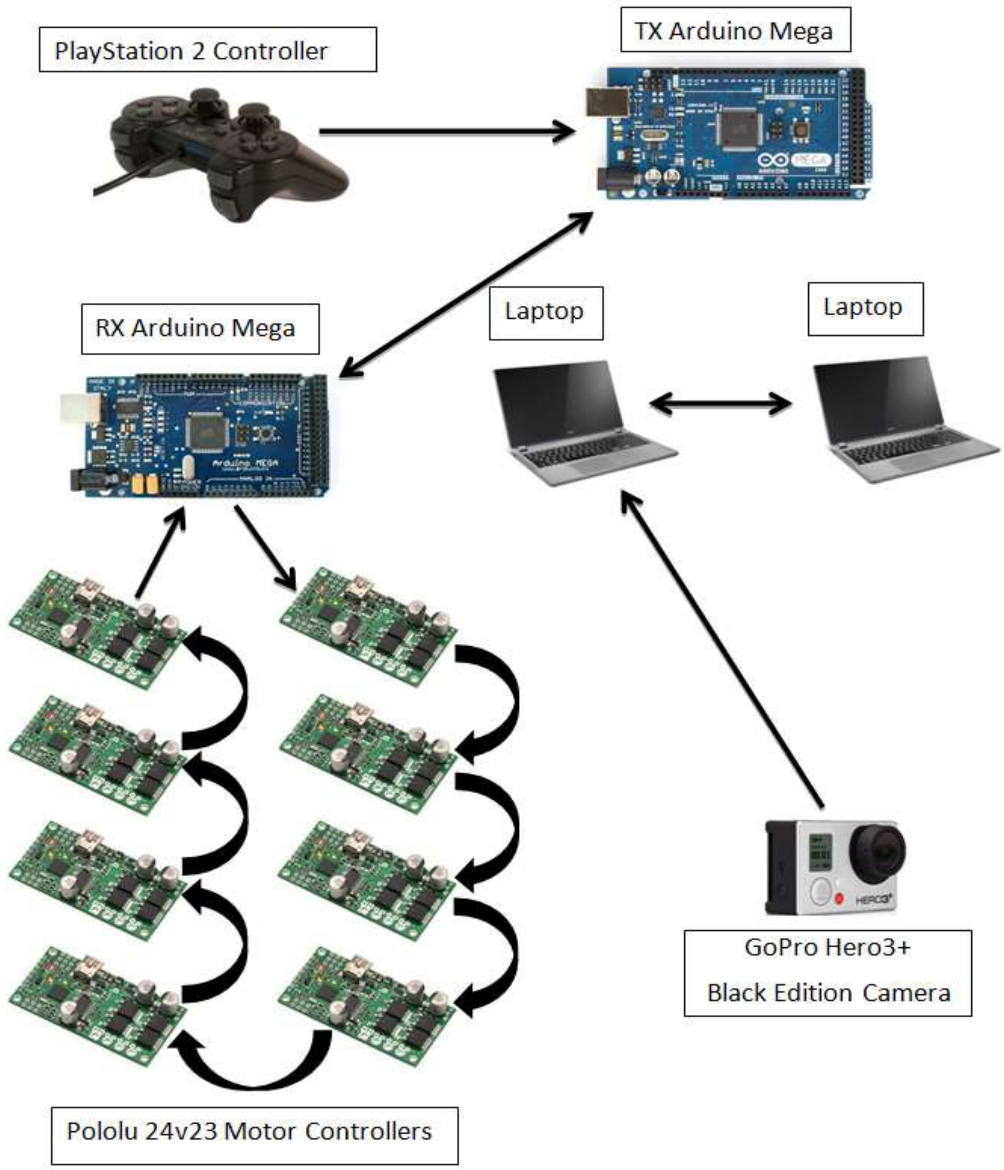
Electronics and Software

Command and Control System

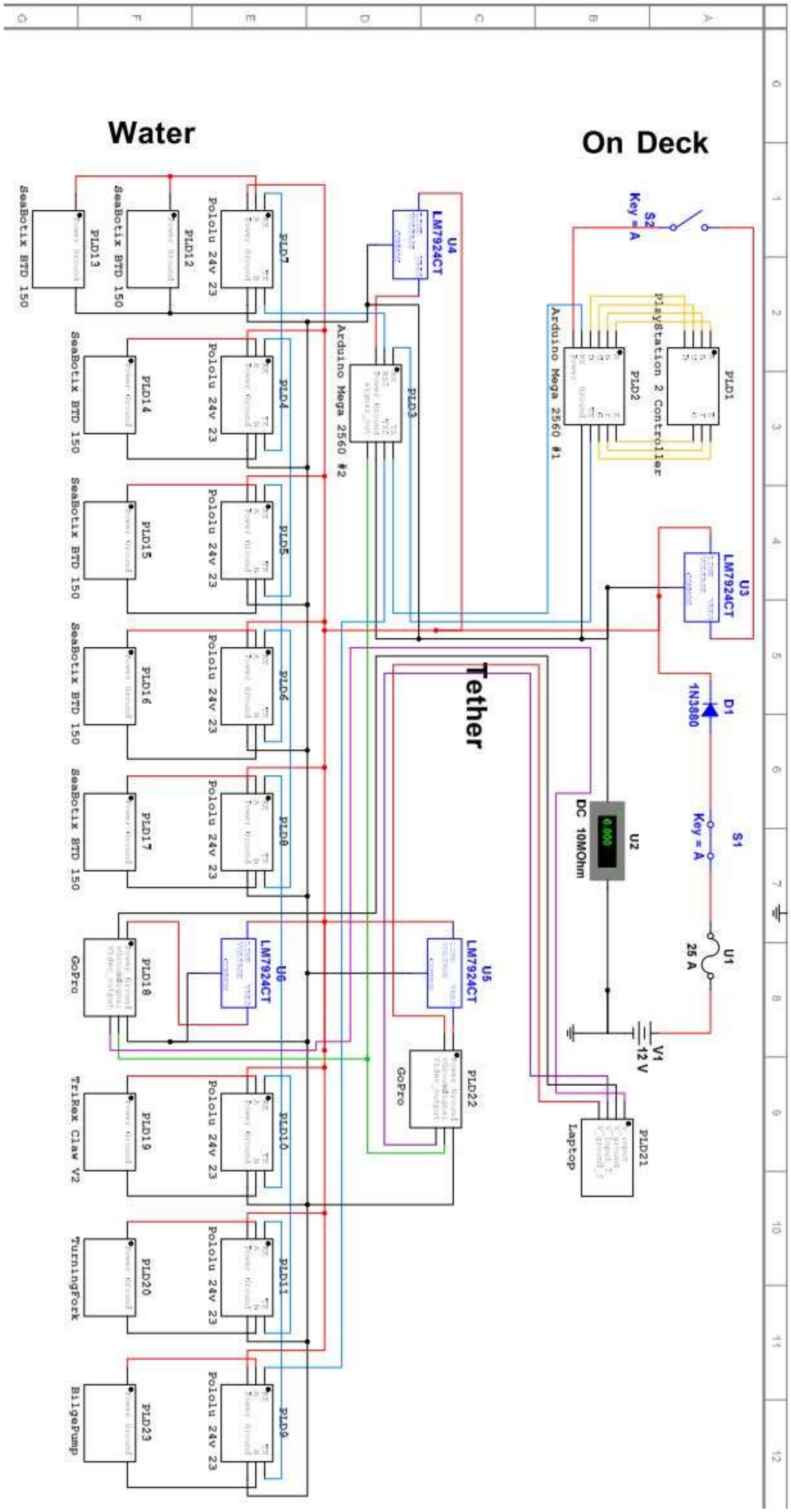
The *Nautilus II* is controlled from the surface with a PlayStation 2 controller. This controller communicates with an Arduino Mega 2560 in the on-deck control box through the use of the PlayStation 2 Controller Arduino Library. The Arduino in the control box then relays the controller information through two serial communication wires down to the second Arduino Mega 2560 on the *Nautilus II* using the EasyTransfer Arduino Library. The on-board Arduino then communicates with the eight Pololu 24v23 motor controllers, which drive our six motors and three tools (the two vertical motors are driven by the same motor controller). The chain of communication is easy to follow, and all of the components in the control box and the on-board electronics tube unplug in order to facilitate troubleshooting and modification.

The following four pages diagram the details of the electrical and software systems. A block diagram providing a generalized overview of the interconnections between the major electrical components is on page 9. The electrical diagram (SID) that follows on page 10, illustrates the wiring details of our electrical circuits. Finally, two software flowcharts that depict the programming for the "Underwater ROV Arduino Mega 2560" are provided on page 11, and the "On Deck Control Box Arduino Mega 2560" diagram follows on page 12.

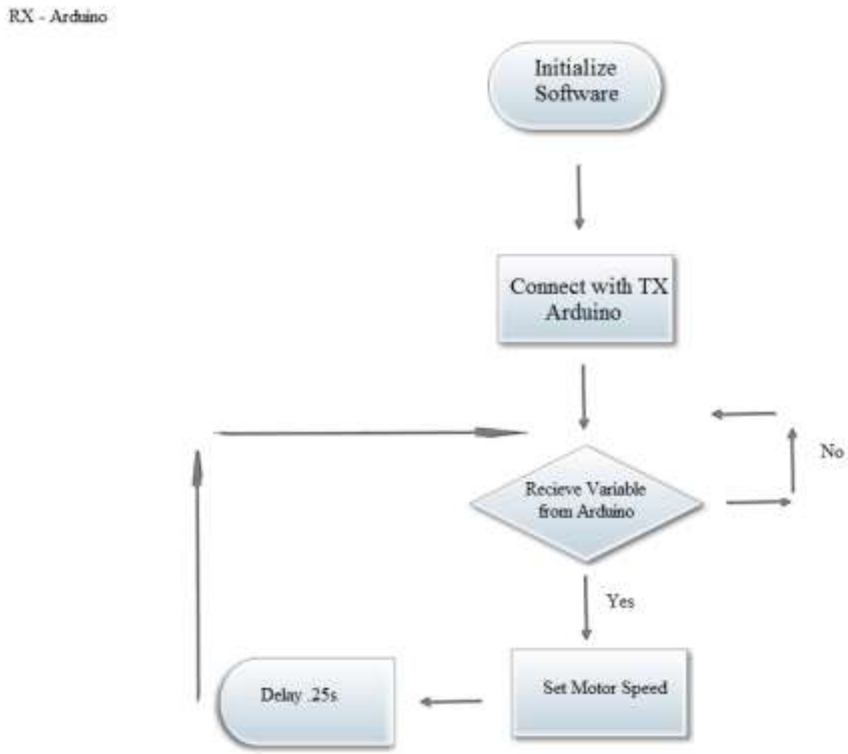
Block Diagram



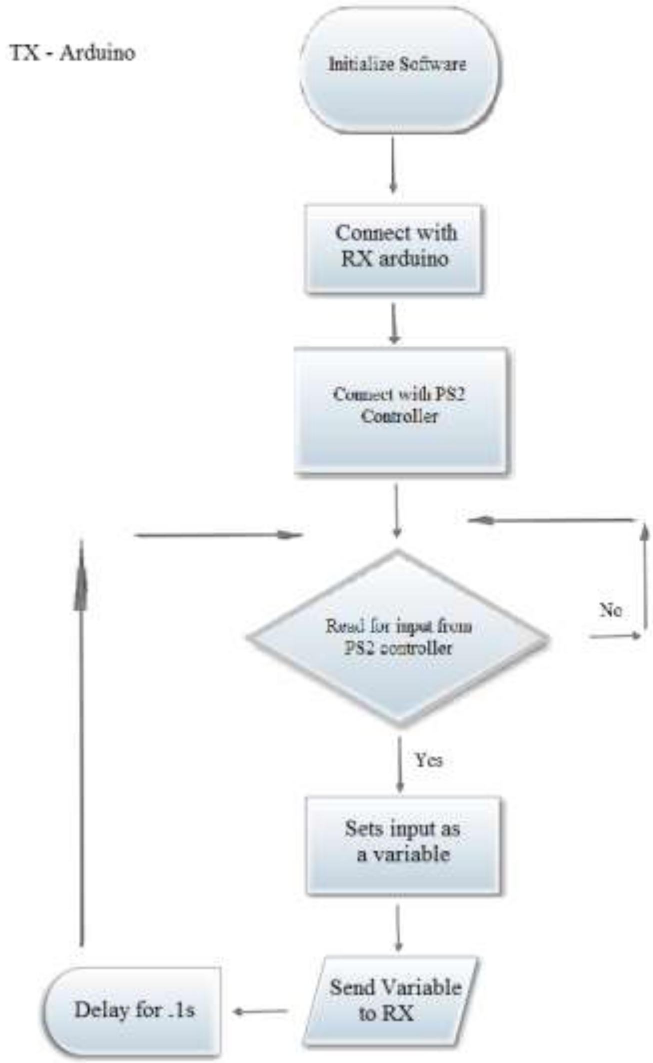
SID


Water
On Deck
Tether
S2
Key = A
U4
LM7924CT
PlayStation 2 Controller
PLD1
PLD2
Arduino Mega 2560 #1
Arduino Mega 2560 #2
PLD3
U3
LM7924CT
D1
1N3880
U2
DC 10MOhm
S1
Key = A
U1
25 A
V1
12 V
U5
LM7924CT
U6
LM7924CT
PLD21
Laptop
PLD22
GoPro
PLD18
GoPro
PLD7
PLD4
PLD5
PLD6
PLD8
PLD10
PLD11
PLD9
Pololu 24v 23
SeaBotix BTD 150
PLD12
PLD13
PLD14
PLD15
PLD16
PLD17
PLD19
TriRex Claw V2
PLD20
TurningFork
PLD23
BilgePump

Underwater Arduino Mega 2560 Software Flowchart



On-Deck Control Box Arduino Mega 2560 Software Flowchart



Design Rational

Laser Cut Components

At PVIT, we are blessed with access to many tools that we use to make many crucial parts for the *Nautilus II*. One of these blessings is our own, in-house *VERSALaser* laser cutter. Our *VERSALaser* can cut through most materials needed for ROV construction and makes useful parts from sheets of varied materials. It has the capability to cut through acrylic, polypropylene, PVC, wood, and any other materials we may need. We use Corel Corporation's Corel Draw X7 to fashion our designs, which are then electronically transmitted to the laser cutter for fabrication. We use the laser cutter for many custom parts on the *Nautilus II* including its polypropylene frame and crosspieces, acrylic mounting components for the SeaBotix thrusters, the *TriRex Claw v3,* and other payload tools. As a safety feature, we use a closed fume exhaust system to vent the benzene produced by laser cutting polypropylene. We prefer the use of a laser cutter for its precision and efficiency. Our in-house tooling capability allows us to experiment with unique designs and materials in an incredibly cost efficient manner.

TriRex Claw v3

Our primary payload tool on the *Nautilus II* is our custom engineered and custom crafted *TriRex Claw v3,* which we believe to be a practical upgrade to last year's *TriRex Claw*. Like the *TriRex Claw,* the *v3* claw is designed around a single non-waterproof Firgelli L12 electrical linear actuator, 50:1 gear ratio with limit switches, see figure 6. This design adaptation gives the *TriRex Claw v3* a 12 Newton grabbing force at 12V. The electric linear actuator also eliminates the need for a separate pneumatic system, which we had found to be inferior because of stiffening tethers due to rigid, non-compliant pneumatic air hoses. See Fig. 6.

Fig. 6 *TriRex Claw v3*

Photo By: Kraig Kreiner

A custom waterproof enclosure is designed and fitted to protect the actuator. The end caps are machined from 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. The tip of the waterproof enclosure holds 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 of the electronics tube.

The *TriRex Claw v3* is designed with three acrylic fingers to eliminate the need for a rotating wrist joint. For the *v2* model, we modified the orientation of the fingers to having one finger on the top, which is able to interlock with two fingers on the bottom. This orientation did not perform as anticipated, so was replaced with a radial orientation that better serves this year's mission which requires us to pick up more cylindrical shaped objects. The ability to redesign and replace the claw fingers is a distinct advantage in meeting changing customer needs. The fingers are encased with rubber grips designed to increase friction with objects and reduce the possibility of the objects slipping from the fingers. 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 precisely pick up artifacts such as flange bolts in an underwater environment. Thus, the *TriRex Claw v3* is perfectly adapted to perform the required tasks efficiently and smoothly.

Frame

At PVIT, we chose to use 0.93 cm thick polypropylene sheeting for the frame of our *Nautilus II.* Based on numerous trial and error experiments with multiple materials such as polypropylene, aluminum, steel, PVC, HDPE, and LDPE, we found polypropylene to be ideal due to its non-reactivity, ability to insulate, and low mass. Also, the material is beneficial because of its durability, low price, and slightly positive buoyancy. Due to mission limitations, the *Nautilus II* has base frame dimensions of 48 cm X 34.6 cm X 29.4 cm. In total, our fully accessorized *Nautilus II* vehicle (including tools and external motors) provides you with a lean and nimble ROV at only 73.5 cm X 57 cm X 37 cm!

Thruster Placement

Fig 7

Motor Placement

Photo By:

Max Ebling

The motor placement on the *Nautilus II* is another unique design upgrade to the model. This model is equipped with six SeaBotix BTD-150 thrusters that are vectored to maximize thrust. The new angled positions of the four vectored motors enable 20% faster speeds than previously delivered, and allows for an extremely small turning radius. The *Nautilus II* has two motors for moving the craft up and down. These motors are located on the side of the frame pointed downwards to maximize upward thrust to help with carrying heavy objects. If we want to move down, we simply reverse the polarity. The new motor placement on the *Nautilus II* makes this model the most maneuverable of any craft that we have manufactured- ideal for the customer that requires both undersea speed and agility.

The *Nautilus II* Brain

Fig 8

The Brain

Photo By:

Max Ebling

Each Pololu 24v23 Motor Controller has a distinct location on the module where it can be easily plugged into the on board Arduino Mega 2560. The motor controller holding device is made out of acrylic cut out on our laser-cutter and allows us to fit the majority of the onboard electronics into a compact, watertight space while remaining sufficiently cooled to allow for more room in the tube for our camera and other vital electronics. To prevent fogging in cold water conditions, we added self-indicating desiccant to maintain a dry atmosphere.

Algae Collection Sampler

Fig. 9

Algae Sampler

Photo By: Max Ebling

To support scientific experiments, the *Nautilus II* can collect algae samples from the underside of ice. The *Nautilus II* uses the suction side of a bilge pump to pull sufficient samples of algae from under the ice. The algae are captured and remain trapped in a tube until safely returned to the surface. The suction collection method is effective in all environments, including an uneven submerged ice surface in rough water and currents. The same bilge pump is used to push water through pipelines. The dual purpose of the single pump makes the *Nautilus II* more efficient with its payload tools.

Water Mover

Fig. 10 Water Mover Photo By: Brian Smalling

In order to test flow through pipelines, the *Nautilus II* uses a bilge pump to push water through a delivery system with a rubber nozzle at the end. The nozzle makes a watertight seal with the test pipe. This is the same pump used to retrieve algae samples.

Cameras

The *Nautilus II* uses two GoPro Hero3+ Black Edition cameras to get a clear visual of the job site and complete assigned tasks. Previous models used the big and bulky SeaViewer camera. We consider the GoPro a superior camera because of its SuperView extra-wide visual angle. It provides an easy video out feed through a USB port into a computer. The two GoPro cameras are located in the electronics tube of the *Nautilus II*. The first one is facing forward to view most of the payload tools. The second is pointed downwards so we can see the *Bident* that turns valves.

The GoPro cameras on board the *Nautilus II* are critical for operating the craft. The cameras must be very durable and able to function in their environment while reliably sending video to the pilot. The video is sent from the camera to a GoPro video output cable. This goes through the tether into an EasyCap RCA-to-USB converter. Power for the cameras are supplied by voltage regulators and a breakout board instead of the manufacturer's supplied battery. The cameras have unnoticeable amounts of latency allowing for accurate piloting of the *Nautilus*

II. Two mounts were fabricated to hold the cameras steady and allow for easy access when one of the end caps on The Brain is removed. Desiccants are added to the tube, and the air is replaced with pure nitrogen to prevent fogging. We found this to be an effective strategy last year when we had to keep our camera view clear in the cold water at Thunder Bay.

Measuring Software

In order to effectively measure the dimensions of icebergs, pipelines and wellheads, we have used our pixel measurement software: *Analyzing Digital Images*. The software takes advantage of the *Nautilus II's* GoPro camera, which takes a video image of the pieces to be measured. PVIT has been developing this technique since 2012, when it was first designed to measure a shipwreck in Florida. A subsequent modification was made in 2014, when it was used to measure a shipwreck in Thunder Bay, Michigan.

Analyzing Digital Images takes known dimensions to use as calibrating factors to measure the diameter and keel depth of any iceberg, the length of a corroded oil pipeline, and the height and length of a wellhead. We've generated an equation that uses given measurements (data inputs) to calculate the measurements we are trying to find:

$$\frac{\text{Reference cm}}{\text{Reference pixels}} = \frac{\text{Unknown measurement cm}}{\text{Unknown measurement pixels}}$$

Fig. 11 Jeweled Iceberg

©Michael Pollack & www.untamedimages.com

Lift Line

To keep costs manageable for our company and clients, we make useful tools out of everyday items. Our lift line is one such example. We made the lift line out of a medium sized D-Ring and magnet, and fabricated an acrylic attachment so that our *TriRex Claw v3* can easily grip the D-Ring and attach it to the corroded pipeline. Tied to the D-Ring is a 75 foot rope that travels up to the surface where an employee will pull up the secured pipeline. As a safety measure to prevent entanglement, we have attached a float to keep the line free. The lift line is an inexpensive and effective new tool for the company.

Fig: 12 Lift Line

By: Brian Smalling

Tether

The tether was constructed using two Ethernet cables and two 14 gauge speaker wires. See Figures 13 and 14. The speaker wires supply 12 volt power and ground to the *Nautilus II*. One Ethernet cable provides wires for serial communications, video signal, video ground, and the voltage probe. The second Ethernet provides HD video capability. The tether is approximately 75 feet long and has a stress relief device that attaches it to the *Nautilus II* to prevent damage to its plugs if it is pulled.

Fig: 13 Tether Photo By: Brian Smalling

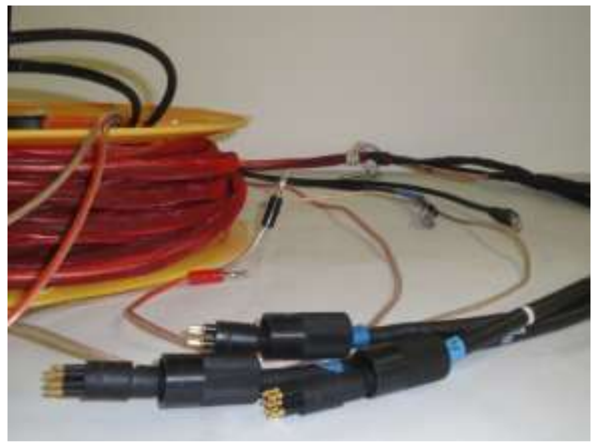


Fig: 14 Tether Connectors Photo By: Brian Smalling

Bident

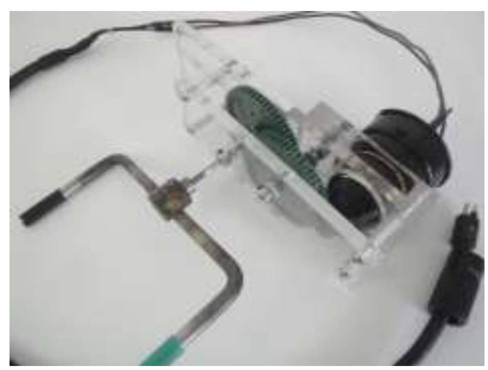


Fig: 15 *Bident*

Photo By:

Brian Smalling

At PVIT, we efficiently and effectively develop custom tools specified to our customers' needs. When called upon to create a tool capable of rotating pipeline valves underwater, we did what we do best, and created our innovative "*Bident*". After careful deliberation among our design team, we devised our current model. Beginning with the raw power, we used a 12 volt bilge pump with sufficient torque to turn the valves and adapted it to our needs. The *Bident* is solid and is unaffected if it is banged around on the deck of the boat; we brazed our iron together using an oxy-acetylene gas mixture. We build our tools to last and are confident with their integrity. We then created a gearbox to convert the motors high angular velocity into high amounts of torque to turn aged, corroded valves underwater without difficulty while also being easier and safer to use due to a lower velocity. The gearbox uses gears in a ratio of 12:62 directly connected to another 12:62 set of gears, allowing for the stepping down of angular momentum to torque. Combining these factors leaves us with a tool that is reliable, adaptable, and highly effective.

Challenges:

Basket

Fig. 16 Basket

Photo By:

Brian Smalling

Throughout the design process of the *Nautilus II,* one problem remained unsolved during the building stage. The challenge we faced was the fact that the *Nautilus II* had to be designed with the capability to carry multiple props and tools down and back up to the surface of the water. This includes the hot stab, flange bolts, and flanges. To resolve this problem we designed and produced a "basket" out of PVC that has the capabilities to safely and securely transport the tools needed for the job. A unique design aspect of our basket is that the tools are positioned for easy grasping by the *TriRex Claw*.

Tools

A significant engineering challenge that the company faced this year was the difficulty of mounting all of our tools on the *Nautilus II* without sacrificing form and function. The mission requires an extremely versatile ROV that has the capability to perform numerous tasks, many of which require separate tools. As we continued to add tools to perform each task it quickly became clear that the front of the *Nautilus II* was becoming too crowded. Tools were beginning to interfere with each other and obstructed our GoPro's field of view. In order to solve this issue the company decided to use modular tools. For example, we use the same bilge pump for the water mover and the algae sampler. Additionally, some tools can be removed when not required for a specific mission.

The most significant challenge has been devising a tool to successfully install a flange to the open ends of the oil pipeline. We have tried a couple different designs, but as of now we have not resolved the issue.

Lesson Learned

"As a first-year on the *Nautilus II* team many of the things that I have learned in this duration of time with my teammates, relate to a number of tools on the *Nautilus II*. On the *Nautilus II* one thing that applies to something that I've learned is the two-prong fork. The two-prong fork is being used to turn the valves on the pipes to get the substance flowing. This relates to something that I've learned in turn is how we were going to design the fork itself and which design would be most efficient. What I've mostly been doing in support of the team is creating and designing the props needed to test run through the mission." **Jacob Criss**

"As a senior and 4th year employee this year, I learned about leadership and the skills necessary to get things done. In the beginning of this year, we had some mismanagement and our working resources were misallocated. We had many people, but it was hard for everyone to find something to do. As senior leaders, we had to step up and take control of our group. After a month or so, we finally got into a groove and were able to put people to work each meeting. Because of this our *Nautilus II* progressed much more quickly than it otherwise would have." **Chandler Jones**

Future Improvements

Future modifications planned include an improved flotation system for the ROV. For instance, foam flotation coated with fiber glass to maximize flotation. Foam, over time, deteriorates. In addition coating the foam would allow us to paint our company colors and logo on the ROV. More importantly, we believe, fiberglass will improve the hydrodynamics and mobility of the ROV in tight spaces.

Another improvement will likely be to design and build an articulating claw with rotating wrist action. We have always used a fixed wrist claw successfully, however, having a more versatile instrument will enable us to accomplish multiple tasks with fewer tools onboard. This will require additional programming, but we are up for the challenge.

Reflections

"This was my 3rd year on ROV but my first year as CEO. This experience has taught me patience. For instance new team members have no experience building ROV's and if I take the time to teach them design and build techniques it improves the experience for the whole team. Teaching also requires time management skills to balance teaching and new work." **Kraig Kreiner**

"As a senior, I felt that I really had two purposes this year. As always, my goal has been to build an effective ROV that is able to perform all of the required tasks. This year especially though I have tried to focus on teaching younger team members and passing on knowledge so that the team can continue to have success in future years. I really feel like my four years of involvement with the MATE ROV competition have come full circle. I remember my freshman and sophomore years when I was learning from the older team members, and I am glad that I have been able to pass the knowledge that I have gained on to the next generation of engineers." **Dennis Smalling**

"With this being my first year on the ROV team, I did not have much engineering knowledge and was rather lost at the beginning of the year. After some mentoring by the senior members I quickly developed my mechanical engineering skills. They taught me how to design and make tools for the ROV to complete tasks and the basics of how the *Nautilus II* functions. This experience on the team has taught me many skills such as operating and designing mechanical parts on a laser cutter. I also learned about time management and how to work with other people in order to get the job done on time. I look forward to learning more next year and learning new skills to use in the field." **Max Ebling**

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Appendix A, Table 2

Budget

Item	Quantity / Notes	Price Each	Est. Cost $
GPS	1	$300	$300
New Plugs/Connectors	20	$50	$1,000
Lengthen Tether to 75 ft	$80 - $200	$80 - $200	$150
HDMI to Ethernet	1	$20	$20
New Sideplates	2	$50	$100
New Diameter Acrylic tube	1 Increase to 6-inch diame	$20	$20
Polypropylene	framework	$40	$40
Acrylic		$50	$50
PVC	various, for mission props		Gift Card
Shrink Tubing	various		$100
Polulus	2 for spares	$80	$160
Arduino			$120
Hardware (Screws/Nuts/etc)	Standard size , ss, 1 box	$50	$50
PS2 Contoller	various spares	$5	$20
Poster Board	design & printing	$60	$60
Possible Sensors/Payload Tools	various, per mission specs		$500
Motor	one spare	$700	$700
MATE registration fee	1	$75	$75
Total, Thru May 2015			**$3,465**
International Competition			
Item	**Cost**		
Crate Transport	Air freight, qty 2	$1,000	$2,000
Teacher	Air & hotel	$1,500	$1,500
Posterboard	1	$60	$60
Total, for International, pending			**$3,560**
Grand Total, incl. Internationl			**$7,025**

Appendix B

List of Figures