ROV TEAM

ROV MATE International Competition 2010

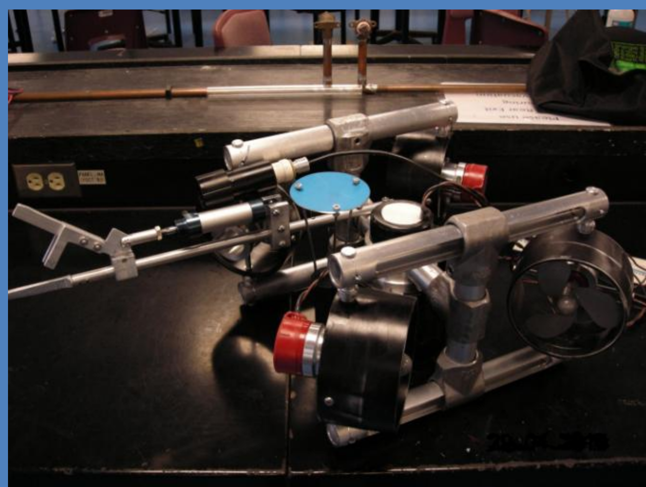

Figure 1: The UVO, ready for action.

Underwater Volcanic Observer

June 24 – 26

2010

Figure 2: Jonathan milling parts.

Figure 3: Cory and Danielle working hard on the LED banks.

Figure 4: Richard cutting vector boards.

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ABSTRACT

The NSCC UVO (Underwater Volcanic Observer) was built to compete in the 2010 MATE (Marine Advanced Technology Education Center) International ROV Competition. The purpose of the UVO is to repair HUGO (Hawaiian Underwater Geological Observatory), collect samples of crustaceans and bacterial mats, record seismic activity and collect temperature data from vents. The UVO was designed with functionality at the forefront. It is mainly constructed of aluminum with a frame that measures 30 cm wide X 30 cm high X 33 cm long. Onboard the UVO there is two pneumatic arms with grippers, five thrusters, three cameras and various sensors. There is transducer on one arm to the record temperature of a venting site. There is also a hydrophone to pick up the frequency of seismic activity. The UVO is controlled by two handmade joysticks designed and machined by the students. All major electronic systems were also designed and manufactured by the students. These features combined will allow the pilot and co-pilot to complete all tasks set forth by MATE. During the designing and manufacturing of the UVO, all members of the team have learned new technical skills, as well as, new communication skills. The completion of this project came about by constantly sketching design ideas, hours upon hours of work by the students' involved and constant communication with all team members.

Figure 5: Clockwise - Sean D, Mentor Glenn MacLeod, Alex Price, Brad Smith, Danielle Roberts, Cory Cauvier, Nathan Gillis, Mentor Peter Oster, Jonathan Kaye and Richard Clark.

DESIGN RATIONALE

TASKS

The theme at this year's ROV competition is underwater volcanoes. With this in mind, the UVO was designed to be efficient, reliable and easy to fix if problems appeared. Our goal is to finish all tasks without having to surface until all tasks are complete, to save on time. In the real world, the longer an ROV is in the water, the more it costs.

TASK 1

The first task requires the UVO to release the HRH (High Rate Hydrophone) by pulling out pins, then lifting and moving the HRH to place it on a site that is "rumbling." The primary mechanical challenge is the placement of the hydrophone in the location of the sound source. The hydrophone will be used to pick up the frequency of the site that is rumbling and display it on a seven segment display at the surface. The hydrophone will benefit from close proximity to the source of audio data. Therefore, they are located on one of the arms to be positioned close to the audio or temperature locations. There will also be a volume bar display to verify the volume of the rumbling. The UVO will also have to take the HRH connector from the elevator and place it inside the HUGO junction box once the cap is removed. A claw or grabbing arm is the first choice to complete this mission. The arm needs to be able to remove the pins holding the hydrophone in place, pick up and move the hydrophone as well as place the power connecter in HUGO.

TASK 2

For task 2, the ROV has to enter a cave and fly to the back wall. On the wall there will be crustaceans, of which the UVO will have to collect three samples. To do this, there are three cameras strategically placed to provide several viewpoints. In the cave there will be little to no light; therefore, the UVO has strips of LED lighting built into the frame for visual clarity. It was decided a separate net arm from the claw arm should be dedicated to collecting crustaceans. This net arm could be specialized to collect and store the samples.

TASK 3

For the vent site sampling mission the claw arm is ideally suited to grabbing and holding anything needed, in this case a sample of a vent.

A temperature sensor must also collect 3 readings from the spires and graph them, comparing vent height and temperature. The sensors for temperature readings will be positioned on one of the arms. The temperature sensor will emit data on a seven segment display on the surface for input into a data table to create a graph.

TASK 4

The collection of agar requires the ability to take a sample of a specific quantity within a restricted geometric area. Therefore, a core sampler with specific dimensions will be plunged into the agar to provide a core sample of a specific quantity.

UVO COMPONENTS

To make this project a success, various tools and equipment were used including CAD (computer aided drafting) software. The goal was to manufacture everything on campus, by the students. Using CAD software helped immensely in the process of designing and building various components. Everything was designed to be budget-wise, completely functional and manuverable. We did this by setting a budget plan and designing and manufacturing our own components. We decided to keep all electronics top-side to reduce the weight of the ROV and make it more manageable underwater.

FRAME

The concept of the initial ROV frame began with the idea of being modular with the ability to quickly repair and change out components. The first major components of the frame were assembled from PVC pipe and connected with Kee Clamps in a basic box shape. After some testing and careful consideration of the mission specifications it was clear that the smaller the frame of the ROV could be, the easier it would be to complete the cave mission.

After further experimentation the PVC pipe was changed to aluminum pipe to increase rigidity while maintaining a low weight. The shape was also changed to take advantage of the aluminum’s strength by using only two H frames connected by the center motor bracket. This shape reduced space restrictions for camera's and tooling within the ROV.

One of the tasks to be completed includes entering an underwater cave. To ensure adequate lighting for the pilots, we installed four LED banks within the frame. Each bank holds 36 LEDs along with an initial current limiting resistor and individual current limiting resistors for each LED. The LED's used are high intensity, which allow 23mA of current. This results in a bright, long lasting LED (refer to Figure 6).

Figure 6: Cory checking to see if all the LEDs are lighting.

BUOYANCY

The original design philosophy from the beginning was to reduce weight on the ROV to limit the amount of foam needed for buoyancy. All the ROV parts were constructed and assembled before beginning buoyancy testing to avoid unnecessary time for modifications after each component was added. During testing, varying quantities of foam were attached until the correct amount of foam was achieved. Once the ROV was neutrally buoyant, the foam was coated with fibreglass epoxy to make it more structural. Additional small blocks of foam were also constructed and covered with epoxy for any situation when a larger incremental amount of buoyancy would need to be attached. Small weights were also prepared to counteract the buoyancy if it later needed to be heavier.

TETHER

The tether from the surface to the ROV is a critical component because the UVO has five propulsion motors and all the electronics controls are topside. The center motor requires 8.4 amps at 12 volts to lift the craft. To send this amount of voltage to the motor a heavy gauge wire had to be used. The horizontal propulsion motors use one power wire per motor and have a shared ground wire with the motor that sits diagonally across from it. For all of the electronic sensors, two CAT-5 cables were sent down to the craft. This type of cable was chosen because it is light weight and each cable contains eight wires. This allowed two temperature sensors, two hydrophones, and two pneumatic switches to be connected, using only the two CAT-5 cables. Tether buoyancy was a major issue because of the inertia created by the weight from the motor cables. To overcome the pulling force created by the added weight, we adjusted buoyancy along the tether.

CLAW ARM

The claw arm for this ROV competition requires the ability to grab specific objects in the water and carry them around. When grabbing structural frames to move around, it would be ideal to grab the object with a claw that would close vertically around the frame. It is possible that it might also be necessary to grab something from the floor or a specific orientation that would require a horizontal closing motion.

To achieve both of these methods of grabbing, a claw design was chosen that will extend and rotate simultaneously (refer to Appendix A). The claw will start with a closing motion near the ROV to maintain craft stability when picking up larger objects like the hydrophone or extend out and rotate to a horizontal closing position.

The actual shape of the claw requires the ability to close around different size PVC framing as well as potentially to grab smaller objects like the pins holding the hydrophone in place. For this a claw with a tip that closes together is combined with a recessed center. The recessed space in the center of the claw is specific to the dimensions of potential PVC sizes in the pool.

In some aspects of the missions it may be necessary to grab an item from the floor of the pool. To prepare for this situation the claw arm is also able to lower to the floor from a neutral horizontal position. All mechanical movements of the claw arm are controlled by the ROV's primary pneumatics actuator system.

NET ARM (crustacean grabber)

Initially the task of grabbing the worms off the wall of the cave was approached with the idea that it would be simple to suck the worms off of the wall and into a storage container. When the dimensions of the worms were inspected more closely it was discovered that the size of any sucking device would need to be too large and powerful. Therefore the approach shifted to a simple net that could have a top that opened and closed (refer to Appendix B).

The idea developed further into a net on an arm able to extend, and open its lid, simultaneously. Once the net arm is extended with the top open, it can sweep worms off of the wall. Once the worms are in the net, the arm will retract and close the lid keeping the worms secured inside. The concept of the lid of the net was further developed to act like individual fingers that would assist in pulling the worms from their hooks. All mechanical movements of the net arm are controlled by the ROV's primary pneumatics actuator system.

THRUSTERS

The placement of the motors on the ROV is within a vector design which uses the combination of different motors to control direction. This method results in the ability to rotate on axis, move forwards and backwards, as well as strafe. This arrangement is combined with one central thruster for up and down movement.

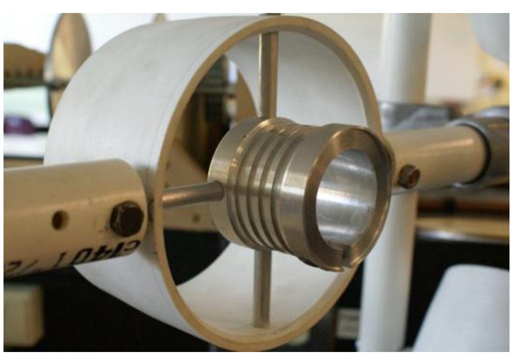

Figure 8: The motor mount and shroud.

The motors selected are Rule bilge pumps. The center motor is a 2000 gph size and the other four motors are 1000 gph. Bilge pump motors were chosen because they are already enclosed in a water tight container. Each motor is held by an aluminum motor mount and surrounded with a PVC shroud for the propeller (refer to Figure 8). The plastic propellers attached to each motor are from pre-existing Coleman trolling motors.

CONTROL SYSTEM

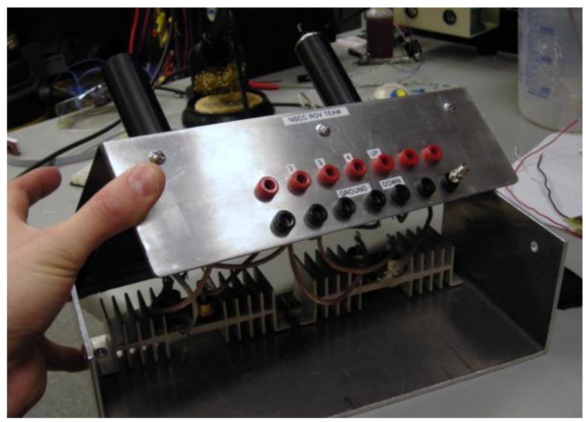

Figure 7: The control box.

The goal for the control system was to keep it simple, but not at the expense of maneuverability. The controls were designed to operate as a skid-steer, such as the steering used in Bobcats and tanks. This type of steering is very intuitive and responsive (refer to figure 7). To design the control system, a student in the Mechanical Engineering Technology program and a student in the Electronic Engineering

Technology program worked close together to meet the needs of the pilot and the UVO. Together they designed a control system that required minimal flight time and experience to master the controls. To reiterate how easy the controls were to operate, children who attended the NSCC Technology Showcase in April were able to remove and insert plastics darts in a board underwater after only a few minutes on the controls (refer to Figure 9). The mechanical students fabricated a base and joysticks for the controls from plastic. The joysticks were mounted over switches that controlled the motors. Pivot pins were milled to allow the joysticks to move freely above the switches. For vertical propulsion, two 10 amp switches were mounted at the top of the joysticks. This allowed for vertical and horizontal propulsion, simultaneously. To be able to operate the propulsion system and arms together switches were installed to be activated by the joysticks for the arms. In order to avoid relays, and keep the electronics simple, high amperage switches were utilized.

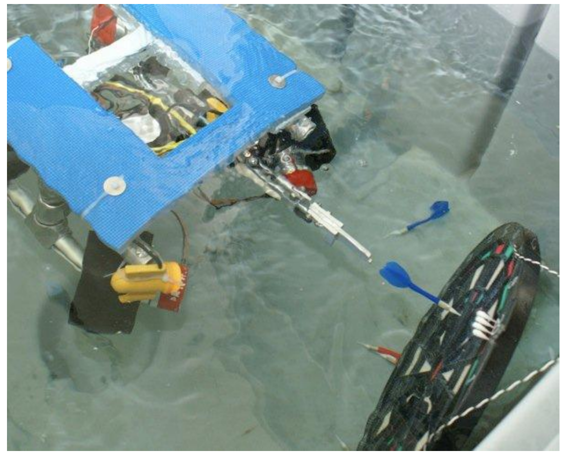

Figure 9: Playing darts.

CHASSIS

The systems chassis was designed to house all the electronic components to keep all the sensory systems out of the water. The circuits and cameras require 12 volts to operate. To achieve this from the supply voltage at the competition of 48 volts, a 48V to 12V converter had to be installed. The center motor requires the use of the 48 volts supply directly through high watt resistors. To provide the power to the monitors, we installed four 12 volt supply plugs. The hydrophone, temperature and pneumatic wiring are all incorporated into two 9 pin plugs. Using these plugs allows for easy removal for troubleshooting. To account for problems that may arise with electronics at any moment, both the temperature and frequency sensory systems are duplicated. This means there are back-ups immediately available should a system fail. For the frequency circuit, an LED volume indicator was installed as well as a speaker to demonstrate the presence of sound. The temperature and frequency sensors will be discussed in more detail below.

CAMERAS

The cameras that were purchased are called "Underwatercams." These cameras are cost effective and provide clear, color images on our LCD screens. There are four cameras on the UVO. One camera is positioned forward for general flying and another camera focuses on the mechanical arms to allow the pilot to have a more accurate view of what the arms and grippers are doing. The third camera is facing a convex mirror and is mounted in the center of the UVO, pointing upwards (refer to Figure 10). This gives the pilot a 360 degree view of the area surrounding the craft. The final camera is a backwards view from the sub which will be most effective in the cave mission.
The monitors purchased are 15" flat screen LCD TVs. The TVs have dual video inputs, so a multiplexer is not needed. A remote came with the TVs, making it easy to switch between camera views. One monitor will be used for the convex mirror camera and the gripper camera; the other screen will be used for the forward and backwards facing cameras.

Figure 10: Sputnik Camera.

SENSORS

For our temperature sensor, we used a transducer and a pic. The temperature is displayed at the chassis on a seven segment display. The temperature sensor can also be plugged into a laptop via USB connector (refer to Appendix G and Appendix H).
To measure frequency, a piezo sensor is wedged in between two pieces of Plexiglas and an o-ring. The sensor is amplified at the bottom and at the top as well (refer to Appendix E and Appendix F).

AGAR SUCTION DEVICE

To acquire the agar sample it was decided to use a sampler with specific dimensions to achieve the appropriate sample size. The core sampler began with two ideas of either a syringe that would suck the sample up; or, a cylinder that would be plunged into the agar with a check valve to maintain suction as it pulled out.

After the first batch of agar was made and experimented with, it was immediately clear that its gelatinous form required the cylinder plunger. To achieve this, a small cylinder, acting as the core sampler, is recessed inside another cylinder. From this position the core sampler is pushed down into the agar. The larger cylinder assists in maintaining structural alignment as the core sampler is plunged into the agar. The larger cylinder also protects the agar sample once it is pulled back inside by having small rubber flaps at the bottom that close around the smaller cylinder when it was pulled back inside. All mechanical movements of the agar suction device are presently controlled by the ROV's primary pneumatics actuator system but may be moved onto an auxiliary pneumatics line in the future.

PRIMARY PNEUMATICS ACTUATOR SYSTEM

The effectiveness of pneumatic compared to electronic actuators was debated and it was decided to stay with an air driven system for the robust nature, and factory sealed components.

Pneumatic cylinders were selected to be the means of mechanical action for any mechanical devices on the ROV. The first pneumatic design tested used three individual two position, five way direction control valves to direct air pressure to the ROV actuators. This design required compressed air to travel through 40 foot air lines before entering any actuator on the ROV. During initial testing of this system, there was a noticeable amount of lag between the actuator response time after the control valve was activated. This system also required as many as six air lines to supply and vent three different movements. This resulted in decreased agility of the ROV due to the bulk on the tether.

A second design was proposed and used after testing with the first design becoming an auxiliary pneumatics system in reserve. The current primary pneumatics system activates multiple actuators on the ROV by using several electronic solenoid valves located on the ROV. This system uses two position, three way electro-pneumatic directional control valves housed on the ROV, in a rigid water tight container. Implementing this design is beneficial because it requires only one air supply line. This single air line to the valve mounting manifold conveys pneumatic pressure across all the valves in the system. To use the actuators, an electronic signal is delivered through a small cable to activate individual actuators on the ROV. All the actuators use a spring return to neutral position to remain stable with the absence of pneumatic pressure.

TROUBLESHOOTING

THRUSTERS

The biggest problem faced by the NSCC ROV Team was vertical propulsion. It all began at the qualifying run in April. On campus, the UVO was tested in a three foot high tub. The center motor worked and moved the craft up and down at an adequate speed. However, when the UVO was placed in the pool to practice before the qualifying run, the extra weight from the water at a depth of more than 5 feet made the center motor inadequate to lift the craft. In order to successfully complete the task, the mechanical students converged and quickly designed a ballast system to lift the craft to the surface.

The students used a plastic bottle and attached a pneumatic hose to it, so when the UVO was ready to surface, the co-pilot filled the bottle with air from a compressor which made the craft rise. The following day the team convened and decided to use a larger motor to propel the UVO to the surface.

After testing a new motor at various depths, the team decided even more lift was required. Without fully understanding the problem the team decided on fabricating a new propeller. The mechanical students immediately got to work and had a new propeller installed and ready to go. The UVO was placed in the pool again, but the propeller made the situation worse. The whole team went back to the drawing board again.

Electronic students examined the voltage drop across the motor and realized that there was not a significant amount of voltage getting to the motor. Various methods were discussed to resolve the situation. To ensure an adequate amount of voltage would get to the motors, the 48V to 12V converter was removed to utilize the full 48 volt supply. An 8 ohm, 100W resistor was used to limit the current and voltage to the motor. After more testing, there was still a lack of voltage to the motor. It was discussed that most of the voltage may be dropping across the wires. To test this theory the wires were doubled up and the UVO was thrown back in the pool. There was an immediate improvement. The final solution was to use the full 48V with high power resistors.

The motors used on the UVO are from bilge pumps and are sealed in their own water tight container; however, during assembly the motor mounts appeared to squeeze the cases causing several to crack. Initially the cracks were very hard to locate because they often encircled some of the natural geometry of the case. Once the cracks were located, they were sealed to prevent further leaking. To ensure the ability to easily remove water from the motors if more water did enter them, removable plugs were put into the cases. This allowed the plug to be removed and the water drained if needed.

Another aspect of the motors that required some thought was how to follow the plan to have each motor remain modular for quick removal if not operating properly. The most difficult task was how to enable the propeller to be removed quickly. Eventually a design was created that used a quick release pin to allow the propeller to be removed quickly without tools.

CAMERAS

The original testing of off the shelf submersible cameras provided room for improvement. Some of the purchased cameras started to fog intermittently and resulted in the manufacture of two new underwater camera cases. A new delrin housing was designed and constructed with anti-fog coatings and quick exchange terminals to allow for rapid replacing of all components in case of failing (refer to Figure 11). Testing to a depth of 30 feet exposed flaws in the o-ring gland design. To determine the exact location of the leak, the camera housings were slightly pressurized while submerged until bubbles formed revealing the exact location. After consulting a mentor new o-ring gland dimensioning proved to be a solution to camera sealing and the problem was resolved.

Figure 11: Camera housing.

CHALLENGES FACED

SAMPLING THE AGAR

The ability to core sample the agar required careful consideration. Using a simple check valve to close the core sampler at the top and create a vacuum had some potential flaws which required awareness by both the design team and the eventual ROV pilot. When pushing the core sampler into the agar, it required the most force initially to break the surface tension. Once it began to cut through, it would continue easily into the agar without much further force. Several ideas were examined for a method to improve the ability to break the surface tension. In the end the most reliable way was to ensure that enough initial force directly perpendicular to the surface of the agar with a backup plan of rotating the ROV slightly if needed to “screw” the core sampler in to the agar.

FRAME WEIGHT

It was very important to our team to reduce weight to enable as little extra foam as possible. Going with the aluminum frame did increase rigidity but also weight slightly. It took awhile to realize the current frame structure would be possible and reduce the weight significantly. Other initiatives such as removing weight from the aluminum pipes by turning their radius down as well as milling out some of the weight from the Kee Clamps helped as well.

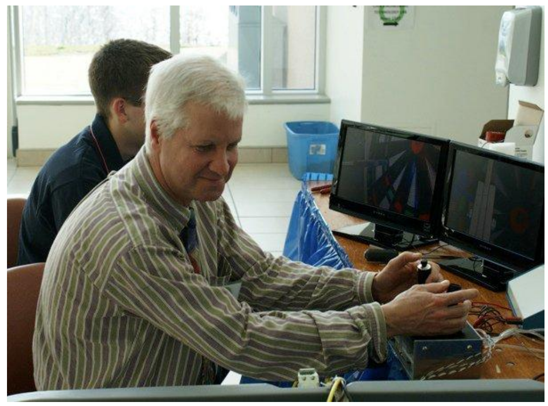

Figure 12: Our mentor Stephen McCarron at the helm at the NSCC Technology Showcase.

FUTURE IMPROVEMENTS

FRAME

One potential future improvement would be to construct the structural frame of the ROV from epoxy coated foam. This would greatly increase the buoyancy initially, and allow for a structural design in any shape desired. It would also increase the effective power output of the ROV by having a lighter frame weight.

COMPONENTS

More research could have been done on the specifications of different components. For example, if close attention had been paid to the spec sheets for the motors, it would have saved the team time on troubleshooting because the spec sheet stated the wire would have to increase in gauge as the length of the wire increased.

LESSONS LEARNED/ REFELECTIONS

Each member of this ROV team had different strengths to bring to the team dynamic when the year began. As a result, each person learned different lessons from each other as well as from the construction of the ROV.

Particular aspects of design such as spending more time on design than construction to begin with, rather than spending time building something that does not work, is a lesson some team members learned quickly.

Another component related to construction that was challenging and educational was sourcing components needed to construct particular components of the ROV.

Overall, this year's ROV Team has been exceptional. The whole team was able to come together and accomplish great things.

PISCES V AND THE LO'IHI SEAMOUNT

In the summer of 1996, there was a bustle of activity off the shores of Hawaii. The largest number of earthquakes ever recorded at any underwater Hawaiian volcano occurred at the Lo'ihi Seamount in a period of three weeks. In response to this, a Rapid Response Cruise was dispatched that was funded by the National Science Foundation. This cruise assessed the immediate risk of danger to the Hawaiian shoreline.

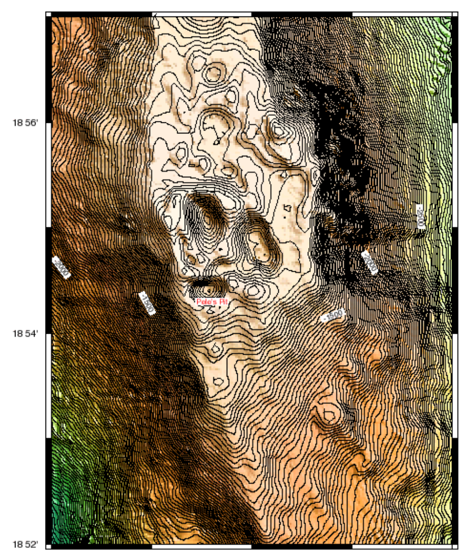

Figure 13: Topography of the Lo'ihi Seamount. http://www.soest.hawaii.edu/HURL/Q199.htm

After the initial cruise, more cruises were dispatched to study the impact the earthquakes had on the seamount. It was discovered that new craters had formed, which in turn transformed the topography and biology of the area (refer to Figure 13). HURL's (Hawaii Undersea Research Lab) Pisces V was used to investigate the Lo'ihi Seamount and collect data and samples.

Figure 13: Bacterial mats viewed from an ROV.
http://www.soest.hawaii.edu/HURL/hurl_loihi.html

The Pisces V is a deep diving submersible craft capable of reaching a depth of 2000m. It can house three people and provides various means of collecting information. The sub has cameras to record the dive as well as various viewports and instruments at hand. There are also two mechanical arms used for various tasks including dropping sensors to measure frequency and temperature. As scientists were exploring the seamount, they noticed large mats of bacteria floating the water (refer to Figure 13).

Figure 14: The Pisces V.
http://www.soest.hawaii.edu/HURL/hurl_loihi.html

In conclusion, the UVO was designed to be able to complete all tasks at once with all the necessary equipment onboard the craft. The Pisces V is so well adapted for its research; the UVO was designed to model the Pisces V in theory.

REFERENCES

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http://www.soest.hawaii.edu/HURL/Q199.htm
http://www.soest.hawaii.edu/HURL/hurl_loihi.html
http://www.soest.hawaii.edu/GG/HCV/loihi-summary.html
http://oceanexplorer.noaa.gov/technology/subs/pisces/pisces.html

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- Ian Dempsey for his flexibility and cookies
- Parents and families of the team for their support and patience
- Classmates for their help and advice
- Our generous sponsors:
    - NSCC and faculty
    - Deep Vision
    - RAE Electronics
    - Jentronics
    - Allendale Electronics
    - Kelly Regan – Bedford MLA

NSCC ROV BUDGET

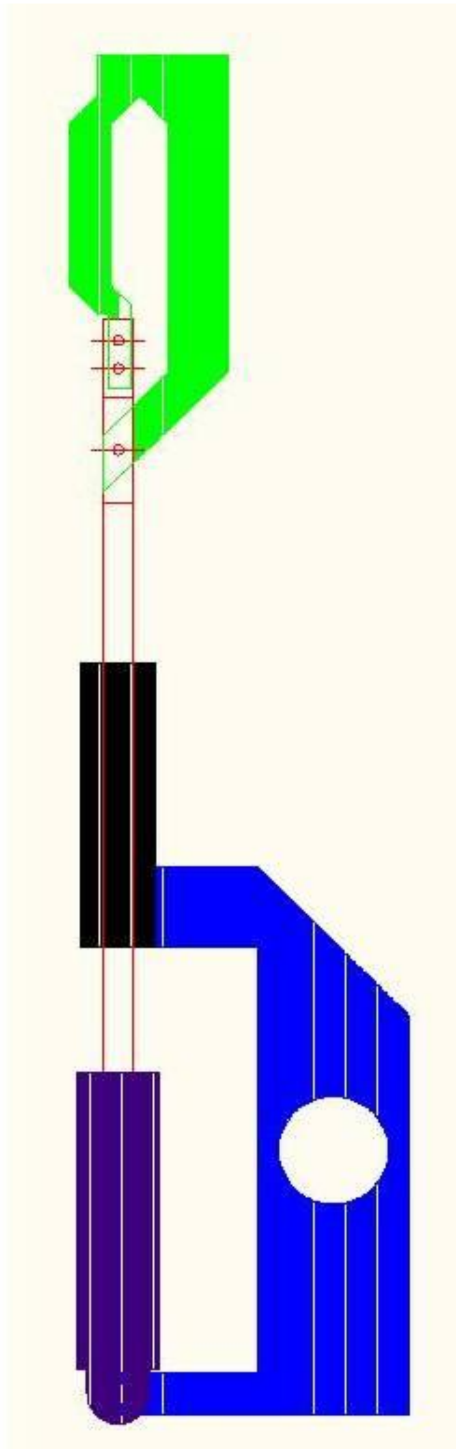
Building Supplies	Store Purchased	QTY	Cost	Donated
Control Box				
Top Casing	Piedmont Plastics		$21.09	
Bottom Casing	Metals "R" US		$45.58	
Joysticks	NSCC	2		$25.00
Switches	Digi Key	10	$68.76	
Diodes	NSCC	4		$6.00
Wiring	NSCC			$4.00
Heat Sinks	NSCC	2		$10.00
Pivot Pins	Metals "R" US			$3.67
Bolts	NSCC	4		$1.50
Power Plug-in	NSCC	12		$7.20
Instrument Box				
Casing	NSCC	1		$23.00
DC to DC Converters	NSCC	2		$320.00
Amplifiers	NSCC	2		$50.00
Speaker	NSCC	1		$3.00
12V plug-in	NSCC	4		$4.00
Fuse Holder	NSCC	1		$2.00
Fuse	NSCC	3		$0.50
Temperature Circuit and Components	NSCC	2		$90.00
Frequency Circuit and Components	NSCC	2		$90.00
Hydrophone				
Lexan Polycarbonate	Piedmont Plastics	2' x 2'	$23.56	
Nuts and Bolts	NSCC			$3.00
Pizo	NSCC	2		$2.00
Wiring	NSCC			$1.00
ROV Motors and Frame				
Horizontal Propulsion				
Motors	NSCC	6		$190.00
Motor Housings	NSCC	5		$500.00
Shroud Pins	NSCC	20		$6.00

Motor Rotation Sleeve	NSCC	8		$40.00
Bolts Rotation Pins	NSCC	8		$35.00
Set Screws	Fastenal	16	$2.34	
Propellers	Coleman	6	$31.45	
Prop Adapters	Metals "R" Us	6	$4.45	
Shroud	Northern Plastic Supply	1	$5.00	
Vertical Propulsion				
Motor	Binnacle's Marina	1	$156.67	
Motor Housing	NSCC	1		$75.00
Center Housing Bolts	Fastenal	6	$1.16	
Shrouds	Northern Plastic Supply	4	$20.00	
Frame				
Metal Tubing	Metals "R" Us	6'	$15.45	
Acrylic Tubing	Piedmont Plastics	6'	$11.56	
Clamps	Metals Plus	6	$90.45	
LEDs	Digi Key	200	$84.56	
Perforated Circuit Board	Digi Key	1	$30.34	
Resistors	NSCC	124		$5.00
Wiring	NSCC			$4.00
Tether				
Motor Wires	NSCC	6 X 45'		$27.00
Data Wire	NSCC	90'		$35.00
Motor Wire Connectors	NSCC	2		$2.00
Date Wire Connectors	NSCC	2		$2.00
Cameras and Monitors				
Yellow Fish Camera	Ebay	3		$240.00
Black Camera	Ebay	1		$80.00
Black Camera Housing	NSCC	1		$40.00
Waterproofing adapter	Home Depot	1	$1.86	
Mirror	Walmart	1	$2.36	
Mirror Holding Rods	Metals "R" Us	3	$1.34	
Mirror Holding Nuts	NSCC	3		$0.60
Pneumatics				
Solenoid	Clippard	4	$157.89	
Tubing	Clippard	100'	$12.67	
Rams	Metal "R" Us	4		$250.00

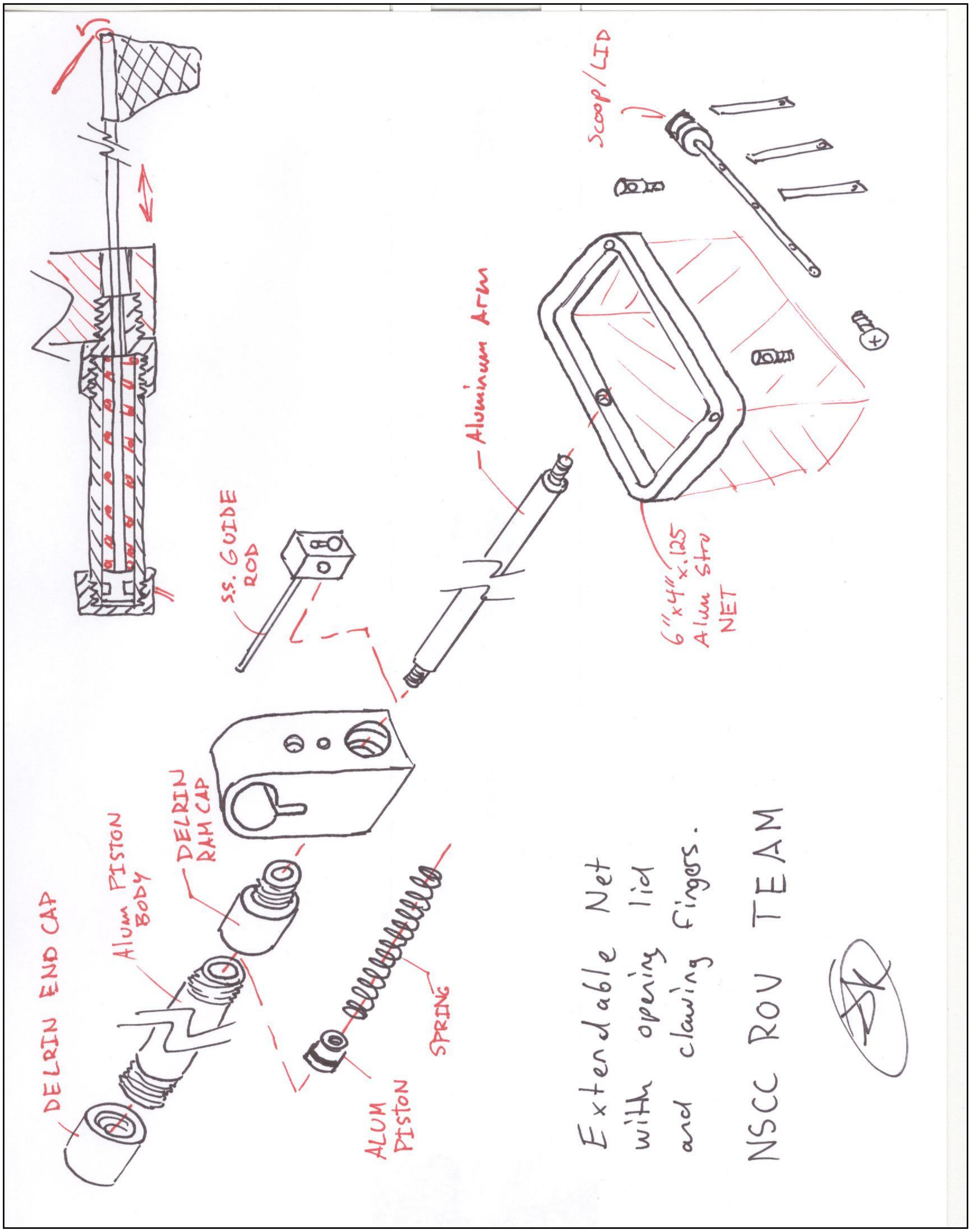
Tools/Parts Kits				
Digital Caliber	Prince Auto	1	$25.68	
O-Ring Kit	Strickly Hydraulics	1	$27.75	
Epoxy	Burnside Fibroglass	1	$70.87	
Zip Tie Kit	Canadian Tire	1	$23.70	
LCD Monitor	Best Buy	2	$345.86	
ROV Manufacturing Costs				
Total Purchased			$1,282.40	
Total Donated				$2,177.47
Total Cost of ROV			$3,459.87	
Traveling Costs				
Airfare	Air Canada	6	$4,800.00	
Accomodations	Hotel		$800.00	
Shipping			$1,000.00	
Food	Campus Food Plan	6	$1,200.00	
Van Rental		1	$600.00	
Miscellanous			$600.00	
Total Budget				$12,459.87

APPENDICIES

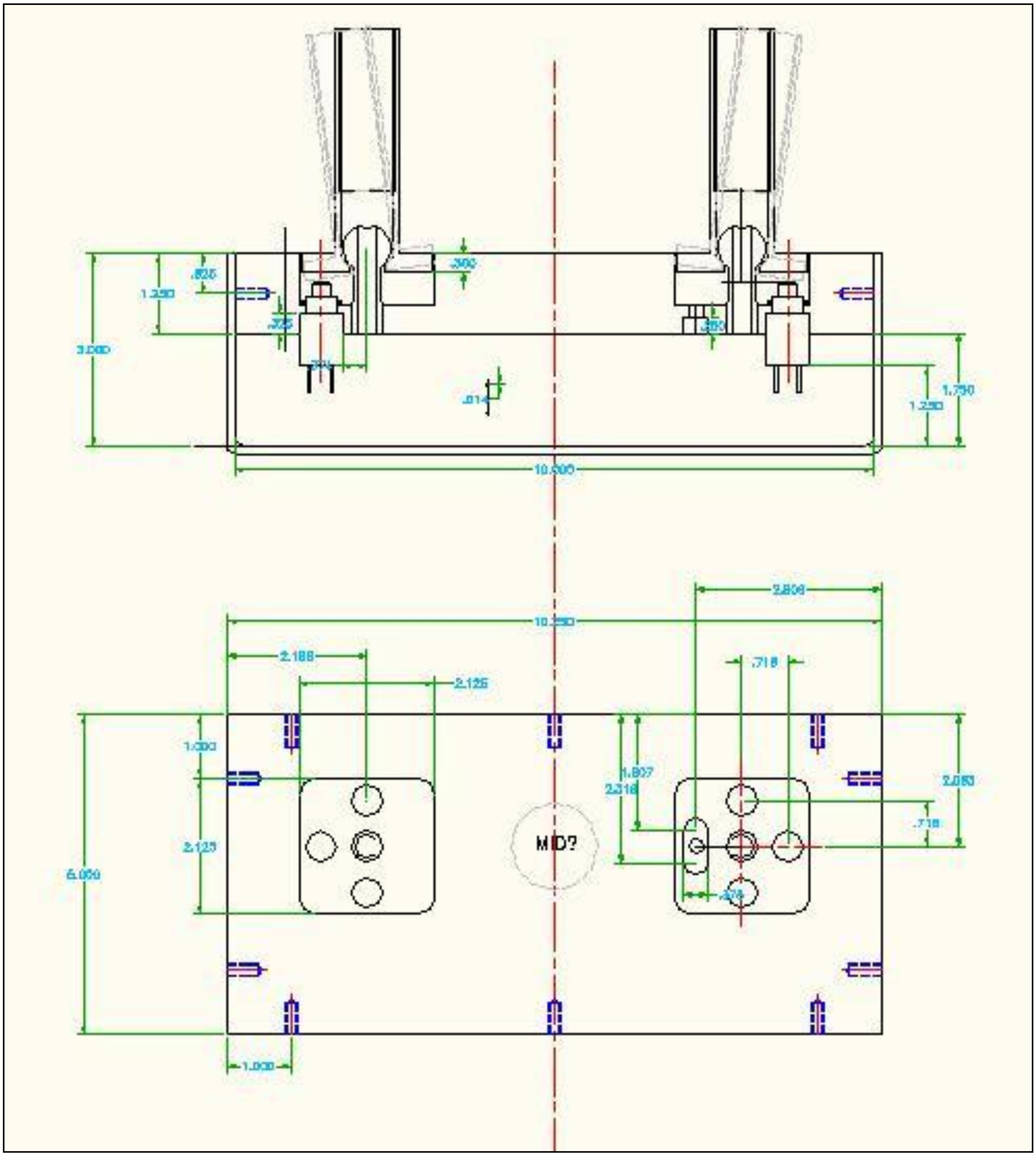
Appendix A – Claw Arm



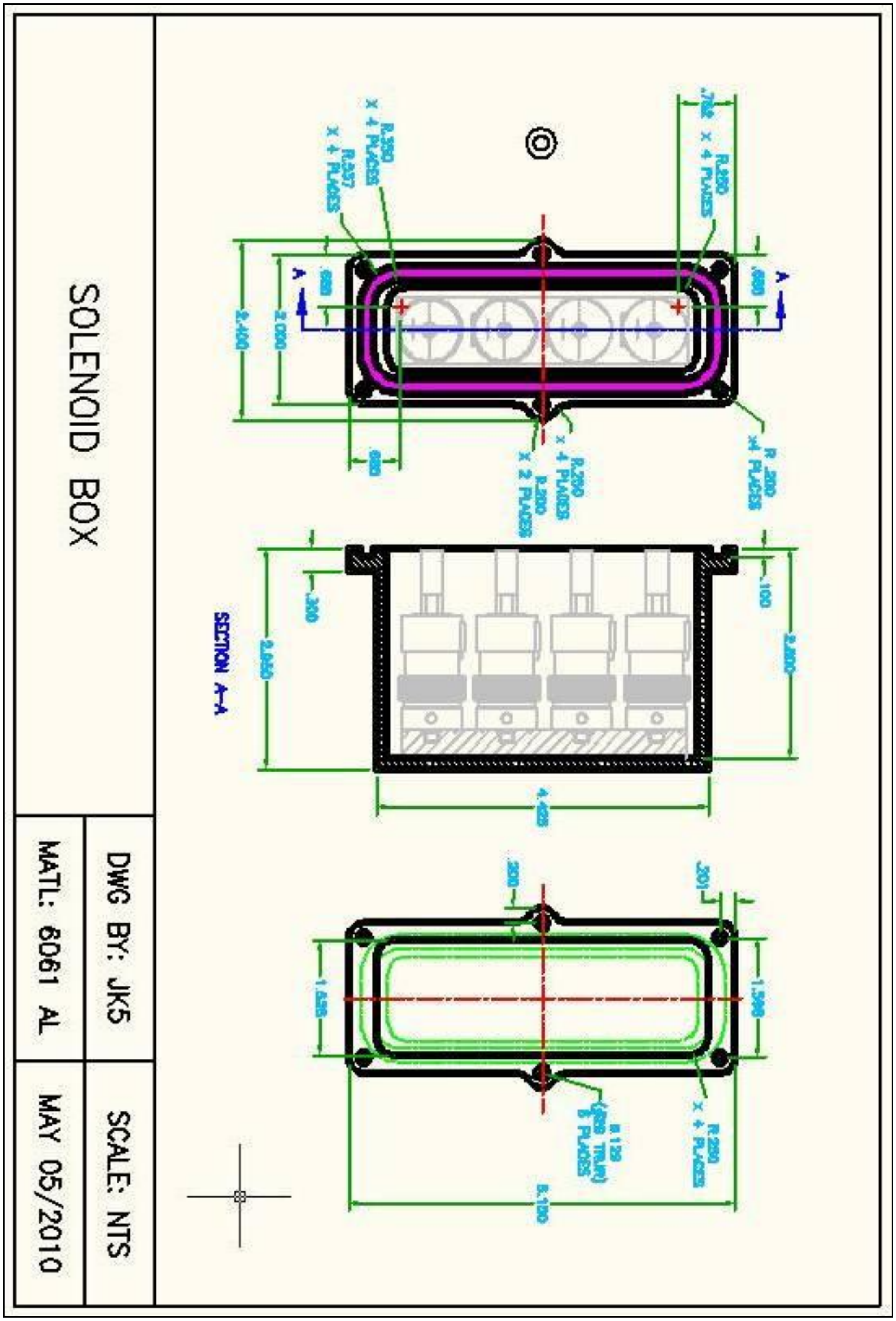
Appendix B – Net Arm



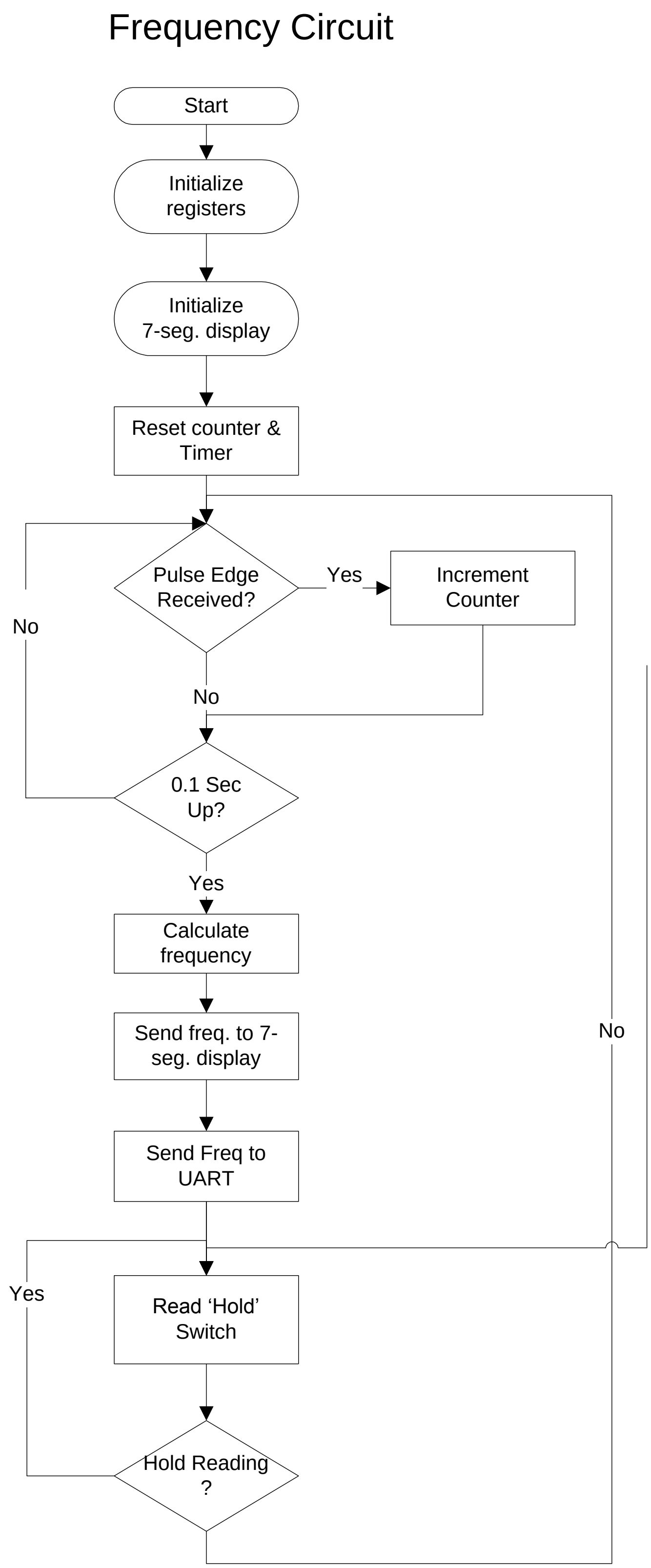
Appendix C – Control Box



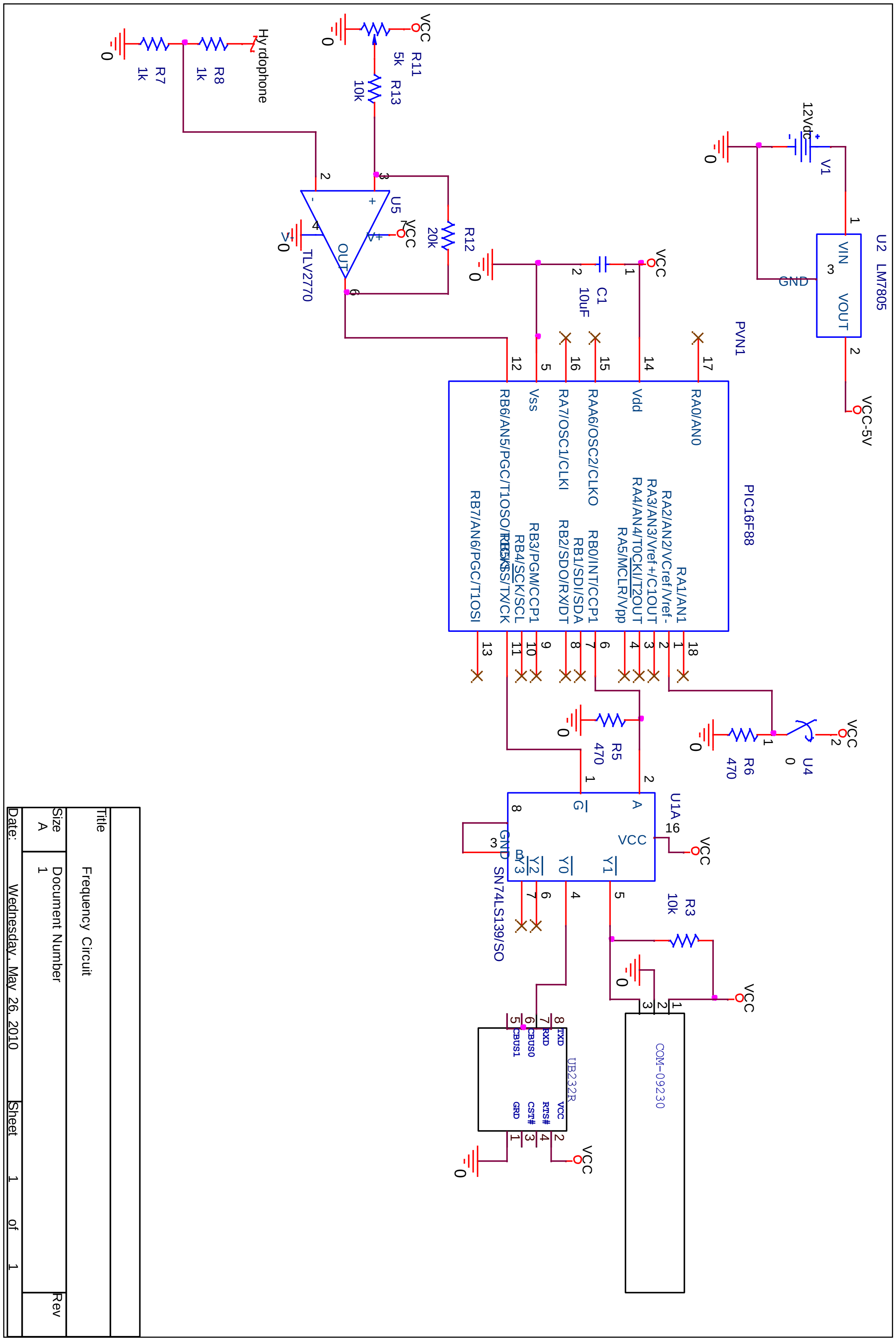
Appendix D – Solenoid Box



Appendix E – Frequency Circuit Flowchart

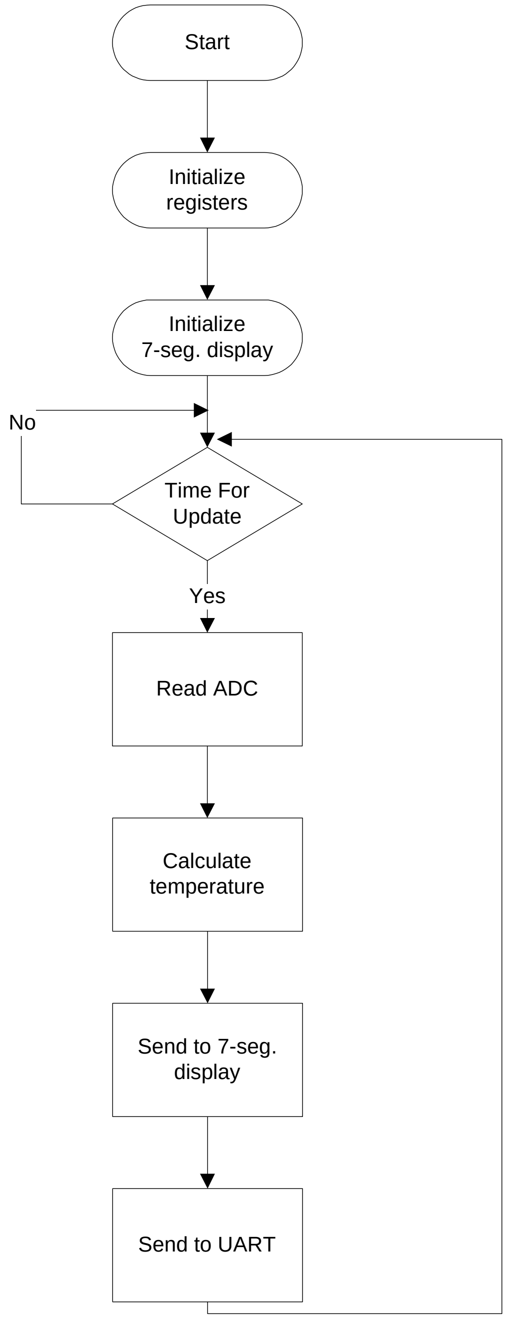


Appendix F – Frequency Circuit



Appendix G – Temperature Circuit Flow Chart

Temperature flow chart



Appendix H – Temperature Circuit