ENGINEERING

MECHATRONICS AND
ROBOTICS TECHNOLOGY

Vicious Submarines
The Electric Brick
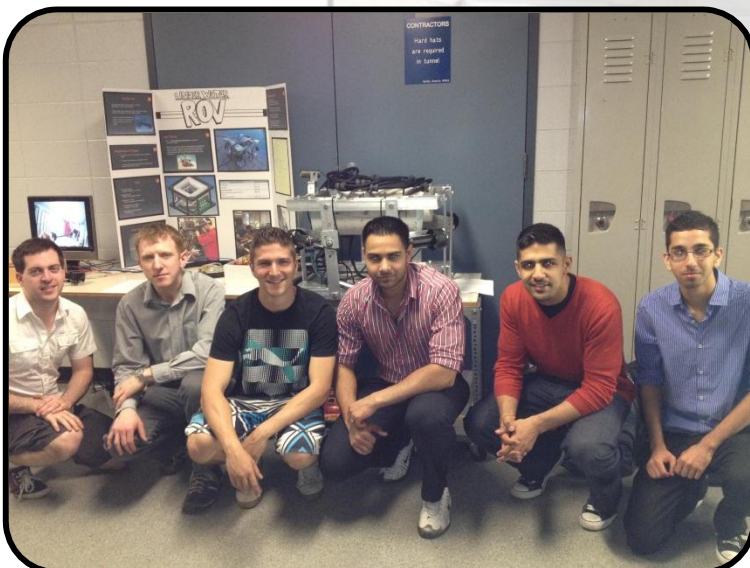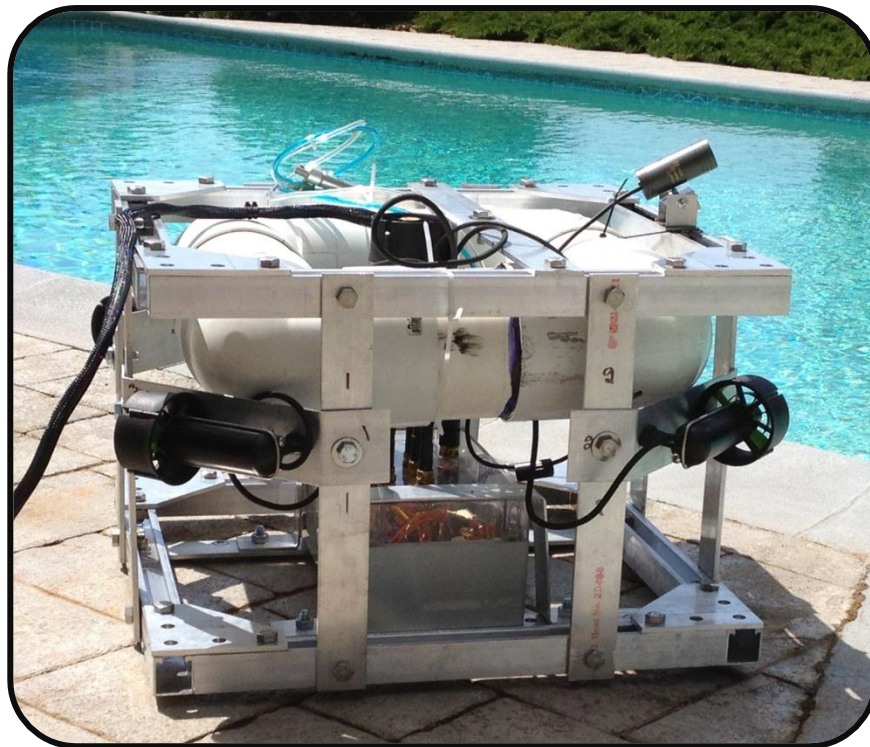
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Table of Contents

Figure 1: Picture of ROV Poolside

Introduction

As specified by the MATE Rover competition, an ROV was to be designed to be able to complete a series of tasks. These include: scanning simulated sensors, distinguishing between metal and non-metal debris, transplanting a mast, extracting fuel, transplanting coral, determining the ships orientation, and determining the overall length of the ship. In order to complete these tasks the ROV needs 6 main systems to be included such as a propulsion system, a fuel extraction system, a gripping device, and an onboard isolated electrical system all incorporated into frame and connected to a controller. This system will accomplish the task of the simulated sensors determining the ships orientation and overall

length by using cameras. The length will be determined by triangulation with the known distance of two points on the ROV in view of the camera and of a known distance apart. The orientation will be determined by positioning the ROV in line with the end of the ship where it will hold a stable position, a screen shot of the display will be taken and then measured with a protractor. The simulated sensor will be accomplished by the vertical thruster which has proportional control to allow it to hover. To be able to distinguish between metal and non-metal debris an inductive sensor will be used. In order to be able to extract the fuel, a pneumatics system was designed that actuates a cylinder causing salt water to be forced into the tank, which then causes the less dense oil to flow through a return line into two inflatable bladders with a main storage and a judge storage sample. Finally, both the transplanting of the coral and the mast will be accomplished by a pneumatically actuated gripper. All of these tasks are controlled by a PS2 remote, through a cat5 tether cable through to the inside of a Polycase container and electrically relayed onboard.

Abstract

This report provides details regarding the design, fabrication, and testing of an underwater remotely operated vehicle (ROV) by the mechanical and mechatronics technology students at BCIT. The main objective was to construct a fully functioning ROV capable of fulfilling all of the tasks set out by the MATE competition by incorporating a pneumatic arm, fuel extraction system, propulsion system as well as electronically controlling these systems through a tethered connection above the water. ROV's can be repurposed for various applications underwater including offshore hydrocarbon extraction, biological research and exploration, as well as pipeline maintenance, welding and extracting fuel from sunken shipwrecks . This ROV was mainly designed for the safe extraction of fuel from shipwrecks on the ocean floor. This is potentially a very dangerous threat to mankind and marine life if one of the hulls were to burst and leak oil because it would kill off all wildlife and plant life in the area which would in turn harm an invaluable food source for many people. The ROV is designed using aluminum c-channeling, a waterproof Polycase electrical components box and various machined mounting brackets. The ROV utilizes five Seabotix thrusters in such a configuration that allows it to strafe left and right, move forward and backwards, rotate in either direction, and well achieve full vertical motion. The fuel extraction system utilizes a 5-3 pneumatic valve to coordinate simulated seawater to be pumped into the tank at the same that the fuel is being extracted and collected into two separate inflatable bladders. The ROV is also equipped with two grippers actuated by pneumatic cylinders which allow the ROV to pick up and re-locate small items. To tie the system together three separate video cameras are allocated to allow the pilot to see what is in front of the ROV, see what is being picked up by the gripper, and at the inflatable bladders to ensure proper actuation of the fuel extraction system.

Budget/Expenses

Electronic Components

# Req'd	Navigation System			
	Name	Source	Cost per unit	Cost
1	Arduino Mega	Sparkfun	$70.00	$70.00
5	High power Motor drivers	POLOLU	$60.00	$300.00
5	Marine Thrusters	BCIT	$650.00	$3,250.00
3	Camera	BCIT	$500.00	$1,500.00
	Wires, Transistors, etc.			$80

Pneumatic Components

# Req'd	Navigation System			
	Name	Source	Cost per unit	Cost
4	Control Valves	Festo	$150.00	$600.00
5	Other valves	Festo	$75.00	$300.00
4	Miscellaneous	BCIT	$100.00	$400.00

Total Cost for building ROV

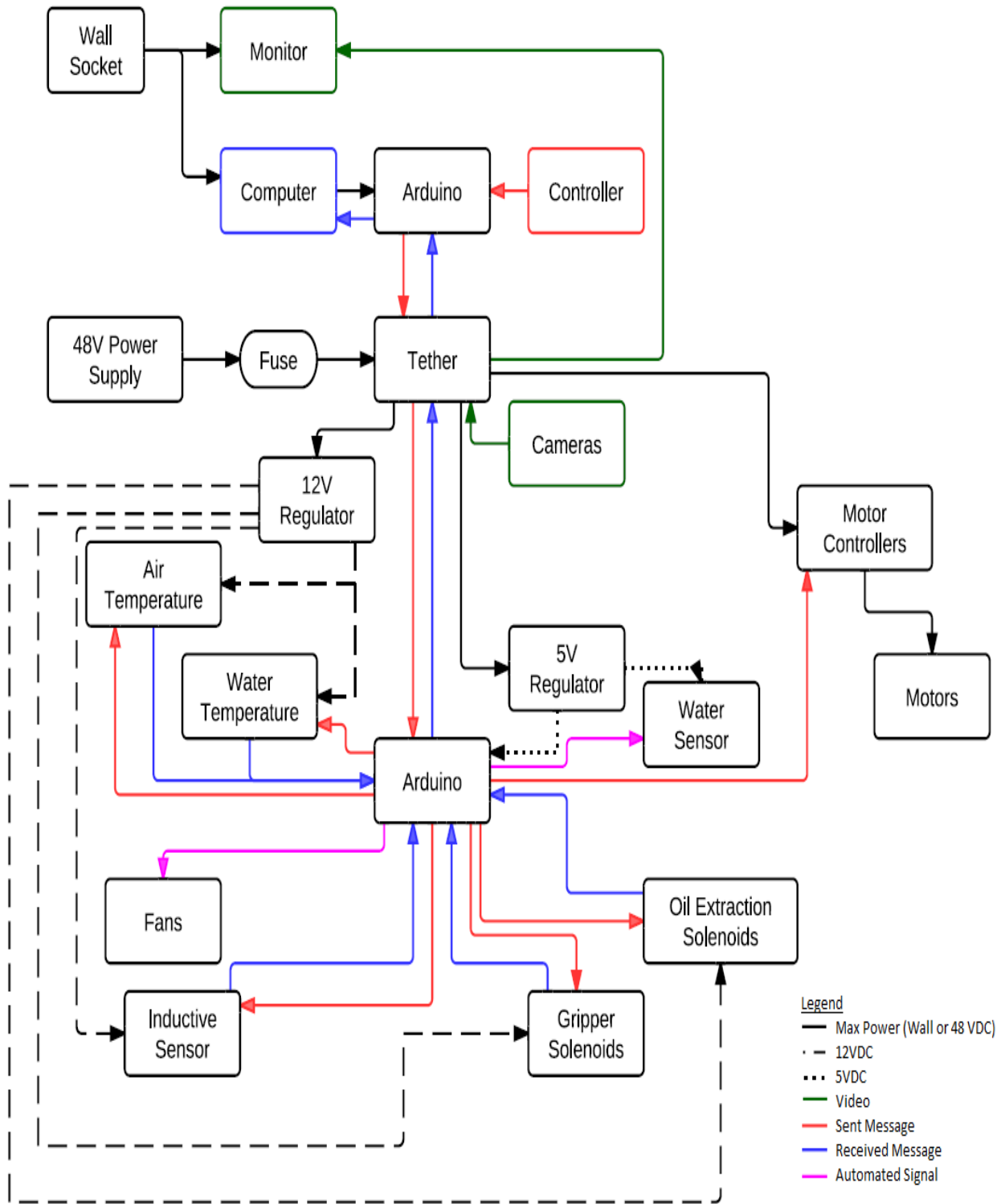|	Price (CAD)
Electronic Components	$5200
Pneumatic Components	$1100
Frame and Misc. Parts	$1000
Total Cost	$7300

Electrical Schematic

Figure 2: Electrical Schematic

Vehicle Systems/Design Rational

Chassis

The chassis for the ROV was built using standard Unistrut aluminum C-channels. Aluminum was chosen because it is non-corrosive, light weight, and easy to machine. BCIT's machine shop has an abundant supply of aluminum in various sizes so that the brackets that were needed to attach the c-channeling, thrusters and the electrical components box were able to be made relatively easily. A company called Pacific Fasteners was used to supply the ½" stainless steel bolts and nuts required to hold the frame together. The fact that the frame could be easily modified allowed a great deal of freedom when doing balancing and buoyancy testing later on in the design and fabrication process. Before being assembled, the Unistrut and custom machined parts were modeled and assembled using Autodesk's Inventor software. All the components that were to be mounted on the frame including the Polycase boxes and thrusters were modeled in order to ensure that the frame is adequate size. The total overall dimensions of the ROV consist of a 2 foot by 2 foot square base that is 1.5 feet tall. The frame and components were also modeled using their respective materials so that an estimate of the ROV's mass could be obtained. This mass value provided a starting point as to how much room to leave for floats that will be required for slightly positive buoyancy (this was an iterative process).
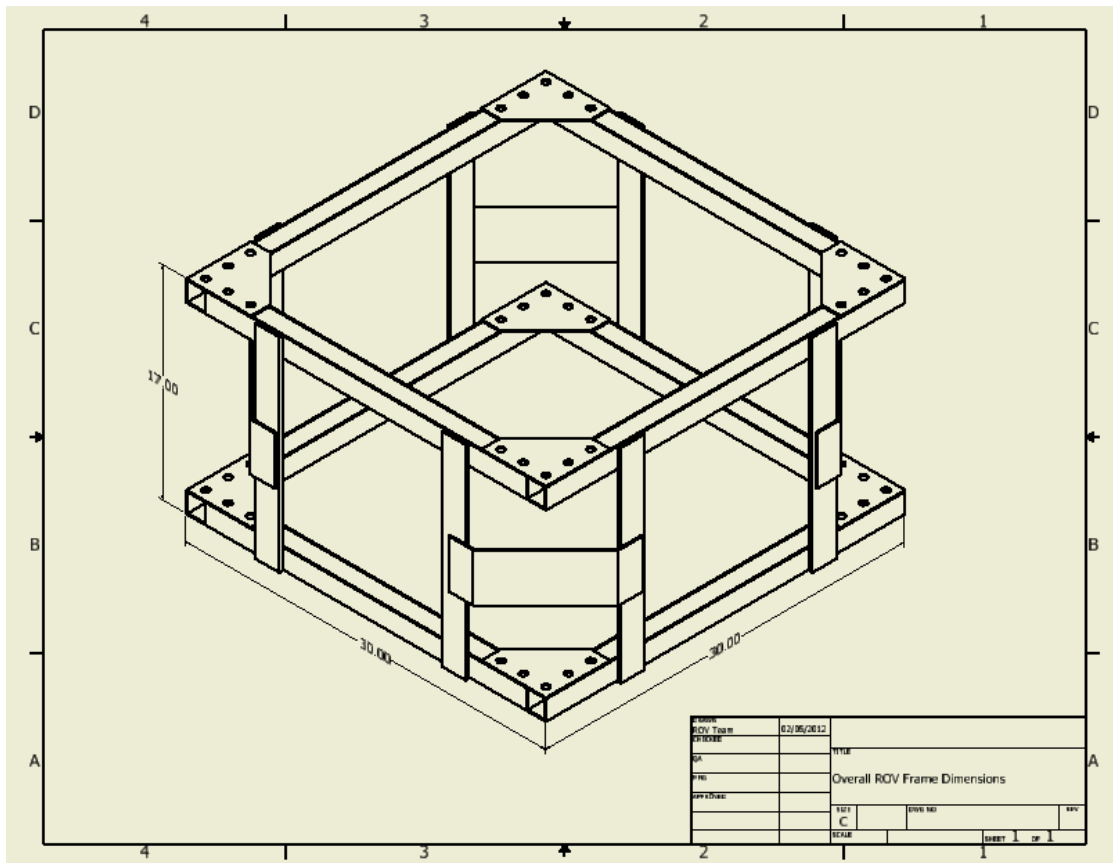

Figure 3: Autodesk Inventor Model of Frame

Submersible Boxes for Electronic components

The ROV employs electronical as well as pneumatic systems in order to accomplish the required tasks. The overall volume required to house the water sensitive electrical and pneumatic components was calculated in order to determine the size of enclosure that would be needed. It was decided to use a Polycase enclosure because they are made of polycarbonate plastic which is easy to work with and the large enclosure (WC-44) has a transparent cover which makes it easy to inspect the components. They are designed for electronic components so they have pre-bored holes that can be used to secure racks. The boxes were also modeled in Autocad and a uniform pressure of 30psi, which corresponds to the approximate pressure at a maximum operating depth of 50 feet, was added to all surfaces in order to determine the maximum deflection that would result using FEA software. Two Polycase enclosures are utilized for this design; one is for the electronic components and the other box is used for the pneumatic components.
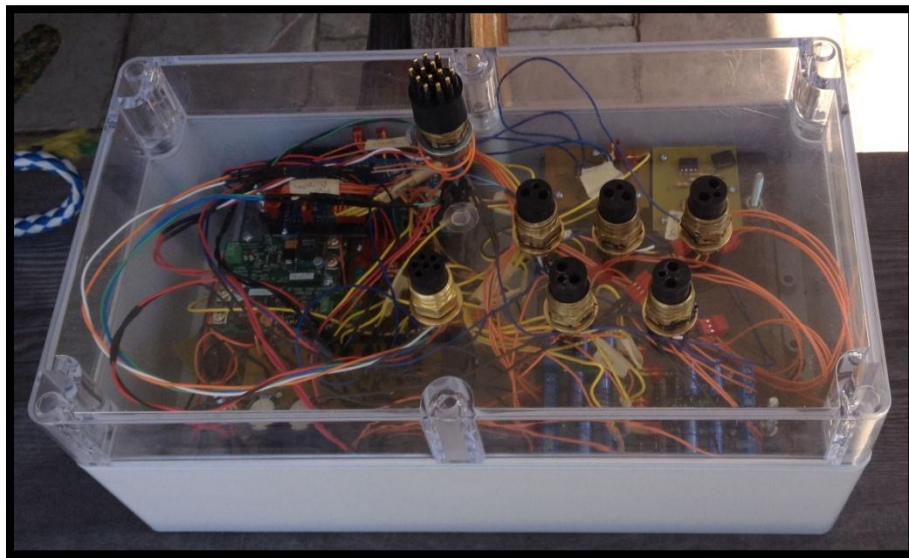

Figure 4: Assembled Waterproof Container for Electrical Components

Control System

Two Arduino Mega 2560 were chosen as the microcontrollers for our ROV. Based on the initial design of the system, a number of parts were going to require serial connections and the Mega was one of the only microcontrollers to contain multiple serial ports. They were kept after a number of design changes since they can communicate to one another using one serial port and troubleshooting may be done at the same time with a computer attached to a second port. User input is gathered by a repurposed Playstation 2 controller. This controller was chosen since it is familiar to the operators and has variable positions useful for variable speed control. There is a readily available open source library for the PS2 controller to allow interface it with the Arduino. The motor controllers are Polulo high power motor controllers which step up 5V PWM signals from the Arduino to 48V PWM signals to the motors.

The software written to control the ROV has safety at the forefront. The directional motors will shut off after ½ second without a signal received from the surface. This gives accurate control over the position without overshooting the desired position too much. If no message is received for ten seconds, the power to all of the motors is cut. This is a safety precaution so that if no control message is received, the sub will float back up to the surface. There is a safety measure implemented if water is detected in the electrical box to send warnings to the surface. Also, if the temperature in the box reaches a set high point, cooling fans are turned on until a critical temperature is reached and warning messages are sent to the surface.

Stability

The ROV was built with symmetry in mind in order to ensure that the center of mass would coincide with the center of the frame. The initial ballast was sized according to calculations which used the mass obtained from the Inventor software. Due to the inexperience of the team members, it was decided that the buoyancy should be overstated and corrected later by simply adding weight. Once the frame was built, a testing tank at BCIT allowed the balance and buoyancy adjustments to be made. The structure was weighed on a scale and an adjustment was made to use a 2 foot length of 6" PVC pipe as a float. The Unistrut C-channel struts were used to house ¼" square bars of steel in them at various places until the structure remained horizontal and had slightly positive buoyancy.

Movement

Four Seabotix thrusters were positioned on the corners of the ROV's frame in a diamond pattern to allow it to strafe left and right, move forward and backwards, and rotate in either direction. A thruster mounted vertically in the center of the frame controls the up and down movement of the ROV. Also, since the ROV has positive buoyancy, this assists motion when rising to the surface.

Gripper/End effectors

Two independently operated grippers are attached to arms that are aligned with either side of the ROV. The gripper's primary function is to so that they can approach the coral piece from the side rather than the front. The grippers will be operated by double acting pneumatic cylinders. The team utilized standard gripping tools that were modified so that the gripping action can be made by pneumatic actuators.

Fuel Extraction System

The fuel extraction system is designed to remove simulated trapped oil from a sunken ship and replace it with salt water. In this task, the oil is actually colored water thus giving salt water a higher density. The team will take advantage of this by simply pumping salt water into the container. This will be done by attaching a pneumatic line to a 2L reservoir containing salt water. The pneumatic line will increase the pressure in the reservoir and force out the salt water into the colored water container.   The less dense colored water will be forced out and replaced by the more dense salt water and will exit out of the container through a line that is connected to a sequencing valve. The purpose of the sequencing valve is to ensure that a 150ml sample is collected in a bladder before the remaining extracted colored water is switched to a line that feeds into a reservoir which will collect the remainder.

Challenges

One of the challenges we faced was working together as a group, particularly since our group includes members from both BCIT's Mechatronics and Robotics program and BCIT's Mechanical Design program which have their own different schedules and requirements. The way we solved this problem is with weekly meetings to brief our teammates on progress and upcoming requirements.

Another problem we solved involved testing of the ROV system. During the first few tests there were issues with buoyancy and the electronics. We solved these issues by using the materials at hand until more permanent fixes could be arranged. For example during the first test we used patio bricks hung in shopping bags to balance the ROV and achieve neutral buoyancy. Also during the first test we had to bypass power from secondary circuits to critical circuits including our surface arduino. During another field test we had to swap circuits to replace a circuit that had been damaged.

Troubleshooting Techniques

When troubleshooting we have found it best to proceed in a logical fashion, starting with the area or connections local to the problem and then moving outwards to the surrounding systems. For example during one ROV field test we found our ROV was not responding to commands. First we verified that the ROV was receiving power, then we checked the control circuitry where we found that the microcontroller was connected incorrectly. Once that issue was fixed we tested it again only to find there was still no response. Upon further inspection we found that a peripheral circuit was plugged in backwards, effectively shorting the power to the thruster and preventing any current from reaching them. We have prevented this from happening in the future by creating better documentation regarding setup and connections.

Our general philosophy is to test our concepts, our components, our subsystems and our complete ROV system, particularly after any changes are made. This has led to the detection of problems before they can affect the system as a whole and allowed us to verify that the different components function together to accomplish the required tasks.

Payload Description

The two main payloads on our ROV consist of the pneumatic fuel extraction system and pneumatically actuated grippers. The fuel extraction system is controlled by a 2-2 solenoid actuated spring return valve so that when an electric impulse is sent into it, the valve switches position allowing pressurized air to flow into the cylinder which is attached to a baffle at the top of the reservoir. As the cylinder extends water flows through a check valve so that no fluid is allowed to flow back into the system. Water then passes through the flow control valve and into the tank ensuring that the maximum system pressure doesn't exceed 40 psig. On the extraction line, a pilot operated check valve is used so that water is not able to flow into the extraction tanks (inflatable bladders) until fluid is being forced into the tank. There are also two other pilot operated check valves controlled by an additional solenoid valve ensuring that the 100mL sample is obtained first and remains a concentrated solution. When the second valve is then actuated, flow switches from the sample bladder to the main extraction bladder that is capable of holding 2L of fluid. This ensures that there is more than enough room in the combination of both tanks to house the total amount of fluid being pumped in so that neither of the bladders burst. The maximum allowable pressure that can be handled by the bladders is well above the maximum system pressure (1400psig) which ensures that even if the tanks become full, the bladders will not be able to burst. The pneumatically actuated grippers are basically two spring clamps with the rod end of the cylinders attached to one handle of each of the grippers. They are controlled by 2 5-3 valves with a closed center in formation of a meter out circuit which allows precise control for the positioning of the rod so that the grippers can be fully open, fully closed and anything in between.

Future Improvements

To further improve our ROV we could incorporate a positional feedback system. This would consist of an inertial measurement unit (IMU) which measures velocity, orientation and gravitational forces using accelerometers and gyroscopes. This system would increase the overall stability of the ROV by compensating for any external forces for example drift due to water currents, and sending impulses to the thrusters. The thrusters would then increase or decrease speed to keep our system on a level platform.

Lessons Learned

During the design process, we modeled everything to scale with exact dimensions and imported correct materials for each part. This ensured that all components would fit and integrate with each other properly. When sizing the ballast, we needed to determine how much volume we needed to displace in order to have the ROV slightly positively buoyant. In this calculation, we used the overall weight of the ROV given to us by Autodesk Inventor. Upon testing the ROV, we realized our calculations were a bit off and the ROV required an enormous amount of weight (60 Lbs.) to submerge by itself. This miscalculation was caused by the incorrect mass given to us by Inventor.

Early on it was apparent that communication was vital for the design and manufacturing process. Initially, scheduling conflicts and a large course load caused members to miss meetings which therefore

slowed the overall design process. We corrected this by scheduling meetings a week in advance and following up with each other when the meeting date neared. In addition, dividing up the workload was difficult since we were not familiar with each other's strengths and weaknesses. Once we started working together we were able to identify the strengths of each member. This increased overall efficiency of the team.

Reflections

Looking back at what has been accomplished throughout our design process many improvements have been made. Not only have we all learned a great deal of knowledge, but we have also built on our technical skills in the fabrication process for our ROV. While at the regional competition in Seattle we were able to successfully complete all required tasks after some on the spot alterations. We were also able to note future improvements that can be made to further better our system as a whole.

Teamwork

The team consists of 4 mechanical engineering design students and 2 mechatronics students. The design student's primary responsibilities include designing and building the structural components, dealing with waterproofing and sealing, determining the amount of buoyancy required, and designing and building the pneumatic circuit for the fuel extraction system and grippers. The mechatronic students took care of the electrical systems, controls, sensors, video, and tuning. The mechanical design students and mechatronic students would meet with the company sponsor once a week to discuss the details of the project at least once every week. The tasks were delegated to the team members based on their individual strengths and interests.

Deadlines for certain elements for the ROV were set and would need to be met in order to stay on schedule. The ROV is also being used as a class project, and the project focuses on completing specific documents and tasks to aid with the initial design process such as a QFD analysis, morphology, and Gantt chart.

Acknowledgement's

The design and development of this year's ROV is made possible through the proceeds that are generously provided by the British Columbia Institute of Technology. Special thanks must be given to Taco Niet who teaches at BCIT and also acts as a mentor for the ROV team. Taco's advice in terms of engineering and teamwork, and ensuring that access to any resources, tools, or people that were required was crucial in the team's success. Pavlos Paleologou and Brian Gaensbauer were of particular assistance in the design of the electrical and control systems. Between them they teach the majority of the courses dealing with microcontroller programming as well as sensors and feedback. Also at BCIT, Dr. Cyrus Raoufi teaches a course about design techniques and processes that are used in successful engineering firms. The course focuses on subjects such as organizing projects, identifying and assessing potential solutions on a technical, economical, and sustainable basis, and preparing engineering project reports and proposals. This course was especially helpful in organizing our ideas during the early design

stages. Darlene Webb, who teaches a communications class that runs concurrently with Dr.Raoufi's project course, was very crucial in terms of ensuring that the team was able to communicate effectively. Darlene also provided alot guidance towards managing stress and dealing with tight deadlines from her years of experience with mechanical engineering students. The ROV team also had weekly meetings with Kevin Peffer's who helps teach a machine design course at BCIT. These meetings were very useful for the team because Kevin's professional opinion on various designs for the ROV helped expedite the design process for many components. Kevin also ensured that the team was on track in terms of meeting all the obligations for Cyrus' and Darlene's classes. Special mention must also be given to Keith Turner, Brian Ennis, Eugene Duruisseau and Jason Brett for their help with machining and assembling the components of the ROV.