High Technology High School
The Fury II Technical Report

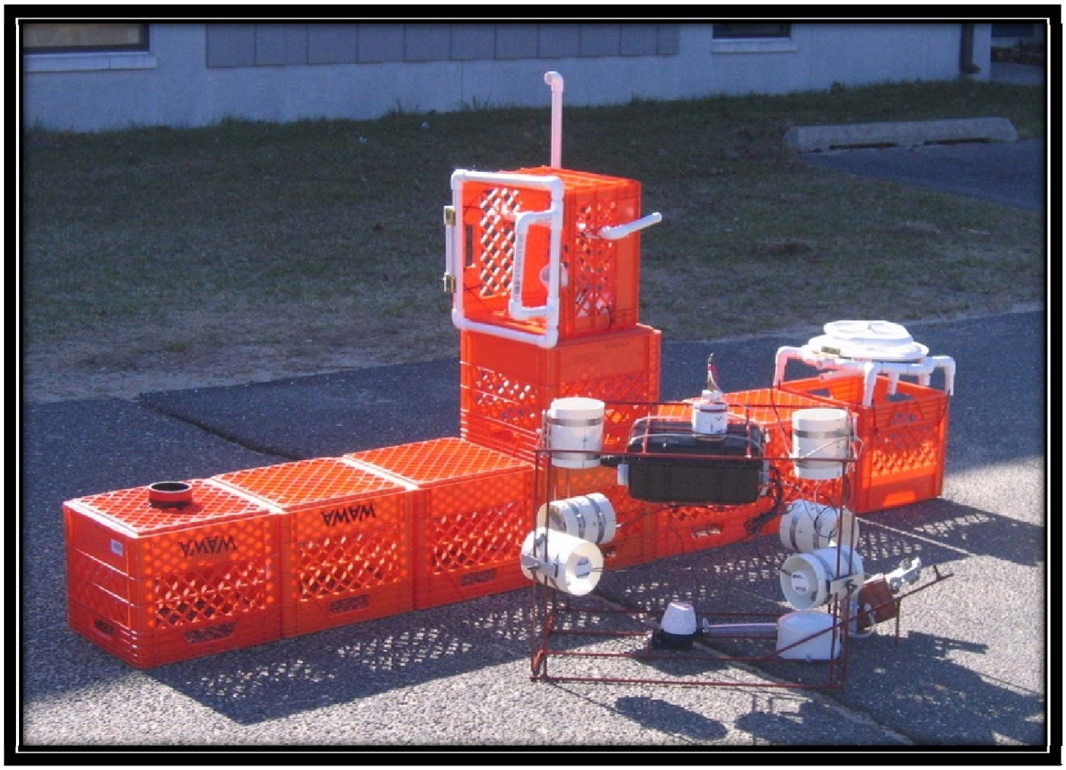

Figure 1: The Fury II (front) with Submarine (back)

HTHS Fury II Team Members
Instructor: Ms. Linda Grunthaner

Andrei Tapliga
Catherine He
Christopher Lui
Connor Janover
Daniel Rock
David Kelly
Donald Husa
James Ting
Jeffery Mooneyham
Jeffrey Kwok
Kevin Risden
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Melody So
Michael Creech
Michael Wollman
Patricia Thompson
Stephen Schraer
Theresa Lye
Zachary Darby

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ABSTRACT

The goal of the Fury Team of High Technology High School was to produce a Remotely Operated Vehicle (ROV). This vehicle needed to be capable of effectively and safely completing the four mission tasks of the Ranger Class division for the 2009 MATE ROV competition within 15 minutes. For this competition, the team took a unique and open-minded approach. Utilizing various brainstorming techniques, an assortment of solutions was accrued to accomplish the four tasks. By employing a rectangular frame design, the HTHS Fury II team was able to develop a lightweight design that provided an open workspace. In and around the frame are other innovative designs that the team developed. Two cameras, strategically placed, provide an optimal view of the surroundings, the claw, and the stationary arm. The claw and stationary arm are used several times when completing the four mission tasks. The implemented 'home-made' underwater electronics box, which was sealed by the team, utilizes an airtight design. It houses all of the necessary electrical equipment for underwater use and allows maximum flexibility in the aquatic environment. Six motors are used to move around underwater. The unique design that the Fury team utilizes is placing the motors at a 45º angle. This motor position method eliminates the need for individual forward and reverse motors. Using vector addition, the robot has the ability to navigate straight, strafe, rotate, vertical, and any combination of the aforementioned directions.

PHOTOGRAPHS OF ROV

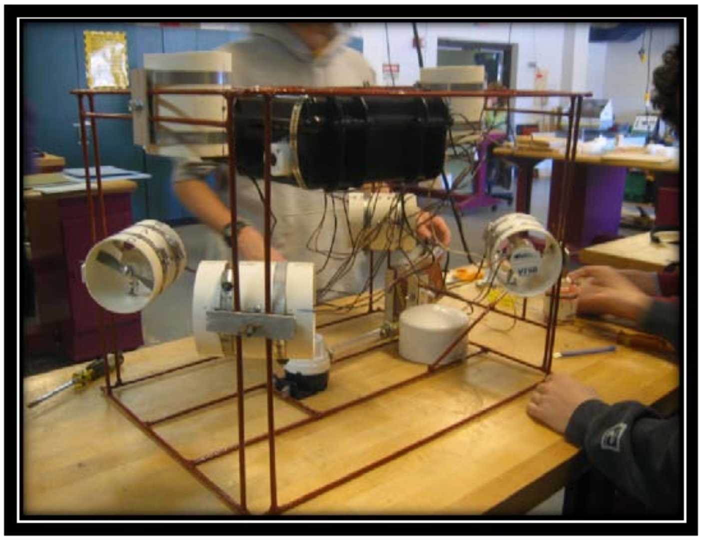


Figure 2: Angled View of ROV

Figure 3: View of ROV (front left) with Submarine (back) and Pods (front right)

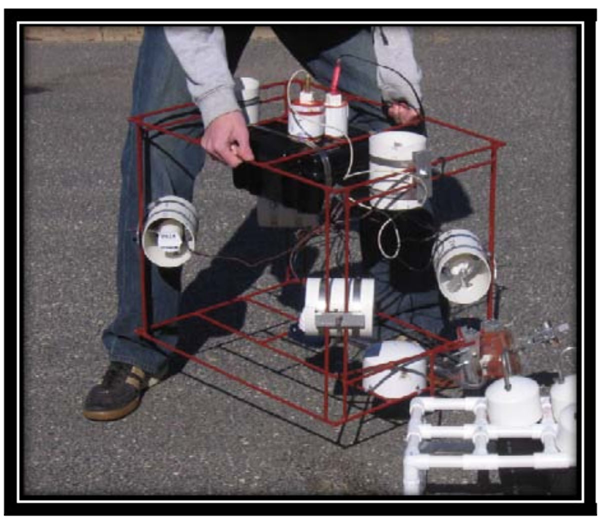


Figure 4: Angled View of ROV

BUDGET/EXPENSE SHEET

In order to have a successful project, certain demands need to be met while staying under budget. To expedite the acquisition of materials, when a certain material or part was needed, a team member would go out and buy the item. If not going to the store and buying it, he/she would go online and order the item to be shipped to either the school or his/her house. Once the item was acquired, the receipt was submitted and the student was refunded the cost of the item through the Robotics Club account. This entire process allowed the team to work, troubleshoot, and apply new techniques at optimal rates.

For the Expense Sheet, see Appendix A, page A1

ELECTRICAL SCHEMATIC

The ROV electronic system contains three distinct components: topside, tether, and bottom side. The topside component revolves around an Arduino Nano microcontroller. The Arduino Nano captures two analog joystick inputs parses it for transmission. The chip generates a TTL serial signal that is then sent to the tether component.

The tether component utilizes a pair of Maxim Max3232 transceivers: one on the surface and one on the robot. The surface side RS232 transceiver takes the TTL serial signal generated by the Arduino Nano and converts it to an RS232 signal. The TTL serial signal must be amplified from a nominal 0-5V level to -12V to 12V level so the signal does not degrade too much over the tether cable. The amplified signal then travels the length of the tether to a second RS232 transceiver, which converts the signal back down to the TTL serial level. The transmission takes place at the speed of 9600 baud determined by the software on the Arduino Nano.

The bottom side component workhorses contains an Arduino Nano and a TI TLC5940 chip, which work together to take the serial data from the top side and parses the information to create valid pulse width modulation (PWM) signals. The TLC5940, controlled by the Arduino Nano, generates the PWM signals. Six NMIH-0050 h-bridges take a pair of PWM signals from the TLC5940 and control the voltage supply to the motors. In total, the Arduino Nano and TLC5940 generate twelve PWM signals. In addition to the PWM motor control, the bottom side component controls the bilge pump through a FIRST Spike relay with a 5V control signal.

The electronics system contains 5V regulators on the topside and bottom side to power the Arduino Nanos, TLC5940, and the h-bridges. To protect the circuit and provide safety, a 25-amp fuse sits at the entry point to the system, preventing an overdraw. Secondly, the motors, camera, and voltage regulators are protected by diodes, which protect these devices from an accidental polarity reverse.

For the Electrical Schematics, see Appendix B, pages A2-A3

FLOW-CHART OF SOFTWARE IN ROV

For the Software Flow-Chart, see Appendix C, page A4

DESIGN RATIONALE

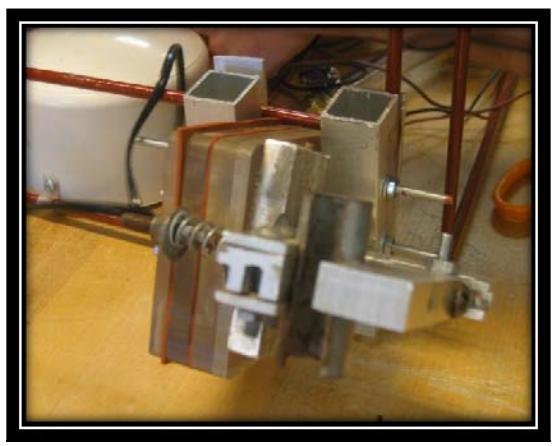
Frame

The frame of the robot, constructed out of welded 0.64cm diameter steel rod, contributes stability and support. The 0.64cm diameter steel rod offers a small cross sectional area to reduce drag while still being cost effective, strong, and easy to weld. Several parallel bars along with vertical bars create a rectangular prism frame skeleton. In each corner of the frame, two parallel vertical bars 3cm apart at a 45° angle to the base allow mounting of the four horizontal motors. This configuration allows adjustment to align the horizontal motor forces with the center of lateral resistance. Along the front of the frame, two parallel bars 8cm apart provide a secure mounting location for the claw and hook, and allow horizontal adjustment for weight distribution. In the center of bottom side, two parallel bars 14cm apart allow the mounting of the Mating Hatch and the bilge pump that powers the claw.

A MIG welder accomplished the construction of the steel frame. Mr. Risden, the father of a team member, provided the welder and safety equipment. Since no one on the team had previous welding experience, Mr. Risden instructed a senior member. Once welding was completed, team members filed down the frame and prepared it for painting. Rust Destroyer red paint provides steel rust protection from the chlorine pool water.

For the Frame CADD Representation, see Appendix D, pages A5-A6

Figure 5: Angled View of Claw



Claw

Our robot required a grabbing device to hold onto the airline for Task 3. In order to minimize cost, the team chose to utilize an existing claw and rework it into our design. The claw uses hydraulic pressure from a bilge pump to open and a spring to pull it closed. Water pressure generated by an Atwood V500 bilge pump pushes against a rubber diaphragm moving a lever and opening the claw. Mounted on two parallel bars in the front of the robot, the claw adjusts horizontally to help in balancing weight distribution. The end of the claw sits at a 45° to hold the airline in the correct orientation for placement into the airline inlet.

For the Claw CADD Representation, see Appendix D, page A6

Stationary Arm

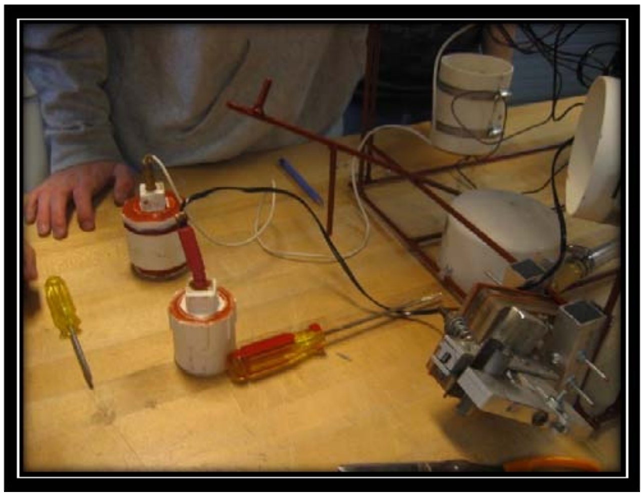


Figure 6: Stationary Arm with Cameras and Claw

In order to complete Task 2 and Task 4, the robot required an arm. The arm had to operate as a universal tool, capable of lifting pods, opening and closing hatches, and turning the airline lever. Due to limitations of using motors underwater, the team decided to design a stationary arm to complete the tasks. The arm, constructed from 0.64cm steel, offers strength while staying compact. To attach the arm to the robot, the arm had notches grinded into the side, increasing the welding area, and then it was welded directly onto the frame. For increased visibility, the end of the arm lies within the viewing angle of both cameras. The arm sits at a 45° angle relative to the robot, which allows the pods to stay secure on the end. On the arm, two smaller pieces of steel were welded to add functionality. A four cm rod extends upward four cm from the tip of the arm to prevent the pods from sliding to the base. A second rod ten cm in length, attached vertically on the bottom of the arm ten cm from the tip, permits the robot to lock and unlock the hatch for Task 2.

Buoyancy

Weighing each robot component dry or in the pool determined the water weight of each. Governed by basic buoyancy and stability principles, the robot design contained positive buoyancy on the top edges and negative buoyancy at the middle bottom. Overall, the entire buoyancy system made the robot neutrally buoyant. The table below lists the measurements taken for each component of the robot.

Piece	Material	Density (N/cm^3)	Volume (cm^3)	Dry Weight (N)	Wet Weight (N)	Buoyant Force (N)
Frame	Steel	0.080974147	554.5844156	44.907	39.221	5.686
Motors (6x)	-	-	25.653	34.335	29.885	4.45
Electronics Box	-	-	190	20.462	-18.964	39.426
Cameras (2x)	-	-	-	30.234	-6.465	36.699
Total					43.667	

After summing the buoyancy values, the robot remained negatively buoyant. Adding Foamular® 150 2" thick closed-cell foam created the needed positive buoyancy. Due to the front left corner of the robot containing the claw and being significantly heavier than the other corners, the foam pieces, strategically placed, balanced the robot.

Thrusters/Propulsion

Due to limited resources, the team chose to use modified bilge pumps as thrusters. After completing bilge pump testing to determine the most efficient force per amperage ratio, the team decided on the Atwood V750. Team members removed the outside housing of the bilge pump as well as the impeller. Propeller adapters were then fit to the pump shaft. Due to the high RPM of the bilge pumps, two blade, low pitch 7X4 airplane propellers optimized the thrust output. A four-inch PVC drainage pipe around the bilge pump and motor assembly, acting like a nozzle, increases the efficiency of the thruster and protects the otherwise exposed propellers. For the propellers to fit inside the four-inch PVC nozzle, the propellers had to be trimmed so they would not scrap the edges.

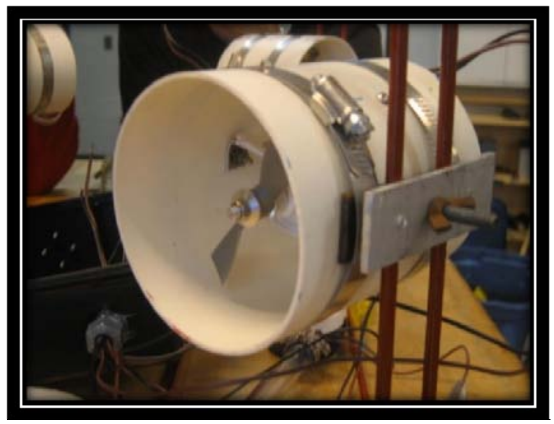


Figure 7: View of Thruster

Six independent thrusters control the propulsion of the robot. Four of the six provide thrust in the horizontal plane. The thrusters, mounted at 45° angles in each corner of the frame, provide the most thrust in the cardinal directions (forward, backward, left, right) due to vector addition. The other two motors provide the vertical thrust.

Tether

The tether consists of two wires, power and data, 18 meters long. A SJOOW 12 AWG, 4-conductor cable, rated for 300 volts, carries power down to the robot. Due to having cameras and electronics on the robot itself, the voltage loss across the cable had to be a maximum of one volt at peak current of 25 amps. To reach this goal, power uses two conductors and ground uses the remaining two conductors. The SJOOW cable specification states that the cable has a water resistant shell and resists abrasions, but at the same time, the cable remains flexible – crucial for the robot's operation. A CAT 5e network cable provides the data signal communication to the robot and video signals to the surface. The cable contains four twisted pairs inside of an insulated jacket. One twisted pair carries an RS232 signal from the Arduino Nano on the surface to the Arduino Nano on the robot. Two twisted pairs, one for each video camera, send the analog video signals to the surface. The remaining twisted pair remains unused except for debugging purposes during testing. Since the tether remains negatively buoyant in the water, foam pipe insulation, cut to six-inch lengths, was attached along the length at two-foot intervals to achieve neutral buoyancy. The foam pipe insulation also keeps the tether cables together to minimize drag through the water.

Electronics Box

A Fuerte SX300 underwater box, bought direct from Fuerte case company, contains the electronics on the robot. The Fuerte SX300 case specifications rate the box waterproof to a maximum of 75 feet – deep enough for the competition. Inside the box lies the Arduino Nano, six motor controllers, one relay, and the power distribution system. The power, network, motor, and camera cables entries required seals to make them waterproof.

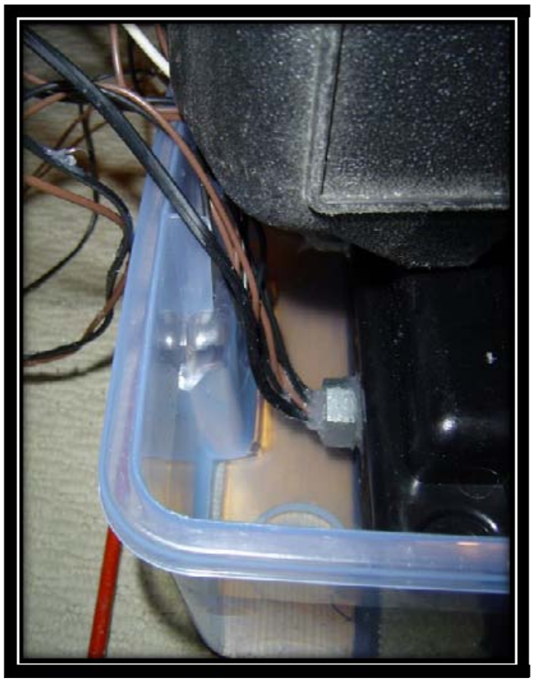


Figure 8: Waterproofing the Electronics Box

The Fuerte case company, which designs these cases for underwater use, offers cable seal installation instructions on their website. The tether power cable required a West Marine through deck cable seal. The seal fits tight around the power cable and provides a watertight seal. To seal the CAT 5e network cable, Belden donated a waterproof Ethernet connector, which allows for cable removal if needed. The connector seals around the network cable and plugs into a gasket-sealed receptacle on the electronics box, which is sealed using an o-ring. The motor and camera cables enter the box through two ½” outdoor electrical connectors. Each connector, although designed for one half inch cable, holds three pairs of wires for the motors and one camera wire. Between the connector and the box, an o-ring makes each connector watertight. In addition, clear ATV silicone sealant filled any spaces between the wires preventing any water from leaking.

Cameras

The ROV vision system contains two waterproof cameras positioned for navigation and actuator manipulation. Both cameras offer 470 lines of resolution, operate between 9 and 15 volts DC, and draw 110mA each. The navigation camera, also used for Task 1, produces a black and white video signal pointing straight ahead in front of the robot. The actuator manipulation camera allows the pilot to see clearly the claw and stationary arm when completing tasks. Due to the extra

Figure 9: View of Camera

precision needed for the tasks, the actuator manipulation camera produces a color video signal, which enhances depth perception and contrast. Mounting the camera at an angle permits an unobstructed view of the manipulation devices.

DESCRIPTION OF A CHALLENGE

A challenge that the team encountered throughout the duration of the project was communication. Not everyone could stay after school or meet on weekends to work on the competition for various reasons, yet those students still wanted to play an active role in the project. Coordinating this effort and making sure every member was always up to date with the happenings of the robot, documentation, parts, expenses, etc. proved a formidable task. To overcome this obstacle, the team utilized the school email system, an online wiki, phone calls, lunch meetings, and an occasional shout down hallways to communicate. After taking some time to adjust, these methods proved to be quite powerful; so powerful that they even expanded into a form of communication that, not only kept those who couldn't make every meeting up to date, but it also gave a sort of 'live-feed' of what was accomplished and what still needs to be done to every member of the club.

EXPLANATION OF TROUBLESHOOTING TECHNIQUES

When working on the initial circuit designs, the analog joysticks, CH FlightSticks, did not have any datasheets. Upon consulting various resources, the team procured standard DA15 pin diagrams. After creating a simple test circuit using the standard pin diagrams, the excepted outputs did not occur. The team then pulled apart the joystick and tested the pins with a volt-ohm meter checking for continuity. Using the data collected, a new pin diagram for the joystick was constructed and compared to the standard pin diagram. The pin diagrams differed by a few pins. The test circuit was reconstructed using the new pin diagrams and the expected results occurred.

Upon constructing the final circuit, one of the Arduino Nano boards started to smoke. Immediately, power was removed from the circuit. After carefully inspecting the circuit, a small piece of stray wire had fallen onto the board causing a short between power and ground. Once the wire had been removed, power was reapplied to the circuit but the Arduino Nano board would not power up. The short circuit destroyed a part of the Arduino Nano forcing the use of a backup chip bought just for this reason. The broken Arduino Nano was removed and replaced. The programming was uploaded to the new Arduino Nano and then checked the circuit to make sure it was functioning correctly.

DESCRIPTION OF SKILL GAINED

The electronics system for the ROV required an underwater case. The case would contain electronics crucial to the operation of the navigation system. The case, a Fuerte SX300, although designed for underwater usage required holes for the various cables. The team needed to keep the existing box waterproof while still allowing cables to enter.

After gathering the cables that needed to enter the case, the team worked together to determine seals that would hold each cable type. The power cable, a 4 conductor 12 AWG SJOOW cable, measured 5/8" for the diameter. The diameter of the cable led the team to choose a West Marine through deck cable seal. The seal contained a rubber centerpiece that had to be cut to fit the cable perfectly. A plastic mounting bracket with a rubber gasket sits flush on the exterior of the case. Before mounting the seal, a 9/16" hole was drilled through the case making sure to make a perfect cut. The custom cut rubber piece was fit over the cable and then the cable was slid into the case through the precut hole. Then the team tightened down a plastic bracket to waterproof the seal. The network cable was next to put through the case.

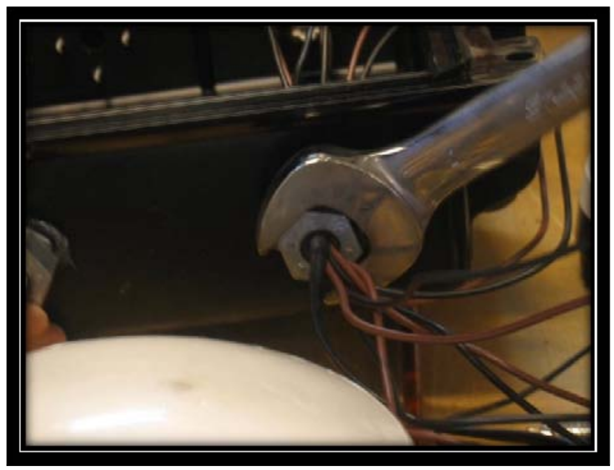


Figure 10: Working on the Electronics Box

The team researched a waterproof network connector and found a device made by Belden. Upon contacting the company, Belden decided to donate a waterproof Ethernet connector for use on the robot. The connector takes a standard network cable and waterproofs the seal between the outside and inside. The only steps necessary by the team was to place a hole through the box, place the connector in the hole, and tighten down the provided nuts.

The motor and camera wires introduced a problem when waterproofing their connection to the box. To accommodate all of the wires, two 1/2" waterproof electrical conduits were needed. The conduits, designed for only one 1/2" cable, had trouble sealing nine wires at once. In addition, there was no gasket between the conduit itself and the box. In order to alleviate the leak between the conduit and seal, a team member purchased an o-ring. The o-ring sat on the threads and prevented the seal from leaking when tightened down. Eliminating the various holes between the individual wires took a lot of testing to find them and seal them. A tube of clear ATV silicone sealant seals between the wires and makes it waterproof.

During the waterproofing process, the team learned to use patience and test thoroughly. After creating each seal, the box was placed inside a small tank for 24 hours to check for leaks. If leaks were found, the team located the problem and fixed it by either using the clear ATV silicone sealant or starting over and making the seal again. Once no leaks had been found the box was deemed waterproof and ready for electronics to occupy it.

DISCUSSION OF FUTURE IMPROVEMENTS

In the future, several improvements can be made to the ROV. For example, several obstacles were encountered concerning the electronics box. After having to deal with several leakage problems, finding a more reliable box would be extremely beneficial. In addition, waterproof plug connectors could be used for the motor wires, camera cables, and SJOOW power cords, allowing for easy removal of the electric box. Finally, a wider angled camera could be valuable for facilitating the tasks that must be completed underwater.

DESCRIPTION OF AN ORGANIZATION Involved with Submarine Rescue

Figure 11: OceanWorks' Pressurized Rescue Module System

OceanWorks International, formally known as Hard Suits International, was established in 1986. Privately owned, the subsea technology company has headquarters located in Houston, Texas and Vancouver, BC. The company provides subsea equipment; subsea systems; and custom fabrication, maintenance, and testing services for various marine industries. They offer a wide range of products and services, including ROV services for oil and telecommunication industries; subsea cabled observatory systems for scientific experiments and studies; atmospheric diving equipment for salvage and construction industries; and system, manufacturing, and testing support for renewable energy industries, and atmospheric diving products and submarine rescue systems for militaries around the world.

The company's submarine rescue product line began with the REMORA, a submarine rescue vehicle first designed and built by Hard Suits International for the Royal Australian Navy in 1995. Concepts from the REMORA design were then improved and incorporated into a new submarine rescue system called the Pressurized Rescue Module System (PRMS), a remotely operated submarine rescue vehicle designed to rescue personnel from disabled submarines and transfer them to the surface. OceanWorks International announced the launch of the PRMS on June 12, 2007, and the PRMS is planned to replace the current US submarine rescue system, the DSRV Mystic.

REFLECTIONS ON THE EXPERIENCE

Team Reflection

Something that we learned from the MATE ROV challenge is how to build a robot from scratch. In previous years, the High Technology High School (HTHS) robotics team has participated in robotics challenges in which kits are provided. With this challenge, we were required to use the engineering design method to devise a design, construction plan, and actual product. In the planning stages, we separated into groups who did background research so that we knew what was available for use in our robot. We then got together in a group to share our research and brainstorm.

After that, we came up with our preliminary design for the robot. This design was then reviewed and what we considered our final working design was planned. We started ordering the necessary parts, from the steel for the frame to the motors for movement. Construction was a team effort, with the older students coaching the younger students so that everyone learned what to do. This project gave us the experience of researching, planning, and building a robot from scratch and imparted that skill to every person who participated.

Personal Reflection

The best part about this competition is that I personally got to work on the robot itself. I, being a junior in high school, have a thing for a more hands-on type of experience. I really appreciated the way the advisor stood back and let us students take control of the project. She helped in terms of safety and the logistics of getting to the competition and back, but for everything else, I was glad that I could do my part. Overall, this was a very rewarding experience for me. I learned new things from the 'veterans' of this project but in addition, I was also able to guide the newer students. I especially enjoyed the collaboration in between the different grade levels. The fact that some members were freshmen and others were seniors was not apparent. One thing I would change if I had to is that I would like to get even more students actively involved. Our team is already big, but the more people we have, the more we can get done.

REFERENCES

- Cornell University's Autonomous Underwater Vehicle (CUAUV)
  - Leader of their robotics team, Erin Fischell, spoke to HTHS' team
    - http://www.cuauv.org
    - http://www.cuauv.org/node/1017
    - http://www.cuauv.org/node/1016
    - http://www.cuauv.org/node/1018
- National Underwater Robotics Challenge (NURC)
  - Provides great How-To's and Resources to get teams started
    - http://h2orobots.org
    - http://h2orobots.org/howto.htm
- Resources used to research the Submarine Rescue Organization
  - http://www.oceanworks.com/
  - http://www.subsea.org/products/specification.asp?prod=2581
  - http://www.globalsecurity.org/military/systems/ship/systems/srdrs-history.htm
- MATE Provided Sources
  - http://www.marinetech.org/rov_competition/resources.php

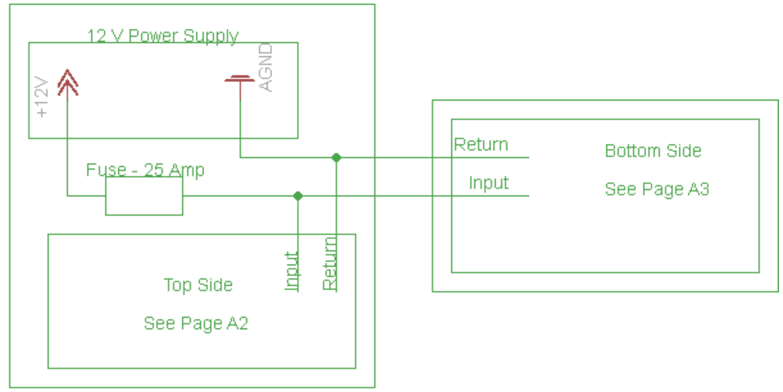
ACKNOWLEDGEMENTS

This project requires considerable time and effort from the members of the team in order to achieve success. However, the completion of a functional ROV would not be possible by team efforts alone. High Technology High School provides both the support and a workshop for the team. The instructor, Ms. Grunthaner, devotes a large portion of her time to monitoring and aiding the course of our progress, building the mission props, relaying information from the Board of Education, and keeping the workshop available for our disposal. Not only did we have support from our advisor and the school board, but also the CADD drawings were drawn jointly with the freshmen class as part of an engineering design course. In addition, a sincere thanks to Mr. Risden for allowing the robotics team to use as well as providing guidance for his welding equipment. Finally, this project would not have occurred without the MATE Center, so our thanks goes out to them as well. Without the joint effort of the entire High Technology Robotics team in conjunction with all of the others working behind the scenes, this project would not have been so successful.

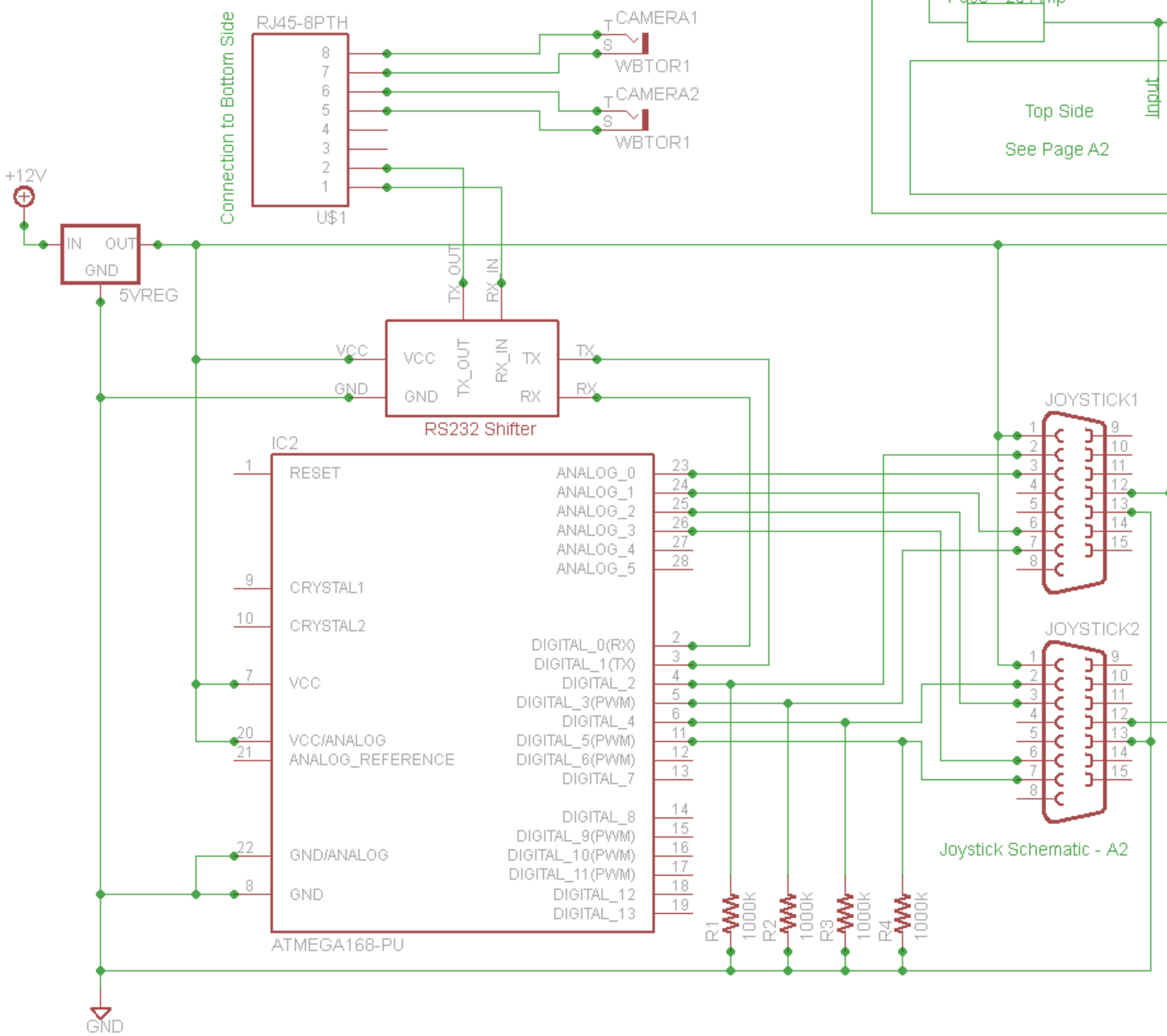
Expense Sheet

School Name: High Technology High School				From: 12/1/2008	
Instructor/Sponsor: Ms. Gruntlaner				To: 5/27/2009	
Date	**Deposit or Expense**	**Description**	**Notes**	**Amount**	**Balance**
12/1/2008	Deposit	Initial Funds		$2,000.00	$2,000.00
12/27/2008	Donation	TI - TLC5940	PWM Chip	$1.90	$1,998.10
1/8/2009	Expense	Grainger - 6 - 1/4" 6' Steel	Frame	$46.94	$1,951.16
1/15/2009	Reuse	Waterproof Cameras	Reuse from existing robot	$60.00	$1,891.16
1/26/2009	Expense	Fuerte Case SX-300	Waterproof Electronics Case	$45.26	$1,845.90
1/29/2009	Expense	6 - TowerHobbies - LXMSF2	Prop Adapters	$21.54	$1,824.36
2/4/2009	Expense	1 - TowerHobbies - LM1691	6 Propeller Pack	$15.44	$1,808.92
2/5/2009	Expense	2 - New Micros - NMIH-0050	H-Bridge Motor Controllers	$59.90	$1,749.02
2/5/2009	Donation	4 - New Micros - NMIH-0050	H-Bridge Motor Controllers	$119.80	$1,629.22
2/5/2009	Expense	2 - SparkFun - PRT-00133	RS232 Tranceiver	$15.91	$1,613.31
2/6/2009	Expense	2 - Radio Shack - 2102497	Male DE-9 Connectors	$3.98	$1,609.33
2/7/2009	Expense	2 - Digikey - 4215FE-ND	Solderable Male Joystick Connectors	$3.78	$1,605.55
2/11/2009	Expense	1 - Home Depot - SKU#120088	4" PVC Drain Pipe	$7.87	$1,597.68
2/12/2009	Expense	6 - Attwood V750 Bilge Pumps	Propulsion Motors	$125.91	$1,471.77
2/14/2009	Expense	2 - Makershed - Arduino Nano	Programmable Chips	$94.23	$1,377.54
2/15/2009	Expense	2 - Radioshack - 2062599	7805 5v Regulator	$3.18	$1,374.36
2/19/2009	Expense	10 - SparkFun - PRT-00643	2X5 Header Pins	$8.60	$1,365.76
3/1/2009	Donation	Belden - Waterproof Ethernet Connector	Waterproof Ethernet Connector	$50.00	$1,315.76
3/4/2009	Expense	1 - Radio Shack - 2761141	3A 50V Diodes	$1.59	$1,314.17
3/7/2009	Expense	1 - Radio Shack - 6400017	Solder	$2.66	$1,311.51
3/20/2009	Expense	1 - West Marine - 540740	Power Cable Seal	$21.39	$1,290.12
3/30/2009	Expense	Home Depot - R10 Foam	Buoyancy Foam	$2.00	$1,288.12
4/23/2009	Expense	Home Depot - 1/4" Brass Barb		$2.39	$1,285.73
5/3/2009	Expense	Home Depot - Fiberglass Materials	Strengthen and Cover Foam	$27.76	$1,257.97
	Total Expense			$742.03	$1,257.97

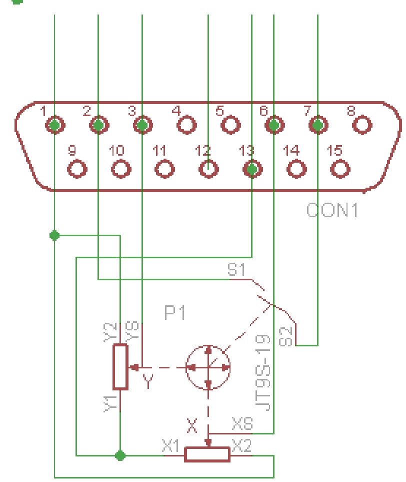
Electronic System Overview



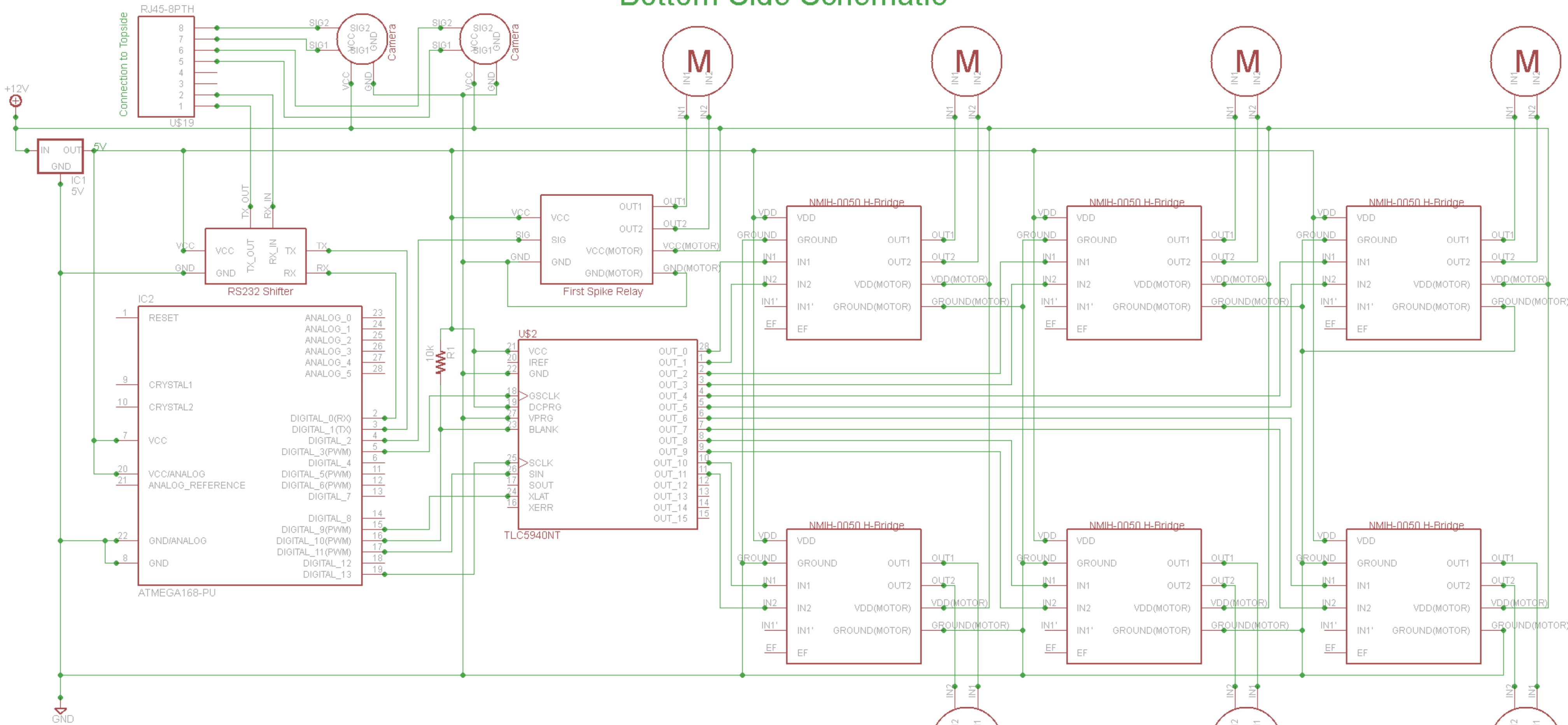
Top Side Schematic



Joystick Schematic

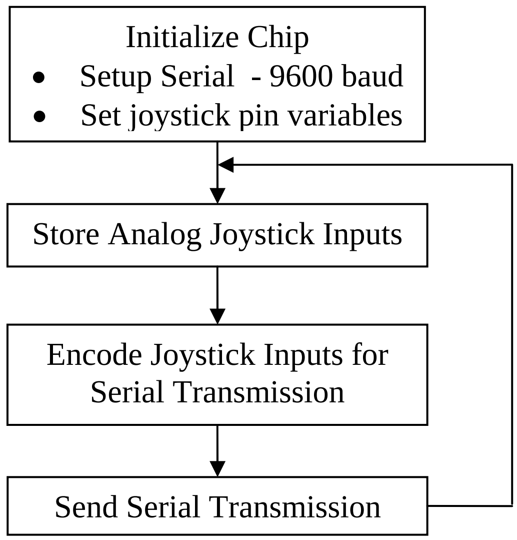


Bottom Side Schematic

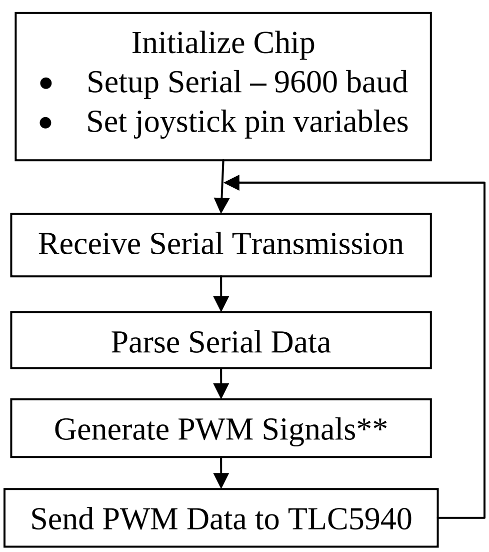


Software Flow Charts

Top Side Software



Bottom Side Software

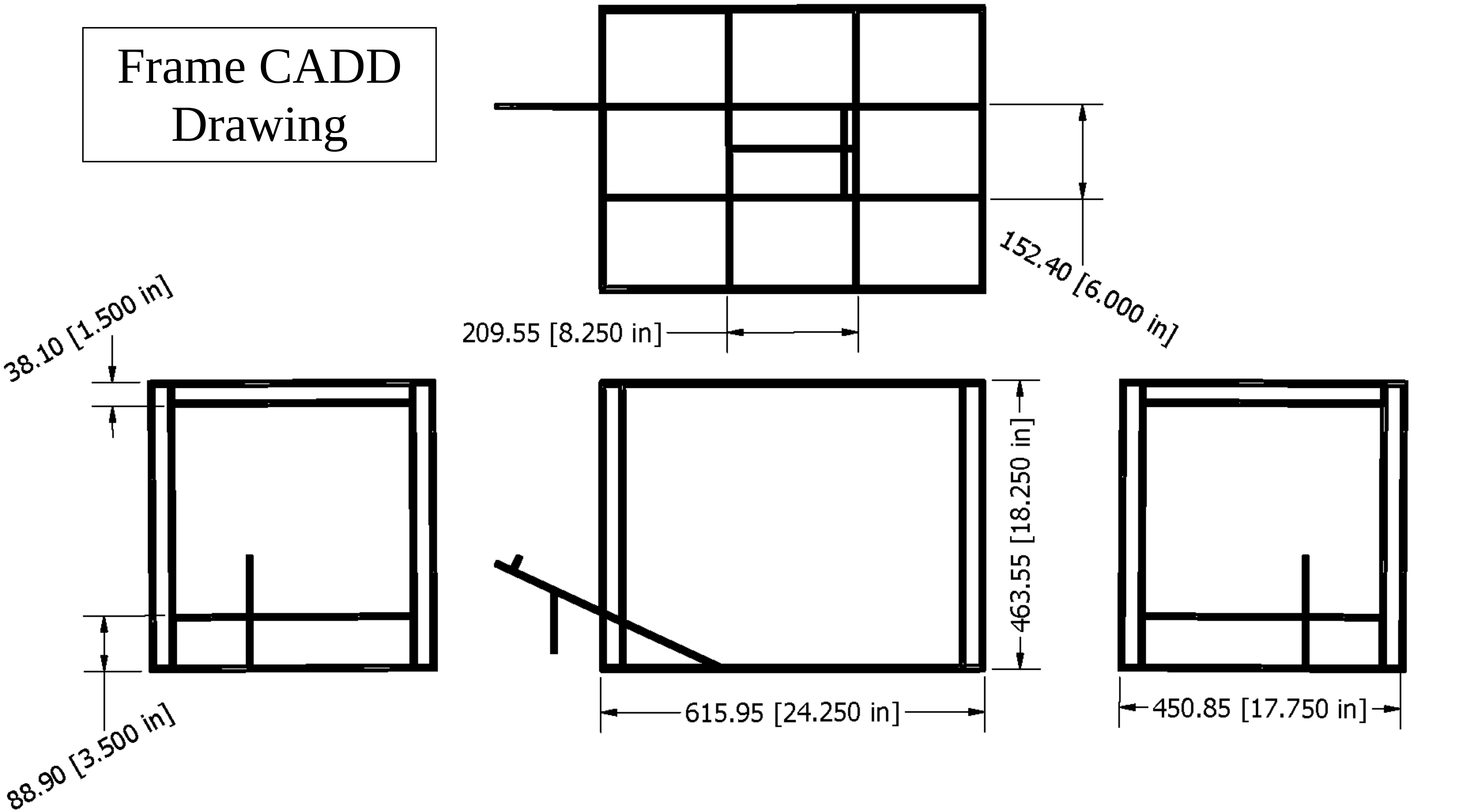


** Generate PWM Signals

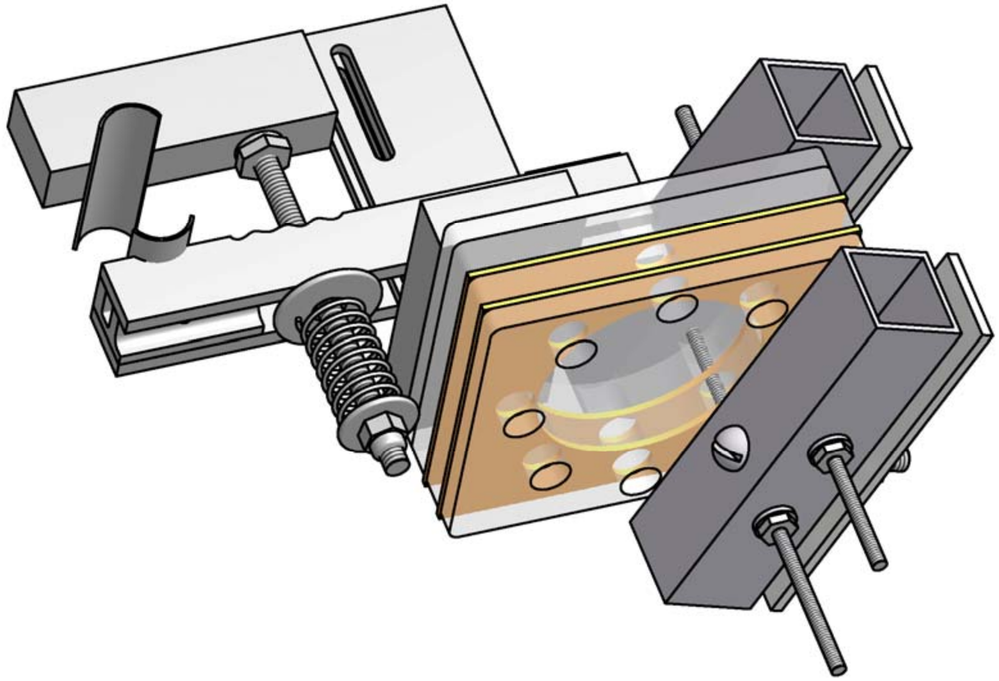
Due to taking a vectored approach for mounting the motors, each joystick axis value is added or subtracted for each motor as shown in the table below and then converted into a PWM signal.

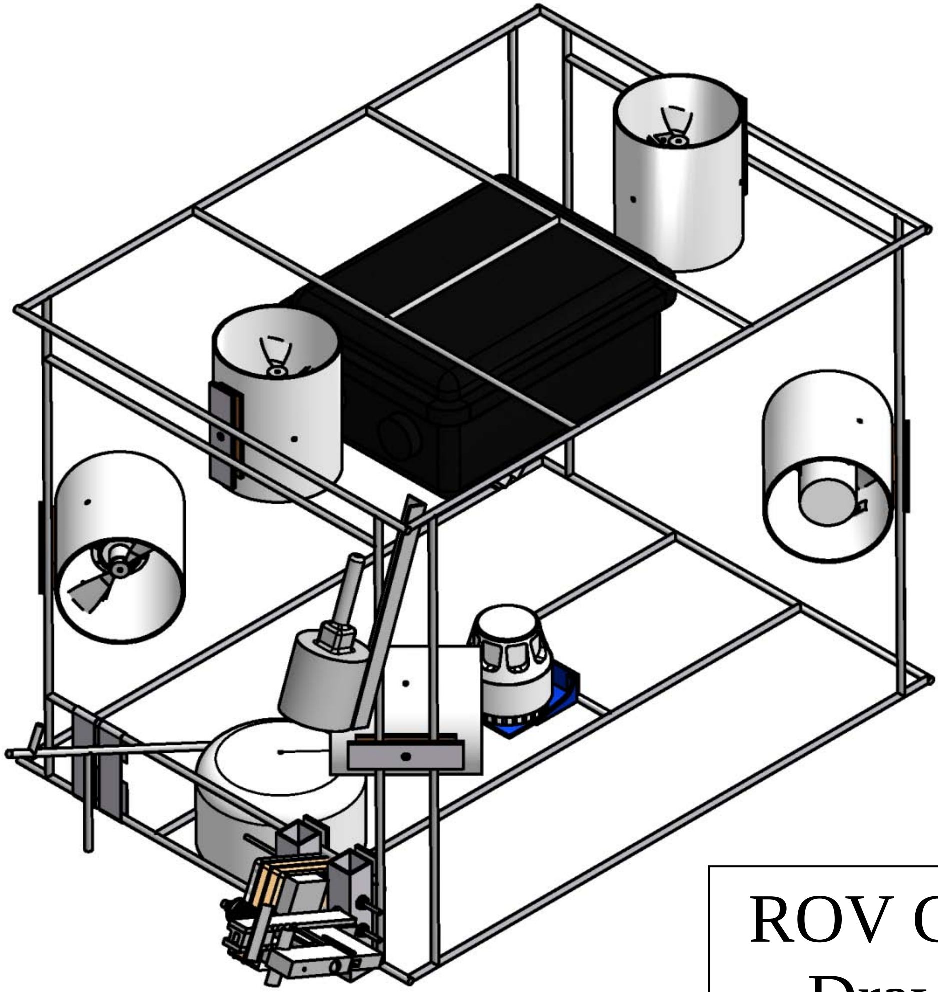
	Joystick 1		Joystick 2	
Motor	X-Axis	Y-Axis	X-Axis	Y-Axis
I	-	+	-	0
II	+	+	+	0
III	-	+	+	0
IV	+	+	-	0
V+VI	0	0	0	+

Frame CADD Drawing



Claw CADD Drawing





ROV CADD Drawing