Aquaphobic

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Abstract

This paper describes the Remotely Operated Vehicle (ROV), *Aquaphobic*, which was designed, constructed, and tested by students from Thomas Jefferson High School for Science and Technology. *Aquaphobic* was constructed with simplicity, reliability, and cost in mind. The overall design of the ROV was planned out before construction began to ensure that the subsystems would be compatible with each other. Ultra-high molecular weight polyethylene plastic was used to create the frame, which serves as the structure for the other systems to attach onto. Four modified bilge pumps were outfitted with marine propellers to provide propulsion for the vehicle. Steel rods and pourable urethane foam were used to maintain stiffness of the ROV while maintaining neutral buoyancy. In order to control *Aquaphobic*, a computer was programmed to read signals from the XBOX controller and send the signals out to the motor controllers. The computer also displayed the reading from the onboard temperature sensor and the video from the three cameras. On the front of the ROV, several devises are used to complete the mission tasks. The funnel allows the ROV to remain over the vent flow while acquiring the reading. A scraper is used to knock the rocks off of the black smoker and into the fish net. A robust gripper was developed in order to pick up the crabs as well as any dropped black smoker samples and return them to the surface. When assembled together, these subsystems form a complete ROV capable of completing the tasks with precision.

Aquaphobic Design Rationale

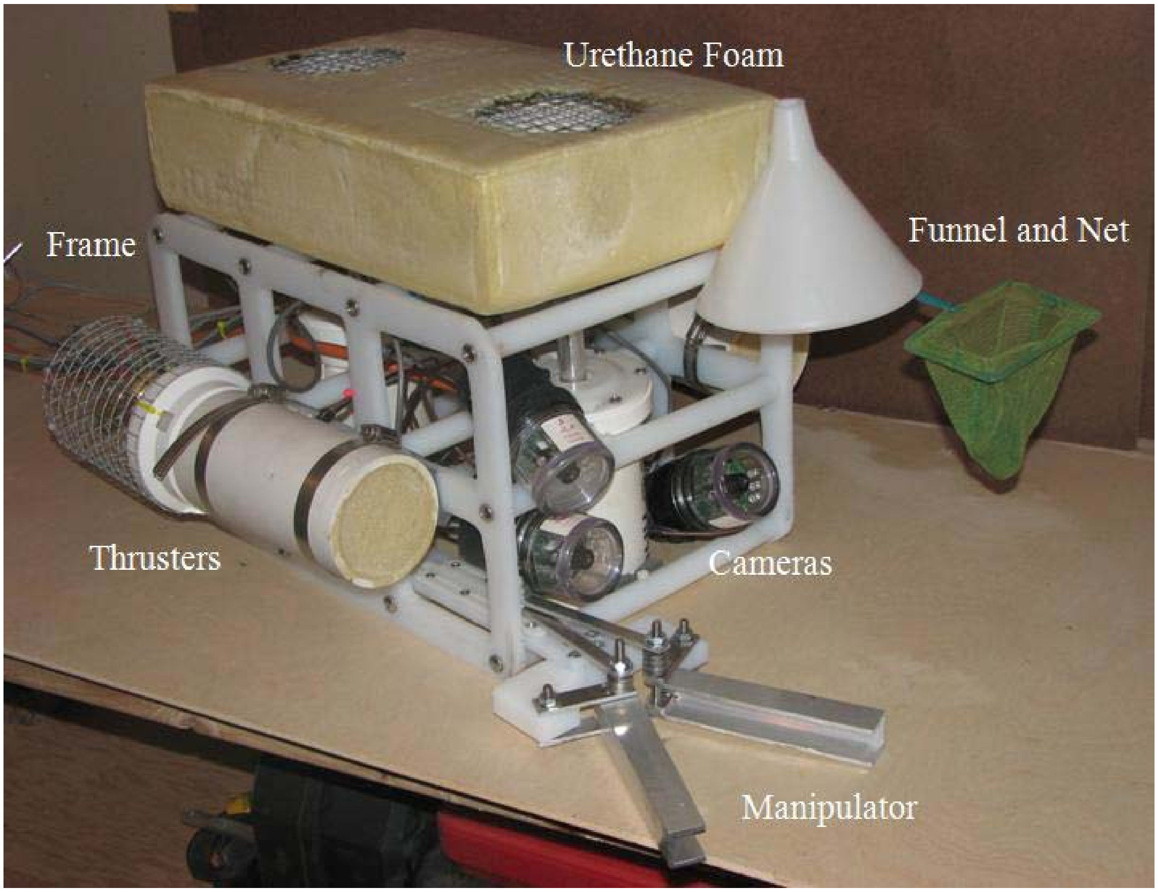


Figure 1 – Completed ROV with Labeled Components

Frame

The frame is the skeleton of the ROV to which all other components are attached. Therefore its shape has a large effect on the rest of the design sequence. The ROV utilizes a conventional rectangular prism shape, 45cm x 25 cm x 25 cm in size (Figure 2). This size allowed for the other chosen components such as thrusters and cameras to fit inside the frame. This shape is easy to build and modify, and, while less efficient than some shapes, it also has predictable movement characteristics underwater.

Ultra-high molecular weight (UHMW) polyethylene plastic was chosen as the structural material over other options such as PVC or aluminum for several reasons. UHMW is a very strong material, being fairly resistant to bending and very abrasion-resistant. UHMW has a density of .93g/cm^3, which is close to that of water's density of 1g/cm^3. Thus from the start, the frame of the ROV is fairly close to neutral buoyancy, which makes the task of designing the flotation and ballast system easier.

The sides of the frame are made of 1 cm thick UHMW sheets. Twelve 1.9 cm diameter UHMW rods held the sides solidly together and provided many attachment points for the thrusters, cameras, and other components. The rods were spaced out so that the thrusters could fit inside the frame either vertically or horizontally between the rods. Each rod was attached to the sides of the frame with one ¼-20 stainless steel screw (Figure 3).

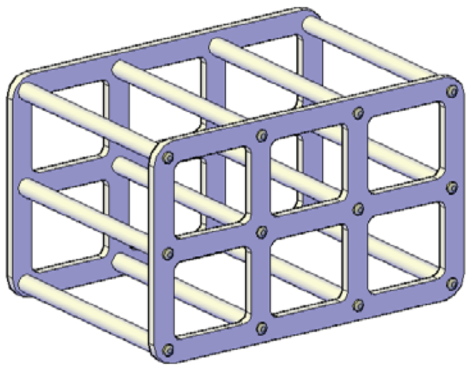


Figure 2 – CAD Render of the Frame

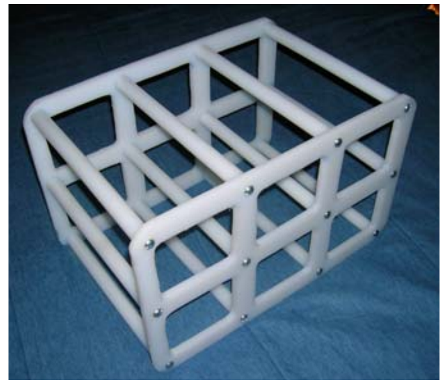


Figure 3 – Completed Frame

Propulsion

For reliability and simplicity, bilge pumps were chosen as the motors for the thrusters. Four 2000 gallon-per-hour Rule bilge pumps were used; two for the vertical thrusters and two for the horizontal thrusters. The plastic impeller was removed from the bilge pump and propellers were attached to the bilge pumps using aluminum propeller adapters turned by team members on a lathe (Figure 4). In past years the team had used model airplane propellers, but this year 7.6 cm diameter marine propellers were used because the blades on a marine propeller are optimized for an aquatic environment (Figure 5).

A large concern while designing the thruster assemblies was having proper safety precautions to keep fingers and other body parts out of the path of the spinning propeller while not restricting the flow of water. Stiff hardware wire with 1.2 cm square holes was chosen because the holes were small enough to keep fingers out, yet not interfering too much with the flow of water. For the two horizontal thrusters, cages were created out of the hardware wire to fit over the propeller and for the two vertical thrusters, the hardware wire was incorporated into the foam block on the top of the ROV (Figure 6).

Figure 4 – Turned Aluminum Propeller Adapters

Figure 5 – Propeller on Adapter

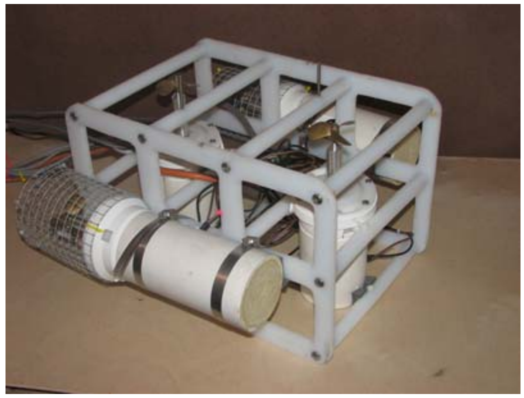


Figure 6 – Mounted Thrusters

Flotation and Ballast

The flotation and ballasting system employed by this year's ROV was rather simple in philosophy and design. The goal of the system was twofold. First to achieve neutral buoyancy, or the state in which the ROV's mass equals the mass it displaces in the surrounding water. The second was to keep the ROV's center of buoyancy above its center of mass to eliminate roll and pitch. Achieving both of these goals was important in the design so that the driver's effort would not have to be expended on keeping the ROV upright. To achieve both of these things, the negatively buoyant motors were placed at the middle and below on the frame of the ROV. A 45cm by 25cm block of pourable urethane foam was cast in a wood mold to precisely fit on the top of the ROV's frame (Figure 7). Steel rods were secured to the bottom of the frame. Steel was chosen because it is denser than aluminum, thus taking up less space in the frame, although it required an anti-rust coating. If the payload tools or other components of the ROV needed to be rearranged, small pieces of steel rod could be easily attached to the ROV to bring it back to neutral buoyancy.

Figure 7 – Urethane Foam Positioned on ROV

Electronics

The primary goal in designing the ROV control system was to command and control all of the functions of the onboard components from the surface. A computer based interface was chosen over on-off switches or relays because in past years when using on-off type switches, the ROV would continue drifting past when the switch was flipped since the ROV is suspended in water. Using a proportional computerized setup allows the driver to move the ROV quickly as well as very slowly and to program exactly how fast the thrusters spin based on various joystick positions (Figure 8).

Input signals were issued to the computer via an Xbox controller, which then sent serial commands to the ROV through a program written in Visual Basic by the team (Figure 9). The serial signal was delivered to a servo controller, which output standard pulse width modulation (PWM) signals through each of its 16 ports, linearly proportional to the input provided by the operator (Appendix A). A dead zone was also programmed so that if the joystick did not return to the exact center, the ROV would not move.

To translate the PWM signal to the actual motors, an electronic speed controller (ESC) was needed. The ESC received the PWM signal from the servo controller and output voltage proportional to the PWM signal input (Appendix B). The varying voltage allowed the motor to spin at varying speeds, producing finer positioning control; instead of just one speed the ROV could be driven at many speeds. If the pulse width of the PWM signal was between .75ms and 1.5ms, then the motor would spin in reverse, faster for lower values. If the pulse width of the PWM signal was between 1.5ms and 2.25ms, then the motor would spin forwards, faster for a higher value. When the pulse width was 1.5ms, the motor would not turn; this was the "centered" value.

The motor controllers had to provide both the voltage and current that the motors required, which for the motors selected was 12 volts and 4.1 amps while running in the water. An electronic speed controller was selected that could supply a maximum of five amps to the motor, which would be sufficient to power the motors at maximum power. The whole electronics setup was modular in design so that malfunctioning components could easily be identified and replaced, or capacity increased to allow for additional thrusters if necessary (Figure 10).

Figure 8 – Computer Cart

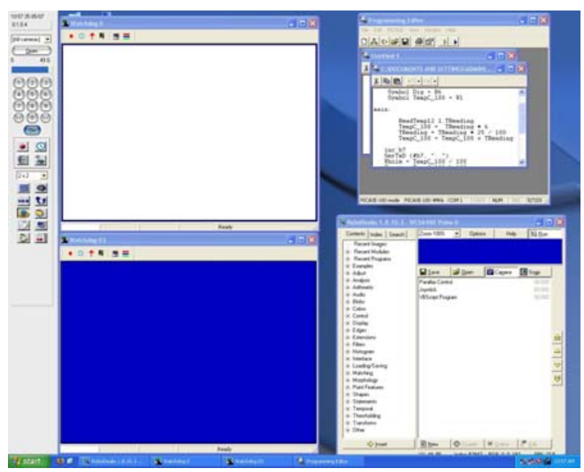


Figure 9 – Software Screenshot

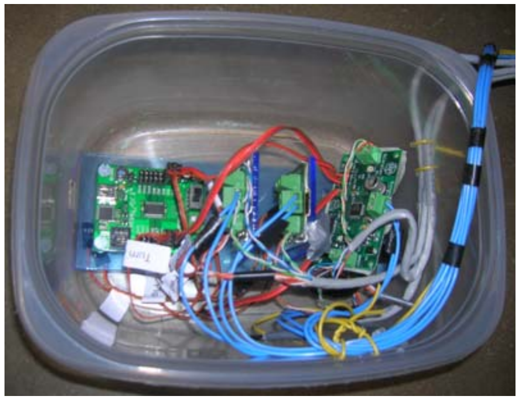


Figure 10 – Electronics Hardware Setup

Cameras and Sensors

A visual system onboard the ROV is an important part because the driver is not allowed to look over the pool edge at the ROV while completing the tasks. Three black and white underwater Seaview cameras were used to observe the various operations of the during missions; cameras were necessary to see what the ROV was doing. The cameras were connected to a video capture card in the computer which enabled all three feeds to be displayed side by side on the computer monitor. Using hose clamps to attach the cameras to the frame allowed the camera's field of view to be easily adjusted if needed.

When deciding on the camera positioning, the main factor that was kept in mind was to maximize the usefulness of each camera. The first camera was attached to the lower corner of the ROV, so that its straight forward field of view would allow the driver to have a level forward view for driving. The second camera was attached to the ROV so that it was facing the gripper at a downward angle. This camera was used whenever the driver needed to precisely manipulate the gripper, especially in the mission in which the ROV was required to pick up the crabs. The last camera was secured to face the aquarium net and funnel for collecting the black smoker samples and positioning the temperature sensor (Figure 11).

In order to complete temperature sensing missions in the hydrothermal vents, a DS18B20 digital temperature sensor was waterproofed and positioned at the narrow end of un upside-down funnel onboard the ROV. When the ROV is lowered in the water, the funnel holds the temperature sensor on top of the black smoker vent in order to keep the temperature sensor in position above the vent flow. This sensor was connected via Cat5 cable to a PICAXE microcontroller at the surface, which then regularly outputted a temperature printout to the computer, using a program written by the students. The PICAXE board's unique layout was developed for use in a variety of applications at Thomas Jefferson High School for Science and Technology and was readily available for the team to wire and program for use on this vehicle.

Figure 11 – Camera Positioning

Manipulator

A primary and essential component required for the completion of various mission tasks is the arm or manipulator. After extensive reflection and experimentation, it was determined that two different types of vehicle arms would be necessary and most effective in collecting various underwater samples. The first part of this subsystem was the gripper, developed for the purpose of picking up vent crabs or black smoker samples from the seafloor (Figure 12). This ROV's gripper consisted of a complex hinge system, whereupon forward extension of an aluminum bar would open the claw, while backward motion would close the claw. This lateral motion was controlled by a bilge pump motor mounted on the manipulator's UMHW base. Motion on the motor would extend or retract aluminum fingers, which were connected to the aluminum claw with stainless steel machine screws (Figure 13). Additionally, jagged "alligator" edges on the insides of the claw allowed for easier capture of animals of long-legged animals such as vent crabs. The gripper component of the manipulation subsystem was located near the bottom of the ROV to increase its mobility and ability to pick up items from the seafloor.

Another component used to complete the tasks was the aquarium net, installed to allow for the collection of black smoker samples (Figure 14). While it would not require more than 2 N of tension force to pull each smoker sample off of the vent, it was determined that much less force would be necessary if a shear motion was used to remove and capture these samples. Thus, the aquarium net allows for the least exertion of force by the ROV by shearing and catching black smoker samples in one upwards motion.

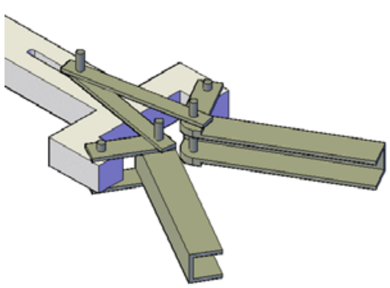


Figure 12 – CAD Render of the Gripper

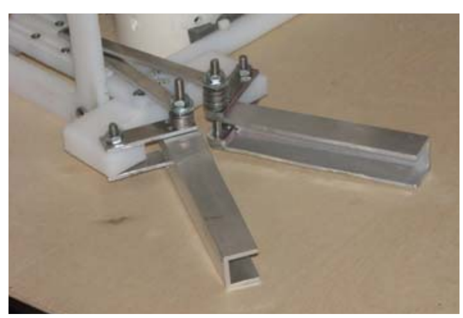


Figure 13 – Completed Manipulator

Figure 14 – Net for Black Smoker Collection

Challenges

1. One of the major challenges was funding. Both of the labs that the team was working out of receive money each year from the school, but this is split among the many projects that are occurring in each lab. Because of this, the money that was allocated to the project had to be spent carefully. Several of the components from the previous year's vehicle were reused including the cameras and bilge pumps. New propeller adapters were turned on the lathe so that they would be the desired length, however reusing the motors reduced the total cost for the propulsion system significantly. Also, the systems were not planned to be overly complex, even keeping all of the electronics topside to reduce the risk of malfunctions which would end the mission and require replacement of expensive components.

2. Another challenge was finding a place to test the ROV in the water. The team's school does not have a pool and most of the public pools are not welcoming to ROVs. The team was able to test in a pool belonging to a friend of one of the team members. Although not as large in size as the pool at the actual competition, this pool still enabled testing of the ROV down to the depth that will be encountered at the competition to check the depth rating on the ROV. It was also large enough to practice driving maneuvers to test the capability of completing the mission tasks using mockups of the mission props that were built according to the specifications provided.

Troubleshooting Techniques

Being able to troubleshoot malfunctions on an ROV is a very important part of the testing and improvement process. There are many things that the team has experienced that can go wrong with an ROV, from thrusters not working to the ROV being unstable in the water. The most effective way that the team has found to troubleshoot most things is to take an approach of eliminating possible causes of the problem. For example, if one of the thrusters does not spin up, the problem can be analyzed with a methodical approach. First, the fuse is checked to ensure that it has not blown from a short or overload. Then the computer is checked to ensure that the joystick is being read and signals are being sent to the servo controller. If neither of these things is the problem then the topside electronics box can be opened. The LEDs on the servo controller and electronic speed controllers indicate whether the signal is being received from the computer and processed. Next a multimeter can be used to check whether the speed controllers are outputting the correct voltage based on the signals. If none of the electronics up to this point are at fault, then the problem is either a cut in the tether or a broken thruster, and both can be tested at this point. By deciding on a systematic approach and following it every time there is a problem, much of the

Future Improvements

One significant improvement would be to put some of the electronics onboard. If the servo controller and electronic speed controllers were onboard the ROV, the tether would only need two wires to carry the power to the ROV, eliminating many of the pairs of wires that are currently running down to each motor. If more sensors were needed, they could more easily be wired into the electronics housing rather than having to run another wire through the tether. Likewise if an additional thruster were installed, such as for sideways movement, another electronic speed controller could be installed in the onboard housing.

However the main drawback to putting the electronics onboard would be the need for a very waterproof housing; even one drop of water in the wrong place inside the housing could short the electronics and cause them not to work anymore. Keeping all of the electronics topside does enable faster troubleshooting; there is no additional housing to open, but at the cost of the tethers flexibility and weight. The benefits and risks of this improvement need to be carefully considered before implementation in future designs because of the cost and risks to the electronics components.

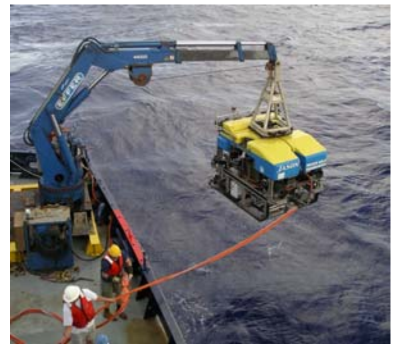
Lessons Learned

A lot of valuable knowledge and experience was gained through the design, construction, and testing of this ROV. When constructing the ROV, there were several operations that required a high degree of accuracy. The propeller adapters are one good example of this because they had to be turned precisely to ensure that the propellers spin centered on the bilge pump shaft so that minimal efficiency is lost. Also, while constructing the frame, the holes in the UHMW sheets for the UHMW rods had to be accurately lined up so that the rods would be perpendicular to the sheets and the ROV frame would not be crooked. By putting safety first, the team managed to avoid serious injuries during the construction process.

Perhaps more important than the technical skills, a comprehension of the enormity of a project like this ROV was gained by the team members. The team was required to choose reasonable goals in deciding on the best solution for each system, while still ensuring that they were compatible with each other and worked towards the ultimate goal of a functioning ROV. During the first part of the year, there was a much more laid back attitude as plans were made. However, as the deadlines for having the ROV done crept up, team members became stressed about completing all of the parts of the ROV.

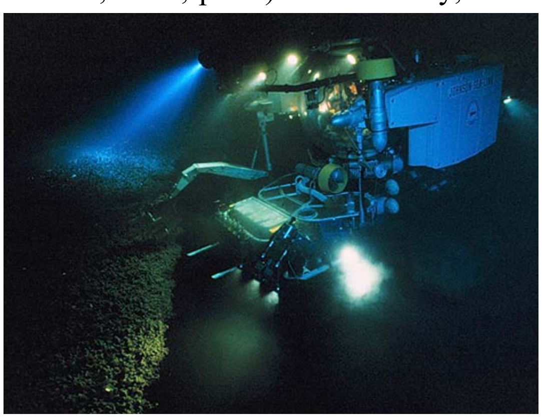
However by staying calm the team was able to refocus its stress into productive building power and enhance the overall positive attitude of the team.

Description of a Scientist



Jason II prior to descent.
http://www.rps.psu.edu/featuredsite/tool.jpg

The mission tasks performed by this ROV emulate actions required of professional submersibles in real-life situations. The collection of vent crab samples especially reflects the efforts of Dr. Charles Fisher of Pennsylvania State University in studying mid-ocean ridges. Since 1985, Dr. Fisher has extensively studied and examined animals found around deep-sea hydrothermal vents and hydrothermal seeps (Distinguished Lecturer Series, 2007). By collaborating with scientists in several fields and establishing an interdisciplinary approach toward research and study, he continues to work towards understanding of deep-sea ecosystems and the complex processes associated with them such as plate separation and ocean crust formation (Van Dover, 2000, p. 25). Additionally, he has led mapping expeditions to identify areas with hydrothermal vents and track the progress of living communities over time (Explorations: Gulf of Mexico: Background). In completing such explorations, the professor makes broad use of remotely operated vehicles such as the *Jason II* and the *Johnson Sea-Link* (Williams, 2005). With over 50 expeditions already completed, Fisher has worked with such submersibles at sea for up to four months at a time. During future expeditions, he will expand into the field of geology and study rocks located in mid-ocean ridges. Sample collection for such projects is simulated by this ROV's collection of black smoker samples.



Johnson Sea-Link atop a brine pool.
http://oceanexplorer.noaa.gov/explorations/02mexico/background/plan/media/5sealink_600.jpg

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Reflections

Working as a team has both its benefits and drawbacks, as experienced throughout this years designing and construction effort. The team was able to combine varying strengths and interests while discussing design ideas and the best way to accomplish the three missions. As the design of each of the systems evolved, so did the dynamics of the team and the methods of keeping each other informed about the progress on each system. More scheduled meetings to discuss the systems, especially ones that need to function together such as electronics and motors, might help the systems to keep on track better in future years. In the final stages of the project and after many hours of research and construction, testing the ROV in the pool for the first time and watching it move around were the most rewarding parts of this process. The regional competition itself was another rewarding learning experience connected to this project. The team was challenged to rearrange the ROV after running into problems at the actual competition, a troubleshooting skill that is inevitable in all real world scientific uses of ROVs. Participating in this project and this competition allowed the members of the team to develop and practice skills associated with problem solving, construction, and communication. It also required the application of math, physics, electronics, and CAD.

Acknowledgements

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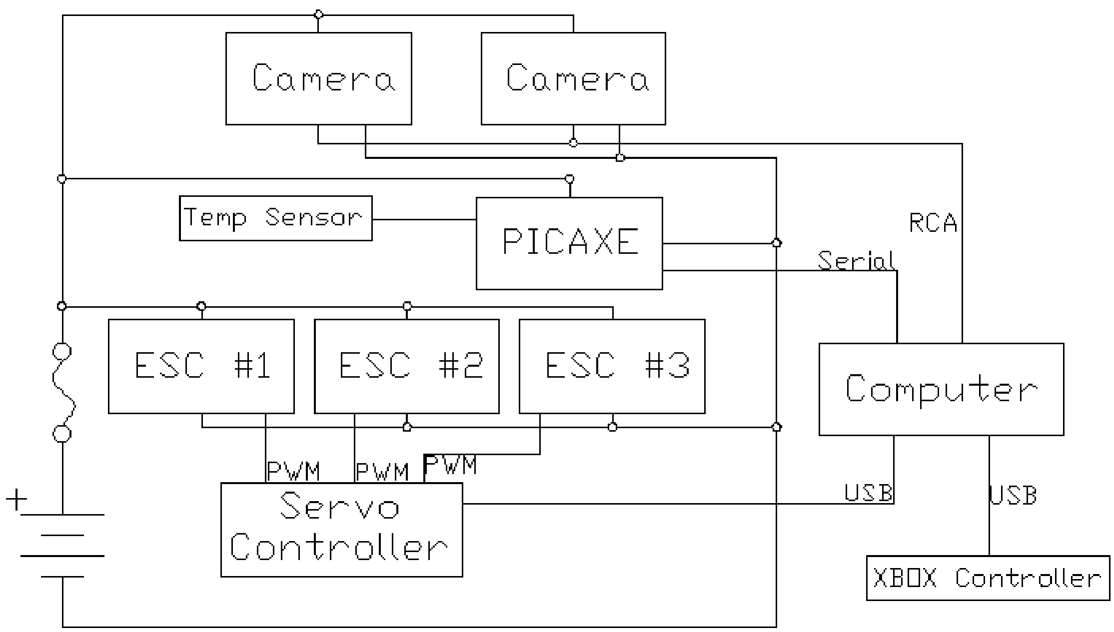
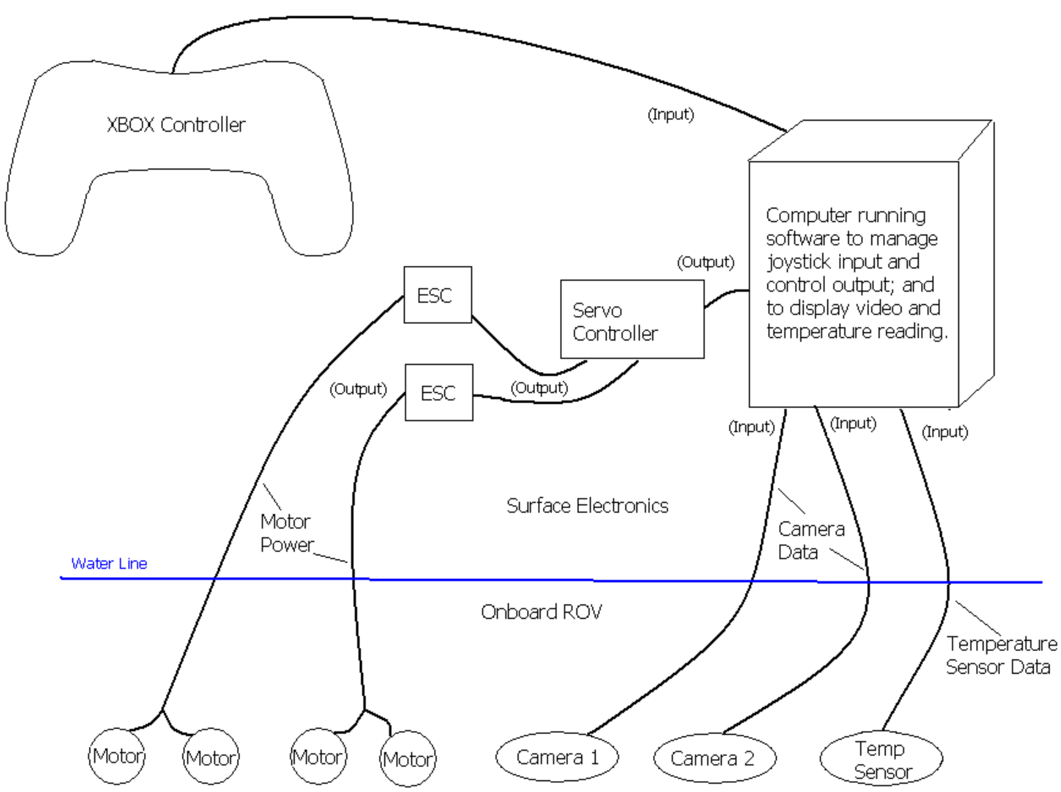
Mrs. Lisa Wu, for her time and mentoring
John Goodwin, for opening his pool for testing
The MATE Center, officials, judges, and staff, for making this competition possible

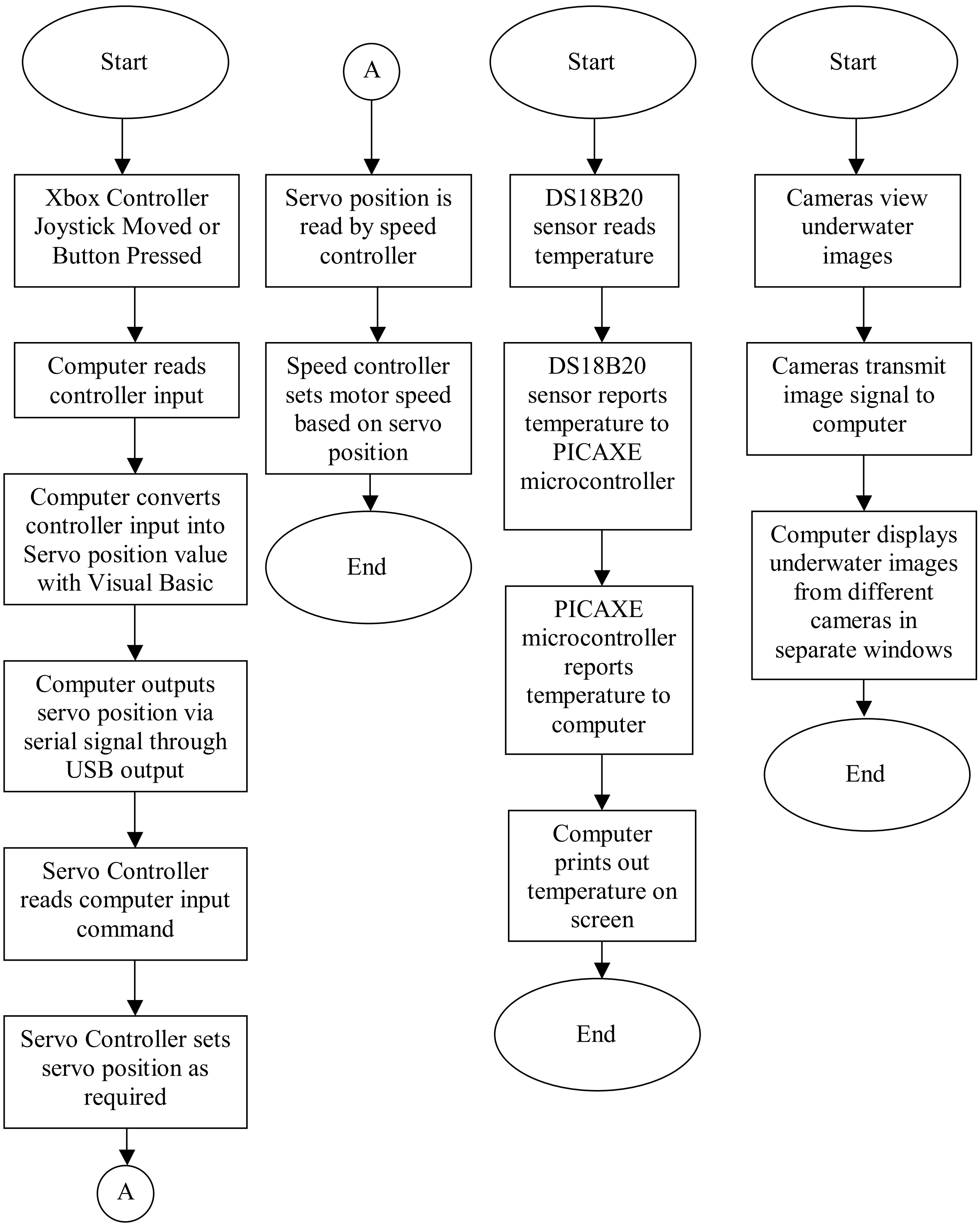
Appendix A – CAD Electronics Schematic and Graphical Electronics Layout Diagram





Appendix B – Software Flow Diagram

This diagram shows the three flowcharts representing the separate processes the computer is running while the ROV is being operated.



Appendix C – Detailed Budget Spreadsheet

PART DESCRIPTION	UNIT COST	QUANTITY	TOTAL COST	SUPPLIER
FRAME				
3/8" UHMW Sheet 12"x36"	$34.35	1	$34.35	Online Metals
.75" UHMW Rods 4' long	$6.64	4	$26.56	Online Metals
1/4-20 SS Screws	$5.83	1	$5.83	Mcmaster-Carr
BALLAST				
Pourable Urethane Foam	$0.00		$0.00	School Lab Equipment
.75" Steel Rods 4' Long	$6.25	4	$25.00	Online Metals
ELECTRONICS				
Parallax Servo Controller	$0.00	1	$0.00	Donation from Parallax
Electronic Speed Controllers	$59.99	3	$179.97	Dimension Engineering
Computer and Monitors	$0.00	1	$0.00	School Lab Equipment
XBOX Controller	$0.00	1	$0.00	Personal Loan
Tether Wires	$67.39	1	$67.39	Home Depot
SENSORS				
WCSA400 Video Capture Card	$0.00	1	$0.00	Loan from Webcam Corp
DS18B20 Temperature Sensor	$0.00	1	$0.00	Free from Maxim
Waterproof Cameras	$0.00	3	$0.00	Reused From Last ROV
MANIPULATORS				
Scrap Plastic and Aluminum	$0.00		$0.00	School Lab Scrap Material
Bilge Pump	$0.00	1	$0.00	Reused From Last ROV
Aquarium Net	$0.00	1	$0.00	School Lab Equipment
Funnel	$3.00	1	$3.00	Home Depot
PROPULSION				
2000 GPH Bilge Pumps	$0.00	4	$0.00	Reused From Last ROV
Propellors	$0.00	4	$0.00	Reused From Last ROV
Aluminum for Propellor Adapters	$0.00	4	$0.00	School Lab Scrap Material
Hardware Wire for Shrouds	$8.00	1	$8.00	Home Depot
MISCELLANEOUS				
Hose Clamps	$1.50	8	$12.00	Home Depot
Cable Ties	$8.00	1	$8.00	Home Depot
	Total Cost of New Materials:		$370.10	