NASA/ASU SPACE GRANT ROBOTICS

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ARIZONA SPACE GRANT CONSORTIUM

MARS SPACE FLIGHT FACILITY

Orbital

"Purposely combining electricity and H_2O"

1. Abstract:

This report describes the design and construction of the Aquabot underwater vehicle by the ASU/NASA Space Grant Robotics team. The ROV is constructed with a small PVC frame and is propelled by a series of bilge pump thrusters. The ROV is controlled directly by an Arduino controller which receives signals from the surface via a RS-232 communication link. Commands are given to the ROV from a computer on the surface running a C# application. As first year robotics team, every aspect of this robots design was a new challenge to surpass. Despite our inexperience, we were able to fabricate a functional robot to compete in the 2009 MATE competition.

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2. Budget and Gnatt Chart

A budget was created at the beginning of year to keep track of the finances. At the end of the year, the actual expenditures were compared with the budget as shown in figure 1. The team ended up spending less money on the materials than originally expected. Since the students were broken up into individual sub-teams, each was allocated an amount of funds to both prototype and build their respective system. A detailed budget is shown in Appendix A.

EXPENSE BUDGET

NASA/ASU Space Grant Robotics

Non-Robot Expenditures	Budget	Actual	Difference ($)	Difference (%)
NURC Registration	$ 250.00	$ 250.00	$ -	0.0%
			$ -	

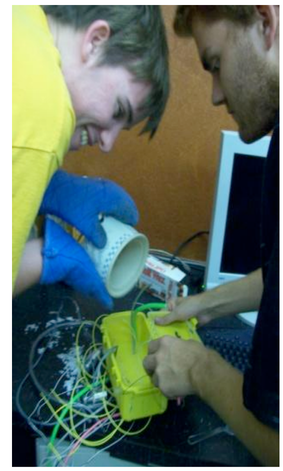
Robot	Budget	Actual	Difference ($)	Difference (%)
Inventivity UROV kit	$ 300.00	$ 290.00	$ 10.00	3.3%
Misc. Repair Parts	$ 50.00	$ 80.00	$ (30.00)	-60.0%
Proto Propulsion	$ 200.00	$ 35.00	$ 165.00	82.5%
Proto Control	$ 100.00	$ 7.00	$ 93.00	93.0%
Proto Frame	$ 50.00	$ -	$ 50.00	100.0%
Proto Lights/Camera/Hydro	$ 50.00	$ 75.00	$ (25.00)	-50.0%
Proto Arm	$ 100.00	$ 50.00	$ 50.00	50.0%
Proto Sensors	$ 20.00	$ 20.00	$ -	0.0%
Propulsion System	$ 200.00	$ 315.00	$ (115.00)	-57.5%
Frame System	$ 150.00	$ 40.00	$ 110.00	73.3%
Lights/Camera/Hydro System	$ 200.00	$ 150.00	$ 50.00	25.0%
Arm System	$ 300.00	$ 115.00	$ 185.00	61.7%
Control System	$ 300.00	$ 113.00	$ 187.00	62.3%
Sensor System	$ 50.00	$ 10.00	$ 40.00	80.0%
Mission Props		$ 110.00	$ (110.00)	
			$ -	
Other	$ 200.00		$ 200.00	100.0%
Total Material Expenses	**$ 2,270.00**	**$ 1,410.00**	**$ 860.00**	**37.9%**

Table 1: Projected vs. Actual Budget

Additionally, a Gnatt Diagram was created to keep the team on track in a timely manner. Each of the systems were to work for the allocated time in the prototype, design, build, and integration phases; time was allocated for review of the phases. The diagram is included in appendix B.

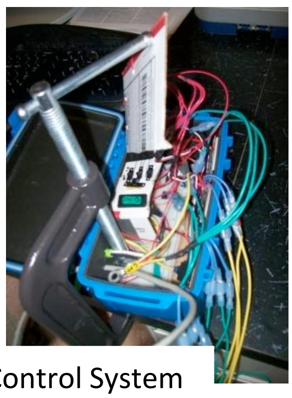
3. Design Rationale

Each of the sub-teams detailed the design rational for their subsystem (sections 2.1-2.6).



Alex Kafka and Mark Garrison sealing the control box with melted wax

3.1. Control System



Control System

The control system used by this underwater vehicle was developed primarily based on the design requirements, as well as the available skills, funds and time. The fundamental consideration which dominated the design was the desire to strike a balance between complexity and cost. Although complex, custom systems are inherently cheaper than simpler, pre-built commercial control solutions, it was necessary to consider time constraints and the available expertise of the team. Finally, after weighing the benefits of custom and commercial solutions, a balance was found between the two.

This system is comprised of two main divisions. There are the surface controls, which consist of a computer, a USB joystick, a video display monitor, and a C# .NET application, and the submerged portion, consisting of an Arduino, four Victor DC motor speed controls, and a small amount of custom electronics on a breadboard. These components communicate using RS-232 serial and a custom packet protocol using CAT-5 twisted pair cable. The submerged controller is powered using a section of extension cable providing 12V DC for all submerged operations. Additional cables that run to the vehicle are used for streaming composite video from several cameras mounted to the robot frame.

3.1.1. Surface Component

The surface control is executed using a custom C# application running on the driver's laptop. The functionality of this application is diagramed in appendix D. This application utilizes Managed Direct X to access data from the joystick interface. The application then communicates to the vehicle using .NET's managed RS-232 interface. A single background thread is used to sample the joystick position, transmit control data over the serial link, request sensor feedback and update the display with current information. This solution was selected based on the experience of team members. The communication protocol is simple, utilizing RS-232 at its native voltages, and organizing commands into packets. The driver computer acts as the master, and the submerged control system will not transmit data without a request from the host. The system also uses keep alive packets to keep the pilot aware of any loss of physical connection, and the application is capable of interpreting five error messages from the device so the engineering team can quickly identify and repair failures.

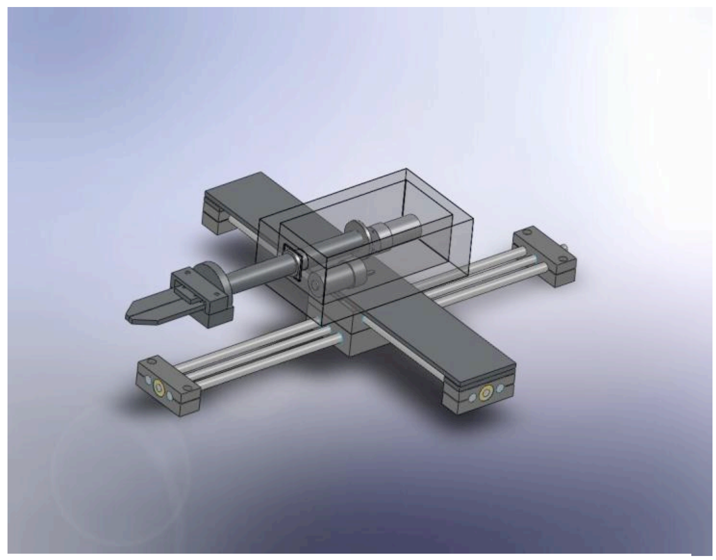
3.1.2. Submerged Component:

The submerged system executes its code on the Arduino development board on an ATmega microcontroller as shown in appendix D. The hardware for this device is described in appendix C. The device communicates with the surface via the provided CAT-5 cable using asynchronous serial at a selectable baud rate. However the controller is not compatible with the RS-232 standard voltages. A maxim MAX232 chip is used to level shift the transmitted and received voltages onboard the vehicle. The software on the Arduino is simple and straight forward. After initialization of motor control outputs, the device sits in an endless loop waiting for serial data; when data is received the software processes that data one byte at a time and responds appropriately. Motor control is affected by bit-banging a Servo control signal, which is a process of writing software that times the transitions of the digital outputs to produce a PWM signal. The decision to use bit-banged PWM was based on the number of motors and the number of hardware PWM peripherals available on the controller. Although the chip itself has six dedicated PWM peripherals, the existing class written for servo control only utilizes two of them. It was decided that it would be easier to simply use an existing bit-bang Servo class than to modify the hardware servo class to use the remaining PWM channels. From the controller, these Servo control pins were connected to four Victor Speed Controls. Power and ground were also provided to each servo connection. Each Victor was connected to the 12V made available by the tether to supply power to the motor. Each Victor was also connected to one of the 1000gal/hr bilge pump motors which comprise the thruster solution. All of the minor electronics on board the vehicle are powered using the 5V regulator on the Arduino development board. The lights, cameras, thrusters, and the input to the 5V linear regulator are powered from the 12V tether directly.

Two sensors were added to the vehicle design to facilitate specific mission goals. A LM35 calibrated temperature sensor is used to constantly report water temperature at the location of the robot, and a differential pressure sensor is used to constantly measure pressure against a fixed chamber to measure depth. These two components are connected to the Arduino controller using analog inputs. However, the pressure sensor proved to have too small of a range to be useful without analog voltage amplification. An op-amp in a differential amplifier configuration was implemented to solve this problem.

The vehicle also has several LED lights onboard to assist the driver in dark underwater scenarios. Each light consists of three high output directional LEDs which are PWM controlled directly from the micro controller using a 3A Darlington transistor.

The actuator and gripper that make up the arm are controlled using a hybrid system consisting of a double through relay and a transistor. The relay is configured in an H-bridge design, however since it contains only a single magnetic element it cannot by itself provide an off position to the motor. Therefore, it must always drive the motor in one direction or another. To solve this, a single power transistor connected to the ground source of the relay allows the control system to disable the arm, as well as provide PWM based speed control. This way an individual motor can be fully speed controlled using just one relay and one transistor.



Solid Work model of the complete arm design with waterproof container, claw, and adjustable slide

3.2. Arm

The arm sub-team reviewed the goals and objectives for the 2009 MATE and NURC competitions and formulated design criteria to meet for building a robotic arm.

Basic:

- Waterproof

MATE:

- Open submarine door
- Place ventilator into hatch
- Turn air valve
- Open submarine hatch (rotate)

NURC:

- Open monitoring station door
- Activate lever for ROV rescue
- Remove debris from mooring chain
- Retrieve core samples (horizontal)
- Retrieve bacteria sample (vertical)

Arm with claw and shaft complete

The team decided to take two different approaches to solve the problem at hand. The first was to use a plastic servo-based arm from RobotStore.com (COTS), and the second approach was to build a metal arm based on designs from www.homebuiltrovs.com (custom).

COTS

Pros:

- Simple
- Lightweight

Cons:

- Basic functionality
- Weak claw
- Small gripper

Custom

Pros:

- Interchangeable grippers
- Strong claw function

Cons:

- Possible weight issues
- Lengthy machining time

The first challenge we came across was using the designs provided by www.homebuiltrovs.com. The plans were drawn out, but there was no explanation to follow the designs. In addition, the plans did not use exact dimensions. The arm sub-team used the designs as a baseline to build our own arm. The basic design was first built in Google Sketchup, but the final version was modeled in Solidworks 2009.

When the team decided to use the Student Machine Shop at ASU approximately 20 hours of training was needed before work on the arm could start. Although the arm team had basic plans for the custom arm, the team had not built one before and many problems needed to be overcome.

Completed claw

After building the custom arm, the team needed a way to rotate and open and close the arm. The team decided to use two gear-head motors from allelectronics.com because they were small and reliable. When the motors arrived, the team needed a way to interface the motors to the arm parts. The original plan was to implement a belt or chain system to link the parts to the motors, however, after placing the arm into the desired enclosure the team discovered that there was not enough room to use a belt or chain, so the team turned to R/C hobby gears for racing cars. The racing spur gears worked perfectly and are in the final design.

Meeting the objectives for MATE and NURC was easy compared to the basic requirement of waterproofing. The original design called for using PTFE seals from McMaster-Carr, but the team quickly learned that these methods were not keeping the water out of the Otterboxes. The team tried silicone and epoxy, but nothing seemed to withstand the water pressure even at a couple of feet. After further research, the team discovered that filling the boxes with wax would keep the motors waterproof. The team attempted the waterproofing procedure, only to find that it was inadequate and one motor was completely filled with solid wax. Learning from the failure of the first motor, the second motor was successfully water-sealed so that it could function fully submerged in water. To keep the hot wax from flowing into the motor, hot glue was used to seal open gaps and petroleum jelly was used to seal screws and rotating shafts.

There are many lessons that can be taken away from the arm project.

- Create accountability within team members. Create a time table and due dates for items to get completed or accomplished.
- Do not rely solely on advertised waterproof boxes; they may be waterproof, but they may not be watertight
- Do not rely solely on epoxy or silicone to provide a good seal.
- When using wax to seal components, be sure that any possible air holes have been filled with epoxy or hot glue before immersing in hot liquid wax.
- Use a 3D modeling program before building any parts to avoid any unforeseen conflicts.
- Call suppliers far in advance of needed deadline for parts.
- Undergoing manual machine shop training prepares for current and future projects and design.

Future improvements to the current custom arm design would include:

- Slip rings for uninterrupted arm rotation with sensor and video cables
- A proven method for waterproofing
- More powerful motors
- Speed control for functionality

Collin Ho in the Student Machine

3.3. Propulsion

Design objective:

To create a watertight thruster capable of providing bidirectional thrust

Parameters:

- 50ft depth capable
- Thrust approx. 4N of thrust both directions
- Be able to operate at 12V - 48V
- Current draw < 10A
- Compact enough to have flexible mounting options

Aishwarya Stanley waterproofing thruster

Design progression:

We had purchased a basic ROV kit, which came with some rudimentary thrusters constructed from 12V bilge pumps and model airplane propellers. The working specifications of the bilge pumps, such as the depth rating and thrust, were unknown. Thus, a spring scale was used to measure the thrust of the bilge pump using a variety of propellers. The bilge pumps were just barely able to provide the necessary thrust, but they did not meet the design specifications for the MATE competition. Specifically, they could not run on 48V DC.

Other thruster options were considered, such as purchasing a commercial underwater ROV thruster, or designing and fabricating custom thrusters from scratch. It was found that commercial ROV thruster options were a bit out of the propulsion team's budget, costing a few hundred dollars per thruster at the very least. Thus the option to design and fabricate our very own thrusters was chosen, since they were within the team's budget and would theoretically provide sufficient thrust.

Emily McBryan and Collin Ho working on the lathe

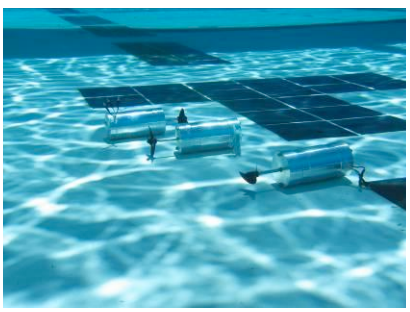
Collin Ho measuring the thruster

Implementation:

The original thruster design consisted of a two-piece aluminum housing and a brushless DC motor that would drive a shaft which would directly transfer energy to an external propeller. The whole unit would be sealed, and the shaft would be sealed with either PTFE spring loaded shaft seals or O-rings. A prototype thruster was constructed using off-the-shelf parts, and the aluminum housings were all machined by members of the team. Brushless DC motors were selected over standard brushed DC motors since they provided a higher power to size ratio, and their peak rpm could be adjusted by the stator winding setup. This way, the motors could be made to run at a lower peak rpm, while providing maximum torque. On a brushed DC motor, gearboxes would have to be used to increase torque and decrease the maximum rpm. Furthermore, brushless motors would operate at a variety of voltages, allowing for more flexibility in powering. O-rings were selected as the shaft seals since they were considerably more cost effective than using expensive PTFE shaft seals.

Testing:

It was found that the thruster provided reasonable thrust, but the single O-ring that was used as the shaft seal was not sufficient to completely waterproof the housing. Water seeped in, which would severely affect the performance of the brushless motor and possibly short the motor connections. A variety of off-the-shelf model boat propellers were tested to find out which one would provide the optimal thrust characteristics. A spring scale was used to measure the thrust generated by each propeller using the same control bilge pump motor.



Water testing the thrusters

testing the thrusters (picture taken by Nick Piacentine)

Propeller testing results		Force (N)				Time to descend/ ascend(sec)	
		Trial 1	**Trial 2**	**Mean**	**STDEV**	**Down**	**Up**
Prop 1	2 bladed, big-centered	3.05	3.00	3.03	0.04	8.37	50+
Prop 2	2 bladed, hemispherical top	3.00	2.75	2.88	0.18	8.69	50+
Prop 3	4 bladed	3.25	3.05	3.15	0.14	8.41	50+
Prop 4	2 bladed, sharp ended	3.00	3.00	3.00	0.00	10.53	28

It was found that the differences in thrust generated by each propeller were within $\pm$ 0.15 N, thus negligible.

Prop 4

Prop 3

Prop 2

Prop 1

Final Design:

In response to the shaft sealing issues, the final design of the thruster consisted of three aluminum body sections; a hollow cylindrical midsection, a motor end cap, and a seal cap. The seal cap was designed to accommodate five O-ring seals to add redundancy to the sealing system. In addition, the brushless motors selected for the final design had a 50% larger stator, allowing for a lower kV winding configuration, meaning even more torque. The solution to many of the problems found in the prototype was to overdesign the specifications. With the final design, almost all the original design parameters were met, but even with the 5 O-ring seals, there was still a little bit of water seepage. However, completely waterproofing the body section joints was discovered to be difficult, since silicone was found to be less effective at depths greater than 5 ft. The final

Bilge pump motor

thrusters to be placed on the robot are Non-Automatic 1000 gal/hr Bilge Pump motors with the propellers that exemplified the best performance. The team was disappointed that their model was not adequate for underwater use, however they are still working to perfect the thrusters they have made.

Latest thruster model

The latest thruster model

3.4. Sensors

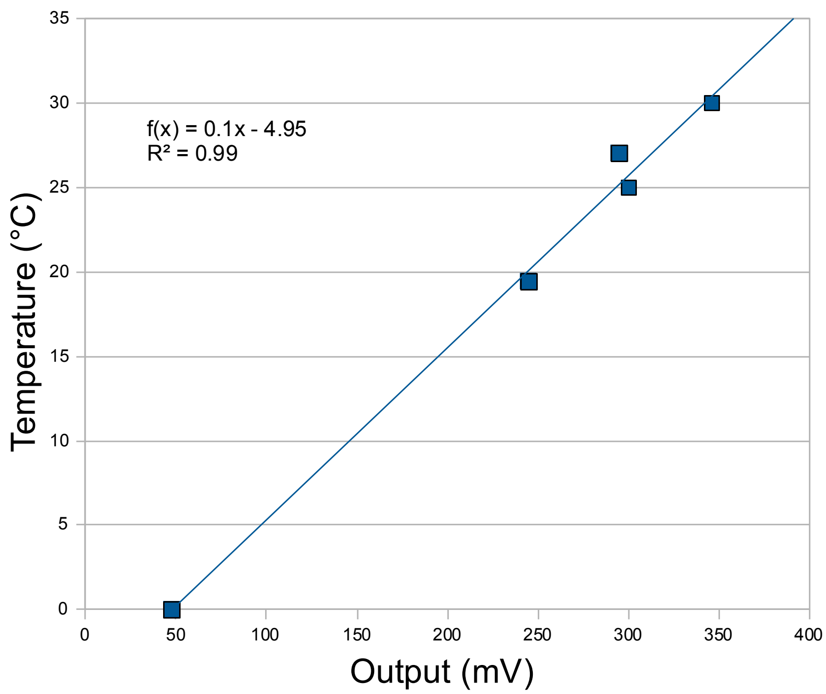
Temperature Sensor:

A standard LM35 temperature sensor was used to measure the water temperature. This sensor is commonly used in computers to measure internal temperature, and it comes pre-calibrated in Celsius. Unfortunately, it is not waterproof, so a waterproof housing capable of conducting heat was built. This consisted of a short length of copper tube, with one end filled with caulk and pinched shut. The sensor was soldered to a length of CAT3 cable and placed inside the tube in a bath of thermal paste. The remaining open end of the tube was then sealed with more caulk, resulting in a sealed container capable of conducting heat to the sensor. The resulting system has a thermal response time of a few seconds and maintains the pre-existing calibration. Testing indicates that the chip has a voltage offset of 48mV at temperatures near and below room temperature, but this offset appears consistent for the range 0-35°C.

The first version of the sensor used three pieces of speaker wire instead of CAT3 cable, and was mounted at the end of a length of flexible plastic tubing to provide additional waterproofing. However, it was determined that the wire gauge was far higher than was needed, and that that level of waterproofing was unnecessary, both of which interfered with connections to the control box. Therefore, later versions of the temperature sensor followed the design previously described.

Pressure Sensor:

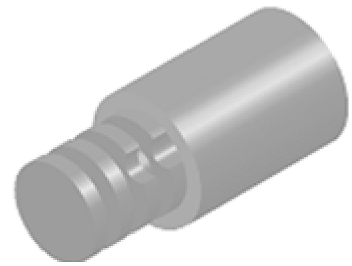
To measure water pressure, and consequently depth, an Omega PX26 differential pressure sensor was used. This sensor was chosen for having waterproof pressure detection ports, returning values within an order of magnitude of the desired 0-1V output range, and for being familiar to the sensor sub-team from a previous project. To waterproof this sensor, it was decided to simply encase the sensor in caulk. The CAT3 cable was run through a length of plastic tubing, such that the sensor was as close to the end of the tube as possible. Then the



entire sensor, except for one port, was embedded in a ball of caulk. This prevented water from leaking into the sensor and maintained surface atmospheric pressure in the covered port to provide a reference point for the differential sensor. To get the output up to an easily-detectable value, it was attached to an operational amplifier in the control box, which was designed to provide a factor of ten amplification to the sensor's signal, resulting in a theoretical output ranging from 0 to 500mV for depths from 0 to 4 meters of water.

3.5. Lights, Camera, Microphone

Overview:

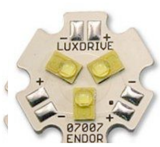


Custom Aluminum heat-sink for LED

The A/V (Audio/Visual) sensors for this year's ROV play a vital role in the completion of tasks in both of our competitions. The A/V Sensors include cameras, microphones, and lighting devices; these are primarily off the shelf items that are adapted to sub-aquatic conditions. The competitions' tasks this year include: observing damages to a submarine hull, recording audio from a volcano, and navigating in blackout conditions.

Lighting:

We are using Luxeon Star LED tri-emitters for our high intensity lights. These consist of three LEDs attached to a single board. We are incorporating these powerful LEDs into custom machined aluminum cases to provide both waterproofing and heat dispersion. The lighting system includes a constant-current converter circuit that maintains an adjustable light output regardless of the input current.



LED array

Lens

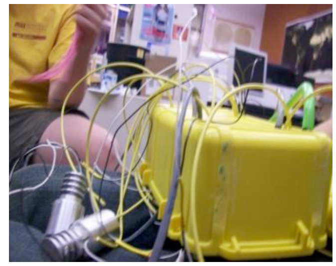
Power

Our 'star' LED arrays are capable of emitting 540 lumens at 700 milliamps of power. We plan to have three lights incorporated into the robot giving a total lumen output of 1620 lumens. Each light is equipped with a wide angle flood-style lens, giving a 25 degree beam angle.

Camera/Microphone:

A standard CCTV camera is being used on our ROV. It has been fitted with a 'Fisheye' lens, giving a 140 degree field of view with minimal edge distortion. The camera is powered by a step-down converter on the robot's control system to allow for 9V power from our 48V main supply. The CCTV camera contains a microphone, allowing for underwater sound recording within a limited range. The camera is placed inside of a Lexan box, making it watertight. The camera is positioned inside of the box such that the lens and microphone are as close to the edge as possible to reduce the possibility of distortion inside of the Lexan cube.

The camera chosen for this ROV has 380 TV lines of resolution (510×492 px) and a minimum light rating of only 1.5 lumens. It auto adjusts for low-light conditions, reducing color in favor of more light input for a clearer, brighter image. The attached microphone is sensitive enough to pick up sound through a 1/8 inch thick Lexan cube, and has a wide enough range to capture almost any audible frequency.



Light control system

Summary:

Our ROV is incorporating cutting edge LED technologies with innovative housings to provide maximum lighting output capable of illuminating the entire pool. The camera is economical and sturdy, allowing for hot swap spares and an array of cameras on the robot. The resolution and viewing angle allow for us to easily complete any task. The microphone incorporated in our camera system is rather simplistic, however, it is sufficient for the competition tasks.

3.6. Frame

Final Aquabot frame with complete thrusters and arm

The frame design constantly changed to accommodate all of the other components. By continuing to update the frame design as our robot progressed, we were able to account for newly discovered details encountered in construction of the other components. This strategy allowed us to fabricate an appropriately dimensioned frame without the expenses of a complete redesign.

Our first design revision consisted of a large, aluminum box frame dominated by a sizable XY pan table used to control the arm. However, this component was ultimately nixed from the design. This updated design no longer required such a large frame. The next design, a cubic skeleton, was based on our prototype ROV kit, which performed adequately. The cubic skeleton design abandoned aluminum as the material of choice because it was too heavy. We returned to PVC because it was much lighter and easier to work with. After we put the aluminum frame design aside we toyed with the idea of using our prototype ROV frame for our robot. However, we soon realized that the controls and arm would not fit on the frame. At this point we discovered that one of the submarine props initially made for testing was the perfect size and shape for the frame. Mounts for the thrusters were taken from the prototype unit and all other tools fit together perfectly on the ROV, now christened Aquabot.

4. Lessons Learned

The team gained knowledge and skills in many areas, perhaps the most useful being machining. In the process of machining and creating parts, team members learned how to use Solidworks to design parts and machine their creations. Incoming freshman and returning students operated mills, lathes, and bandsaws under the watchful tutelage of resident machinist Mark White at the ASU Student Machine Shop. These skills were essential in building the robot and provided another level of insight into ROVs.

Perhaps the most significant lesson was the importance of sharing knowledge and information. Although most members are engineers, they come from different fields, contributing knowledge of electronic wiring, frame building, robotic arm design, modeling, computer programming, underwater environments, and much more to the general pool. Without combining everyone's unique talents and educating the team, the robot would never have come together. By sharing bits of knowledge from different fields, members have advanced their understanding of robotics design, building, and operation.

The value of tutoring and sharing information spread beyond the team. Several members served as mentors for FIRST high school robotics teams at Hamilton High School and at Marcos de Niza High School, helping high school students with their competitions and spreading a love of robotics. The team also participated in events such as Homecoming and Earth and Space Exploration Day, teaching adults and children from the local community about robotics and engineering. Sharing ideas and knowledge within and without the team will continue to be a core goal.

5. Future Improvements

This has been our first year as a team, so we have many improvements planned for the future. The team created a mechanical arm, thrusters, and controls from scratch, but they were not waterproofed in time to be included in the final design. Hopefully they will be waterproofed and incorporated into the robot after competition. Finding new innovative methods for creating watertight and waterproof components is an important area for further research, since conventional waterproofing methods don't always work under high depth and pressure.

The team plans on creating a custom control system and microcontrollers. Building a customized system will provide hands-on electrical engineering experience, as well as allow for an integrated, streamlined design perfectly correlated to the robot.

For future video, the team plans on using fiber optic cable to transmit data. This is an opportunity to work with cutting-edge equipment, allowing for error correction and increased data flow. Fiber optic cable is also neutrally buoyant, and will allow for fewer wires in the tether, simplifying data transfer between the robot and controls.

Another improvement the team plans for the ROV is the addition of variable pitch propellers. These will be tricky to mount but will allow for greater range of movement and increased maneuverability.

The team built an aluminum frame for the robot, but buoyancy was a major issue in the use of aluminum as a material. Currently the robot has a PVC pipe frame, which is very light and works well underwater, but hopefully the obstacles to using a custom aluminum frame will be overcome in the future.

6. Reflection

"As a freshman, I did not have much to contribute to the team as far as skills and experience went. I was really hesitant to put myself out in the team because I was afraid I would drag them down with my lack of experience and would frustrate others if I failed. I stayed on the sidelines for a while and put my time in the Machine Shop. Advised by mentor Mark White, I learned how to use the lathe, mill, bandsaw, and other such machines. In order to maximize shop time I was also taught Solid Works by fellow student team members. I gained confidence in myself as I became one of the machinists for the team. I put my experiences gained in the shop towards the claw team and the propulsion team, creating the aluminum pieces that would be used on the robot. I learned so much in the shop and thought I had found my place on the team. As the build season started coming to a close, the ROV was far from finished. Mike Veto, the president, placed me on the propulsion team. I was wary to dive in because the thrusters needed work past the point of machining. But I took the confidence I had gained and went forth with very little knowledge of propulsion and waterproofing motors. I found that the team is made up of really understanding

people who won't hesitate to teach someone something new. I helped test the motors in the pool and learned how to waterproof them. With this came the hardships of sealing air in a constantly changing pressured environment. I learned the fundamentals of motors and watched in awe as my teammate wound and created a motor by hand. We tested different propellers which taught me the importance of dynamics and what materials act best under the stress of water. I found that my place on this team is not in one specific place or area, but everywhere I can help. I learned that there is no limit to what I can learn and there is always someone who is willing to teach me. I am eternally grateful I found this team at ASU and for all the academic adventures we as a team have journeyed on."

~Emily McBryan

7. Submarine Research

With the emergence of submarine warfare in the mid 1900's came the call for safer conditions for the crew. Ever since, the US Navy has been working to create better technologies that could protect the submariners.[1] The primary way to reduce the risk of submarine operations is to prevent problems before they occur. The Navy has instituted the SUBSAFE program, establishing casualty control procedures and implementing maintenance and material requirements for greater reliability.[2] They also created and installed emergency recovery systems to improve the integrity and recoverability of the submarines in the event of a casualty. The Navy has developed a three-pronged rescue program consisting of Survival, Escape, and Rescue.[2] By equipping crew members to help themselves, as well as training surface support crews in submarine rescue, the Navy is able to greatly reduce its casualty count for submariners. The current limiting factor in the survivability of the crew is the atmosphere control. Through the redistribution of lithium hydroxide canisters and the use of passive carbon dioxide scrubbing, the crew's support systems can last for up to four days. With future micro pore carbon dioxide scrubbing systems, that time should increase to at least seven days.

Submarine

In addition to sustaining the crew on board a damaged submarine, the Navy is also working on ways to allow crew to escape the sub in the event of an emergency. Currently the Navy has "Submarine Escape and Immersion Equipment", which consists of a full body suit that includes thermal protection and a built in life raft. It allows crew members to escape at depths down to 600 feet and survive on the surface.[3] To augment the on board emergency procedures, the Navy maintains several rescue vehicles that can be used to save the crew of a submarine. The Navy has two Submarine Rescue Chambers (SRC) that can rapidly be transported to a support vessel and deployed to a disabled submarine.[4] These SRC's are capable of rescue down to 850 feet and can be mated to the damaged submarine. The US Navy also maintains one Deep Submergence Rescue Vehicle, capable of rescues down to 2000 feet. This vehicle is maintained in a ready state at all times, and can be moved to anywhere in the world within 36 to 48 hours.[4]

8. References:

1. "Current submarine rescue services." Janes Naval Force News. Ed. IHS (Global). 19 Feb. 2001. IHS (Global). 26 May 2009 <http://www.janes.com/defence/naval_forces/news>.

2. Grossenbacher, John J. "Submarine Rescue: Ready For the Unthinkable." Undersea Warfare 3 (2000). The Official Magazine of the U.S. Submarine Force. Fall 2000. US Submarine Force. 26 May 2009 <http://www.navy.mil/navydata/cno/n87/usw/issue_9/contents.html>.

3. Submarine Search and Rescue(SMERLO)(ISMERLO). 14 May 2009. International Submarine Escape and Rescue Liaison Office. 26 May 2009 <http://www.ismerlo.org/>.

4. "US Navy's Submarine Rescue Team." U.S. Government Info - Resources. 17 Aug. 2000. About.com. 26 May 2009 <http://usgovinfo.about.com/library/weekly/aa081700a.htm>.

9. Acknowledgements

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- LED Dynamics
- Digi-Key
- Industrial Metal Supply
- Otterbox
- Innovative Designs/Scorpion Motor
- Solid Works

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We would like to recognize the support of the staff of the Mars Space Facility for all of their support and patients in all of our efforts. A special thanks goes out to Meg "Mars Mom" Hufford for her invaluable support and supplies, to Scooby for helping us with posters and graphics, and to Chris Kurtz for all of the assistance with the computer lab, software, and electronic supplies.

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Mark E. White has been monumental in the success of the space grant robotics team. He has donated hundreds of hours to help train the students in the arts of machining in a fun and exciting atmosphere. Without Mark's influence we would never have learned how engineered designs become real hardware. Thanks Mark!

Shea Ferring has been largely responsible for the success of the Space Grant Robotics Team. His vision to expand hands-on engineering and professional mentorship to students has outreached to nearly hundreds of students. Thanks for the push to expand robotics!

Dr. Phil Christensen has been a huge support for the robotics team. He has provided us with a place of operations for the team at the Mars Space Flight Facility, furnished the team with tools to work on the robot, and has spent time guiding the team and helping us out when in time of dire need. Phil's vision to expand the educational experience amongst the college students is a praise worthy characteristic that should be emulated in all college professors.

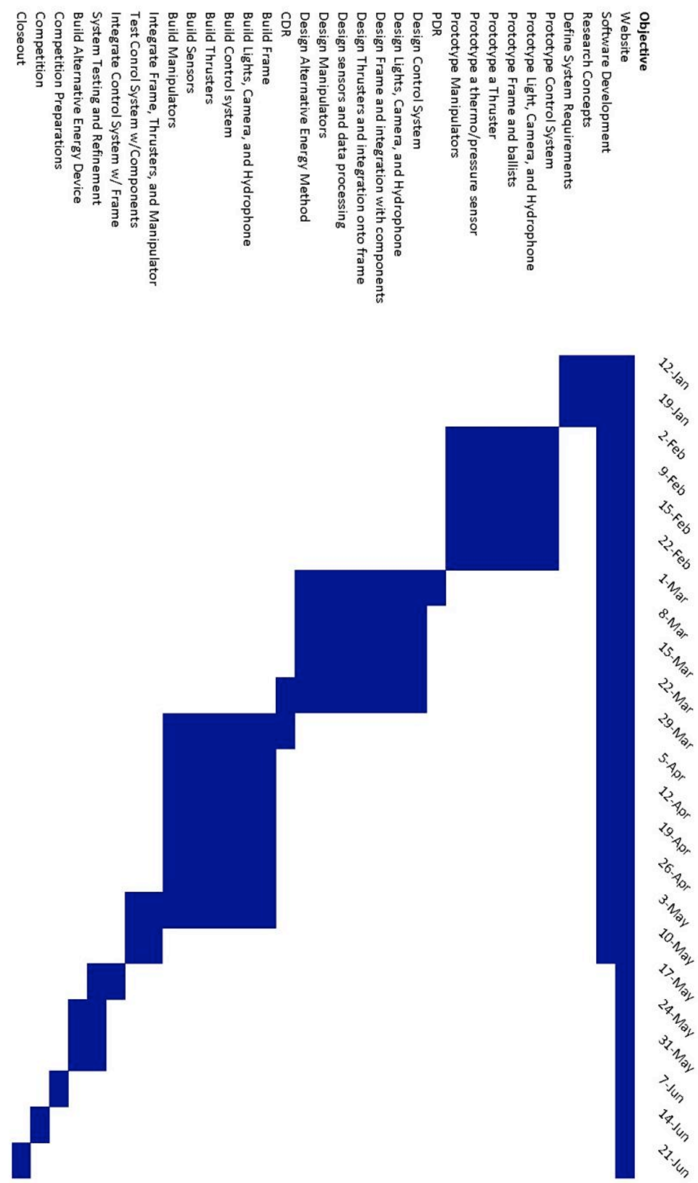
Appendix A: Detailed Budget

System	Part	Supplier	Cost	Donation
Prototyping	ROV	iNeventivity	$290.42	
	Sand Paper/Cement	Home Depot	$14.28	
	IR Camera	Harbor Freight	$39.66	
	Hamilton Repair Parts	ACE	$25.00	
	TOTAL		$369.36	$0.00
Arm	Plastic Servo claw	Jameco	$22.70	
	Spring Loaded Seal 1 1/4"	Mcmaster	$26.05	
	Underwater Sealent (3 @ $6.72)	McMaster	$20.16	
	Spring Loaded Seal 1/4"	Mcmaster	$11.03	
	Stretch Rotaray Shaft 1/4"	Mcmaster	$4.13	
	Buehler Gearhead Motor (2 @ 13.41)	All electronics	$26.82	
	DC-DC converter	All electronics	$7.24	
	Bildge Pump Motors	Dusky Online	$47.33	
	TOTAL		$165.46	$0.00
LCM	LED	LEDDynamics	$0.00	$332.57
	Camera Housing Plastic and Silicone	Home Deport	$12.26	
	Camera Housings Aluminum	IMS	$10.16	
	Camera Housings Aluminum	IMS	$4.28	
	Camera Hardware	Fry's Elec.	$60.37	
	Cameras	Supercircuits	$110.46	
	Thermal Cut-Off	Digi-Key	$0.00	$20.00
	50 ft. RCA Component Cable	MonoPrice	$24.86	
	TOTAL		$222.39	$352.57
Sensors	Sensor Hardware	Home depot	$17.36	

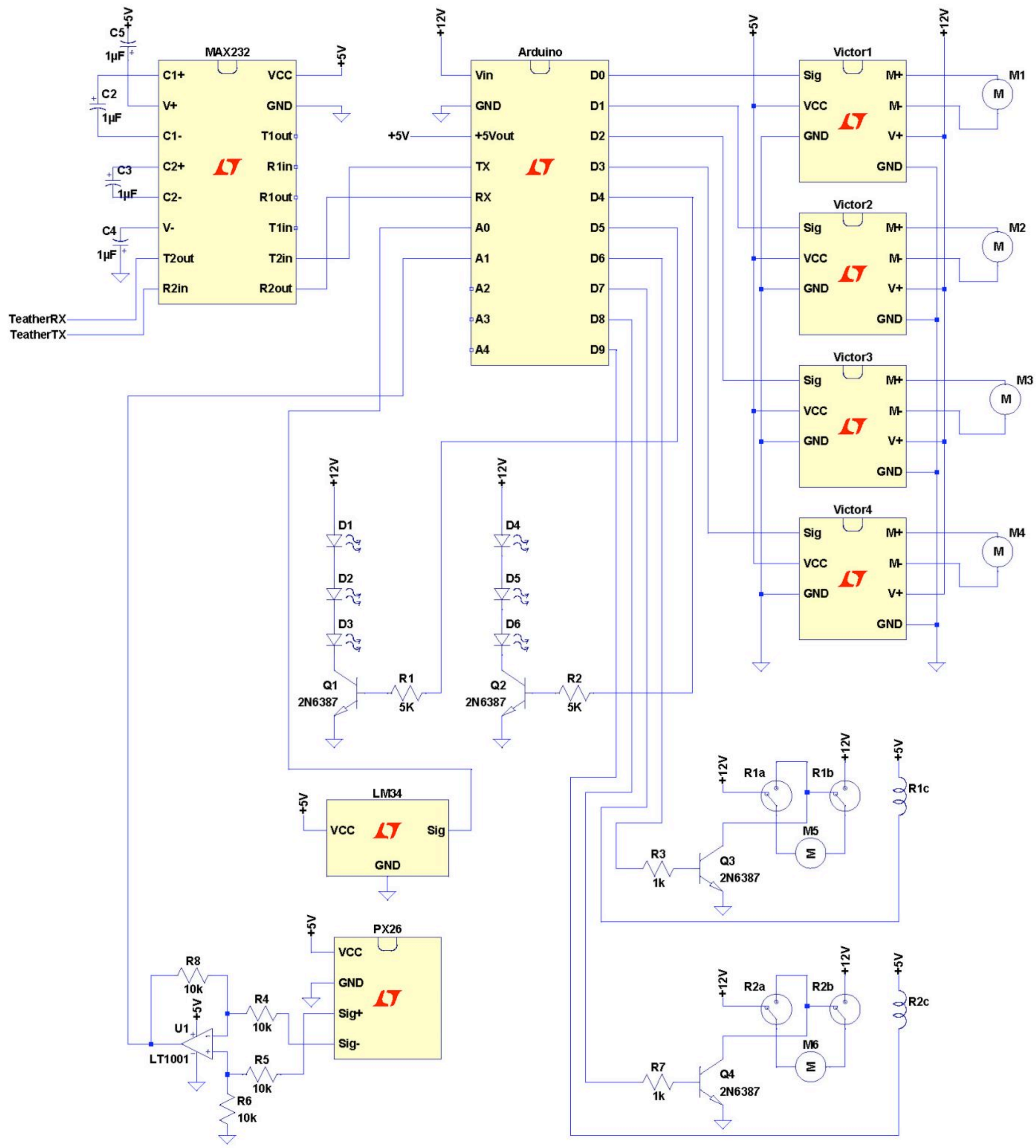
	Sensor Hardware	ACE	$13.93	
	TOTAL		$31.29	$0.00
Thrusters	Fastners	Ace	$3.99	
	Props	Hobby Lobby	$28.09	
	Grease	Ace	$16.41	
	Misc. Parts	McMaster	$33.25	
	Scorpion Brushless Motor	Innovative Designs	$35.47	
	Scorpion Wound Brushless Motors (2 @ 49.50)	Innovative Designs	$99.00	
	Brushless Speed Controllers (3 @ 44.89)	Hobby Action	$134.68	$0.00
	TOTAL		$350.89	$0.00
Frame	Otterbox x 3	Otterbox	$0.00	$90.00
	Aluminum (100lbs. @ $5/lb.)	IMS	$0.00	$500.00
	Scotchcast	Lights, Camera, Action	$24.31	
	Fastners	ACE	$17.04	
	TOTAL		$41.35	$590.00
Mission Props	Fastners	ACE	$7.28	
	PVC and Fastners	ACE	$43.75	
	PVC and Fastners	LOWES	$57.85	
	Total		$108.88	$0.00
Controls	Ardruino Board	Sparkfun Electronics	$38.58	
	Misc. Electronics Parts	Fry's Electronics	$10.75	
	Misc. Electronics Parts	Fry's Electronics	$33.23	
	Power Cord and Fuses	Low's	$37.55	
	TOTAL		$120.11	$0.00
Software	Solidworks (15 @ $100 each)	Solidworks Co.	$0.00	$1,500.00

	TOTAL		**$0.00**	**$1,500.00**
	Grand Total		$1,409.73	$2,442.57

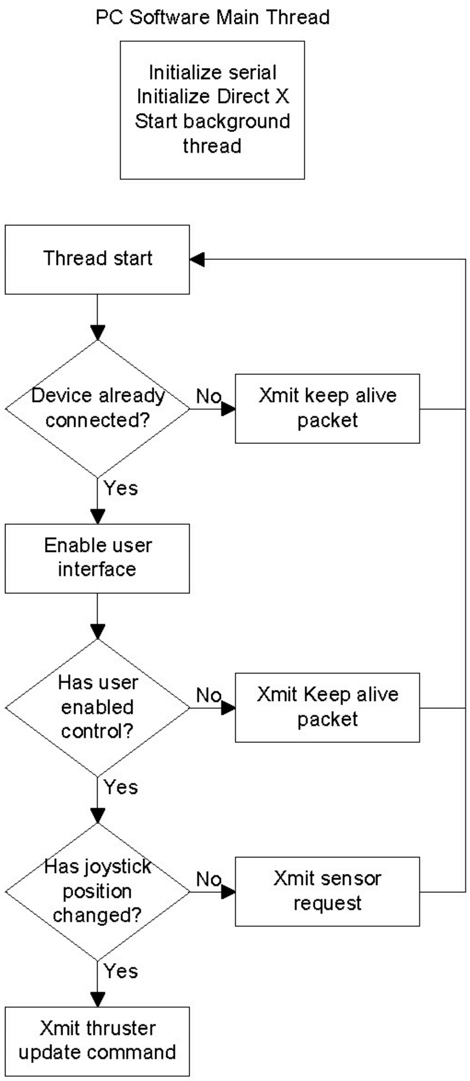
Appendix B: Gnatt Chart

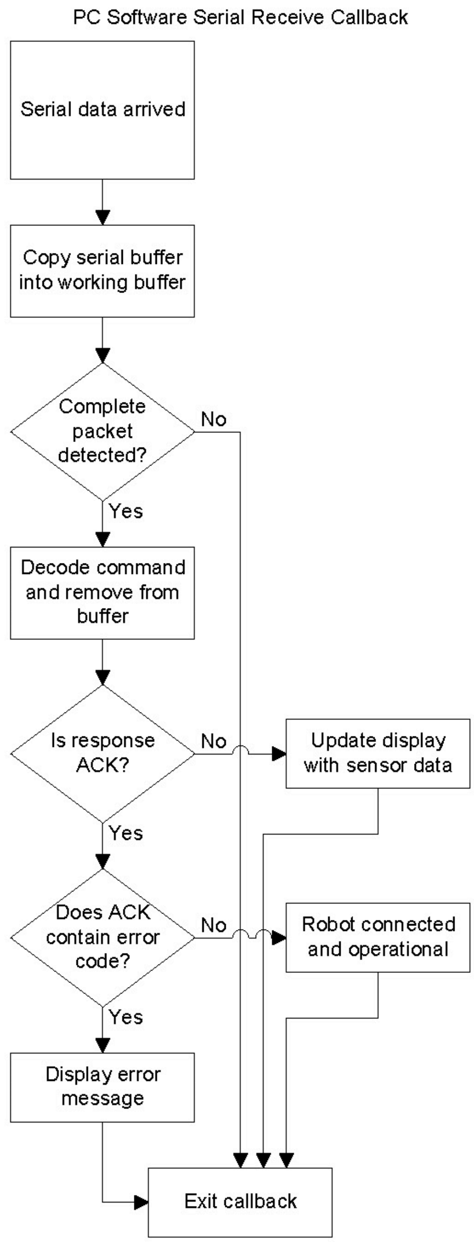


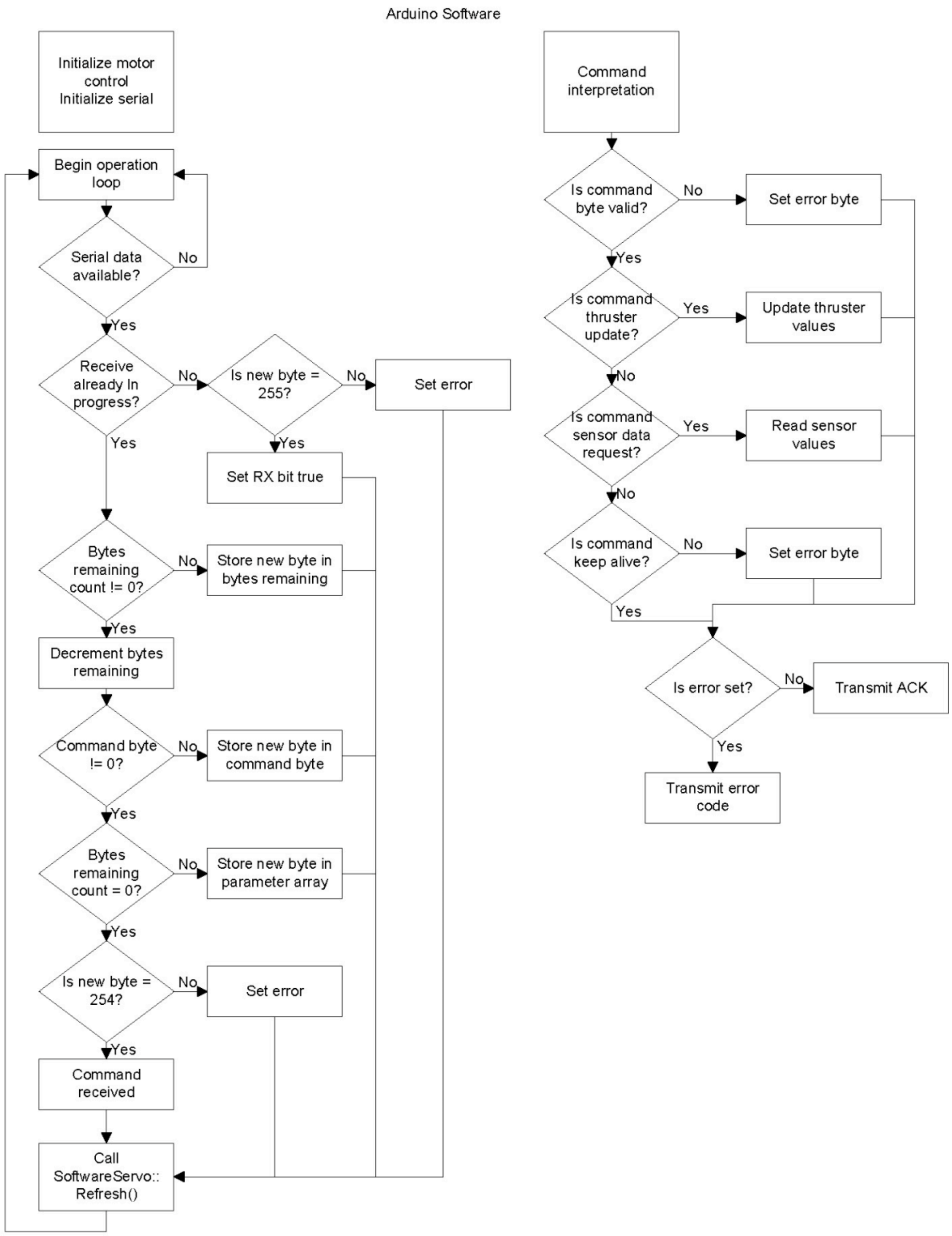
Appendix C: Electrical Schematic



Appendix D: Software Diagrams






Arduino Software
Initialize motor control
Initialize serial
Begin operation loop
Serial data available?
No
Yes
Receive already In progress?
No
Is new byte = 255?
No
Set error
Yes
Set RX bit true
Yes
Bytes remaining count != 0?
No
Store new byte in bytes remaining
Yes
Decrement bytes remaining
Command byte != 0?
No
Store new byte in command byte
Yes
Bytes remaining count = 0?
No
Store new byte in parameter array
Yes
Is new byte = 254?
No
Set error
Yes
Command received
Call SoftwareServo:: Refresh()
Command interpretation
Is command byte valid?
No
Set error byte
Yes
Is command thruster update?
Yes
Update thruster values
No
Is command sensor data request?
Yes
Read sensor values
No
Is command keep alive?
No
Set error byte
Yes
Is error set?
No
Transmit ACK
Yes
Transmit error code