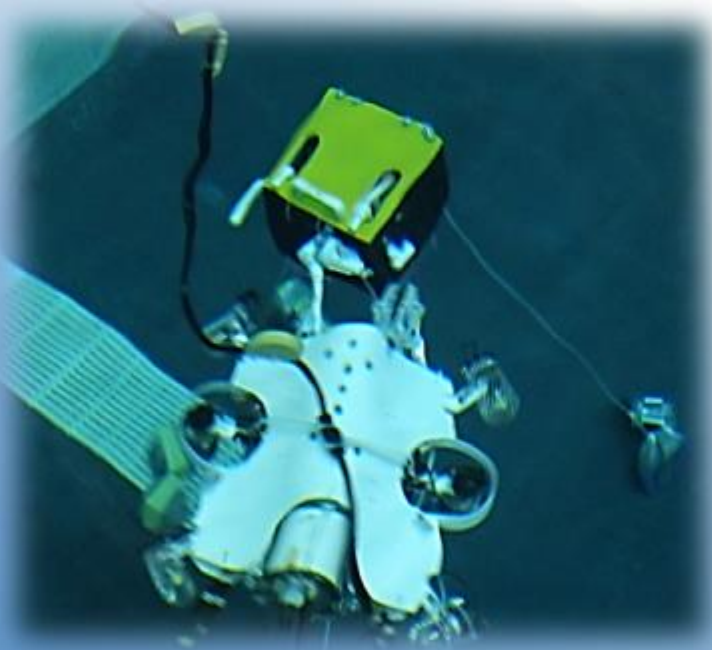
2013 MATE International ROV Competition, Ranger Class

# AMNO & CO

Seattle, Washington, USA

# *The Rust Bucket*




**Team Members:**
**Alex Miller: Mechanical Engineer, Machinist, Troubleshooter**
**Clara Orndorff: CEO, CFO, Electrical Engineer, Technical Writer**
**Nicholas Orndorff: Software and Research Expert, Mechanical Engineer**

**Mentor:**
**Mary Chang**


AMNO & CO is not affiliated with any school or organization

# Table of Contents

## 1. Abstract

As a company this is our fourth year of building specialized Remotely Operated Vehicles (ROVs). This year, we have built an ROV to aid ocean scientists and researchers in installing and maintaining Ocean Observing Systems (OOS). We feel that many of the existing ROVs are highly specialized, which can limit their functionality. Our goal is to provide an inexpensive, multi-purpose vehicle.

In order to accomplish this, we have conducted extensive research pertaining to ROVs and their systems and we have used this information in order to prototype and build an ROV that can dependably install and maintain an OOS. Our ROV contains many unique, multi-functional components, which include a motor controller based control system and a versatile, homemade, solid aluminum, actuator-driven manipulator with the capability to open hatches and pick up and transport sensors of all sizes.

We have eliminated many, if not all, of the challenges we were faced with in this project. We know that this year's ROV is better than any we've made before and we are proud of how well it can accomplish the tasks set for it.

(Word count: 187)

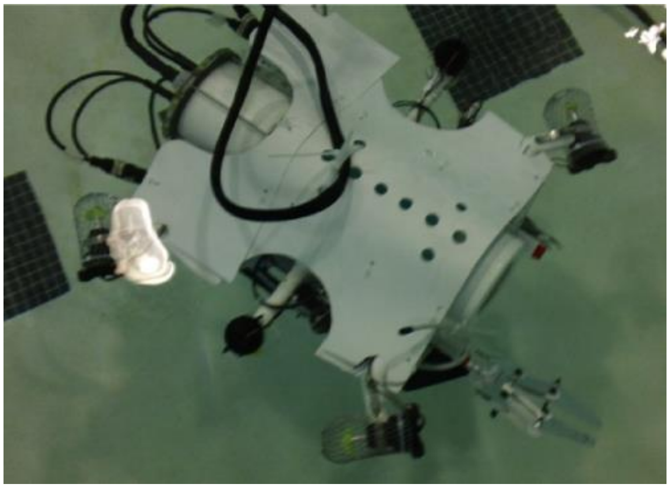


**Figure 1: The Rust Bucket**

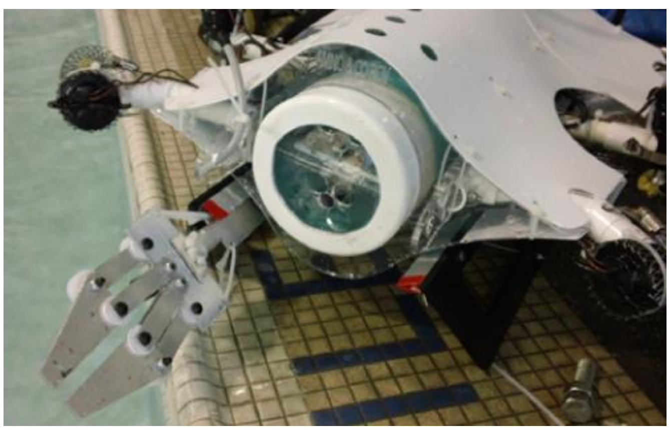


**Figure 2: The Rust Bucket, a front view**

## 2. Company Information


**Alex Miller**
Company roles: **Machinist, Mechanical Engineer, and Troubleshooter**
Competition role: **Pilot**
Contributions[1]: **Arduino programming, frame design**
Years of participation in the MATE ROV competition: **4**
Grade: **8**
School and location: **Washington Middle School, Seattle, WA**
Career goal: **Mechanical Engineer**

**Clara Orndorff**
Company roles: **CEO, CFO, Electrical Engineer, Technical Writer**
Competition roles: **Pilot, Tether Manager**
Contributions[1]: **Control system, tether**
Years of participation in the MATE ROV competition: **4**
Grade: **10**
School and location: **Ingraham High School, Seattle, WA**
Career goal: **Mechanical Engineer**

**Nicholas Orndorff**
Company roles: **Mechanical Engineer, Software Expert, Research Specialist**
Competition roles: **Pilot, Tether Manager**
Contributions[1]: **Control System, Manipulator**
Years of participation in the MATE ROV competition: **4**
Grade: **8**
School and location: **Hamilton Middle School, Seattle, WA**
Career goal: **Mechanical Engineer**

[1] Design components not listed were primarily team efforts

## 3. Mission Theme

The oceans can tell us about conditions such as global warming and pollution. To access this information, Ocean Observing Systems (OOS) are needed. OOS are often deployed by ROVs.
Many types of OOS are used, each with their own purpose. An example of an OOS is an Acoustic Doppler Current Profiler (ADCP), which can make measurements about the currents.
These measurements can in turn provide data about the Earth's climate change.
This year's mission tasks relate to a real world example. Off the western coast of the United States, scientists are preparing to install a Regional Scale Node (RSN) to collect data about currents, seismic activity, and more. The RSN contains first a primary node, which supplies power, and secondly, an array of sensors to take measurements (see section 13). The data it will collect is essential to our understanding of the oceans and how their health contributes to the planet, but in order for this data to be useful ROVs must maintain the OOS. This is the reason behind the mission tasks: for example, in task 3, the replacement of the ADCP allows new and correct data to be collected and analyzed.

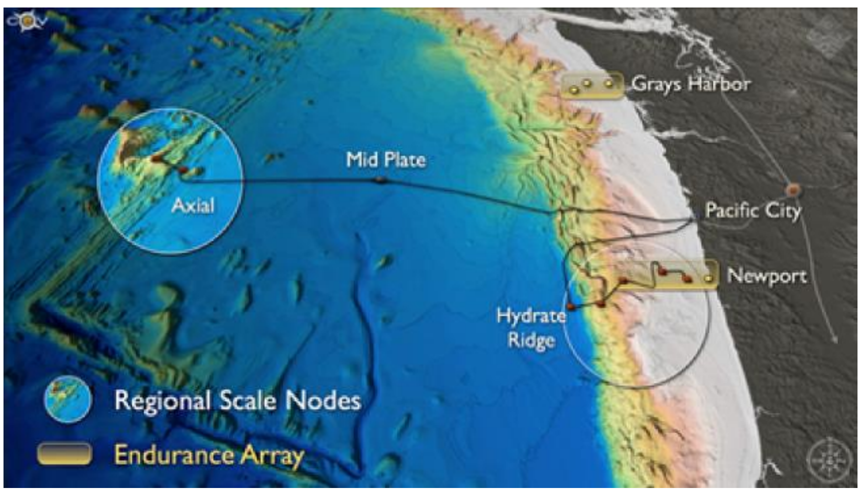



**Figure 3: The layout of the RSN (see section 13, 1)**

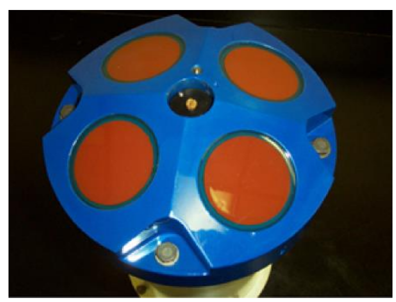


**Figure 4: An ADCP (see section 13, 4)**

Acronyms of RSN components that will be used in this report:
*BIA – Backbone Interface Assembly*
*SIA – Scientific Interface Assembly*
*CTA – Cable Termination Assembly*
*OBS – Ocean Bottom Seismometer*

## 4. Safety

Safety was taken very seriously, to prevent injury to the company, the observers, and the Rust Bucket itself. The company's safety checklist can be found in Appendix 1.

**Safety features on board the Rust Bucket:**

- Shrouded thrusters
- Warning labels for moving parts
- Strain relief on the tether

**Safety features at the surface:**

- 25A fuse for the entire ROV and a 3A fuse for the temperature sensor
- Strain relief on all cables
- Main power shutoff switch

**Safety protocols for working on the Rust Bucket:**

- Safety glasses and closed toe shoes at all times
- Gloves and masks when working with potentially harmful substances

During the construction of the Rust Bucket, there has been time to understand the value of our safety features to the company and to the vehicle. For example, there were several electrical errors that resulted in blown fuses. If the fuse hadn't been in place the electronics could have been damaged beyond repair.

## 5. Design Rationale

This year, the competition tasks require an ROV that can:

- Maneuver effectively and capably to avoid tangling in the many ropes present in the pool setup
- Use multipurpose tools to complete a variety of tasks that require many different types of motion

The focus of this year's design was to create an ROV with the following properties:

- A hydrodynamic frame, to increase maneuverability and speed in all the dimensions of motion
- An effective motor controller-based control system, to increase maneuverability
- Multipurpose payload tools, to better accomplish the mission tasks
- Onboard electronics, to minimize the size of the tether

## 5.1 Frame

The purpose of the frame design was to create a hydrodynamic basis for the rest of the Rust Bucket's components. This part of the vehicle has three basic features: the ribs, the shell, and the skids. The entire frame and surrounding structure was first modeled out of laser cut cardboard to gain a better understanding of how the frame would fit together and support the mission components.

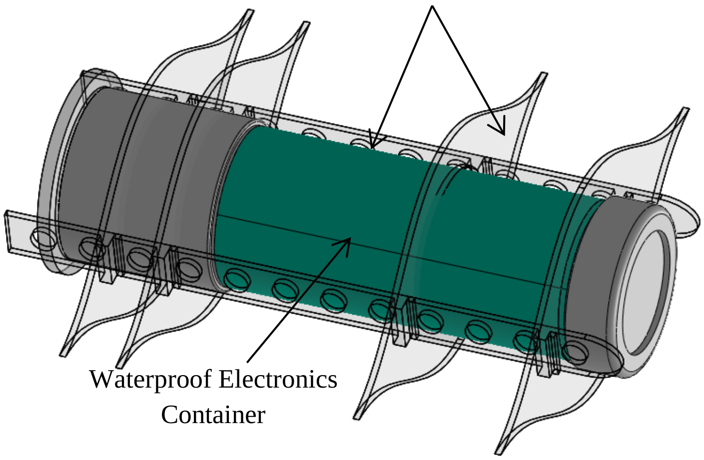



**Figure 5: A Solidworks rendering of the rib structure (Not pictured: motor mounts and skids)**

The 4 ribs are constructed from 0.64cm cast acrylic with 16.2cm circular cutouts in the centers to hold the Waterproof Electronics Container (see section 5.2). These ribs taper to the edges to give the frame its hydrodynamic structure. To do this, we were taught how to use a 90W $CO_2$ laser cutter. This feature of the frame was modeled using Adobe Illustrator and Solidworks™ 3D CAD software.

The shell is made of 0.32cm high impact styrene. This flexible plastic can contour to fit the shape provided by the ribs and can be easily fastened in place with zip ties. Among other things, the curved shell reduces drag by reducing the turbulence that would form around otherwise exposed objects, for example the acrylic ribs and the wires.

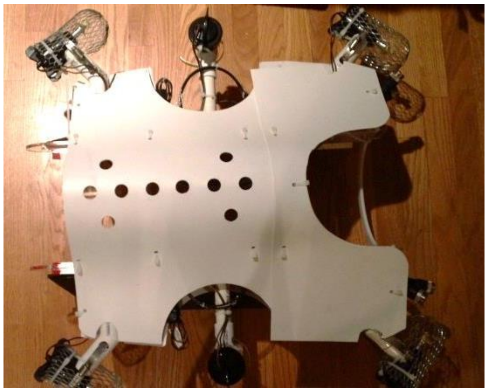


**Figure 6: The styrene shell**

The skids increase maneuverability while the Rust Bucket is operating on the sea floor. With a high density, their Starboard material is environmentally stable, which makes them optimal for their purpose. For these reasons, among others, the skids will not be damaged by the ocean bottom or the corrosive salt water. In addition, the skids provide sturdy mounting surfaces for payload tools to optimize the ROV's capability to perform the mission tasks.

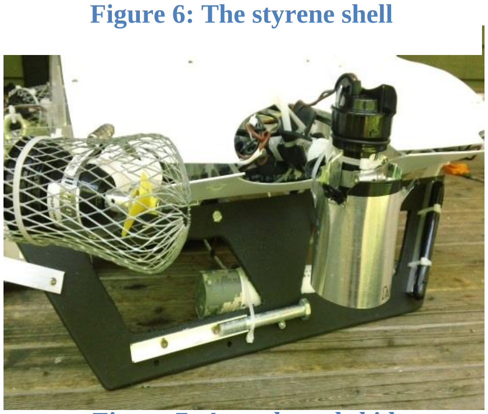


**Figure 7: A starboard skid**

## 5.2 Waterproof Electronics Container


Figure 8: The WEC

The Waterproof Electronics Container (WEC) is constructed from 15.2cm polyvinylchloride (PVC) pipe. The WEC runs the length of the frame and is sealed in two places; the front and the back. Inside the WEC, all the electronics are mounted on an acrylic rack. The entire WEC can be removed from the frame for maintenance and ease of transportation. The convenience of this unique feature was only discovered during the prototyping process, which reinforced to us the usefulness of prototypes.


Figure 9: The WEC, a front view

At the front of the pipe a seal is formed with a modified PVC end cap. The center of the end cap was removed and replaced with a 1.27cm clear acrylic plate for the camera (see section 5.8). This joint has 3 seals, including PVC glue, marine epoxy, and silicone sealant.


Figure 10: A not-yet-installed penetrator


Figure 11: The WEC, a back view

At the back of the pipe, a gasket is employed as a removable seal with the aid of threaded rods to compress it. The gasket is compressed against a 1.27cm acrylic plate. As the onboard electronics are housed in the WEC, 5 homemade penetrators must go through the acrylic plate. These penetrators are made from IP-68 rated in-line connectors. The water-blocked cables for these connectors are potted through the acrylic inside brass hose barbs with epoxy and silicone.
Before its use with electronics, the gasket seal of the WEC was tested to ensure that it was waterproof to a depth of 5m.

## 5.3 Buoyancy and Ballast

All the necessary buoyancy is provided by the WEC. The calculated volume of the WEC, 0.0102$m^3$, provides enough of a buoyant force that ballast was needed. 3.9kg of ballast were added at locations according to locations on the centers of mass and buoyancy. This makes the Rust Bucket neutrally buoyant. In addition, flotation was added to the tether so it doesn't impair the Rust Bucket's driving abilities.

### 5.4 Propulsion

The Rust Bucket is propelled by 1250 Gph bilge pump replacement cartridges. These thrusters were tested and produced the following values:

| | 1250 Gph |
|---|---|
| **Theoretical current[2] (amps)** | 3 |
| **Actual current[3] (amps)** | 3.5 |
| **Power[4] (watts)** | 42 |
| **Resistance[5] (ohms)** | 3.4 |
| **Thrust[6] (Newtons)** | 12 |

**Table 1: Properties of bilge pump Replacement cartridges[7]**

A total of 6 1250 Gph bilge pump replacement cartridges are used, 2 for vertical motion and 4 for horizontal motion. The vertical thrusters are aligned with the horizontal center of the ROV and mounted out to the sides for stability. A horizontal thruster is placed at each corner of the vehicle and vectored at a 45° angle for strafing motion. Each thruster is equipped with a 2-bladed propeller. Horizontal thrusters are shrouded with drain guards and vertical thrusters are shrouded with aluminum flashing to concentrate thrust.

**Figure 12: A horizontal thruster**

Each of the horizontal thrusters has variable speed (see section 5.5). Variable speed is not necessary for motion in the vertical plane.

[2] Theoretical current is the value given for a bilge pump replacement cartridge in its intended use, with an impeller.
[3] Actual current is the value measured for a bilge pump replacement cartridge in this application- that is, underwater, with a propeller and a load (the ROV). This was measured with a clamp on multi meter.
[4] Calculated using the rule *Watts = Volts x Amps*
[5] Calculated using Ohm's Law: $Resistance = \frac{Volts}{Amps}$
[6] Measured with a spring scale, uncertainty ± 0.25 Newtons
[7] For additional measurements on the thrusters, see Appendix 2

## 5.5 Control System

The majority of the Rust Bucket's electronics are located in the WEC. This control system is based on 4 Pololu 18v7 motor controllers on a homemade circuit inside the WEC, with terminal blocks for wire control. These motor controllers come with their own software interface, but this interface requires a significant amount of user input. Each of the horizontal thrusters is connected to one of these motor controllers and the signal from these motor controllers travels up the tether to the control box.

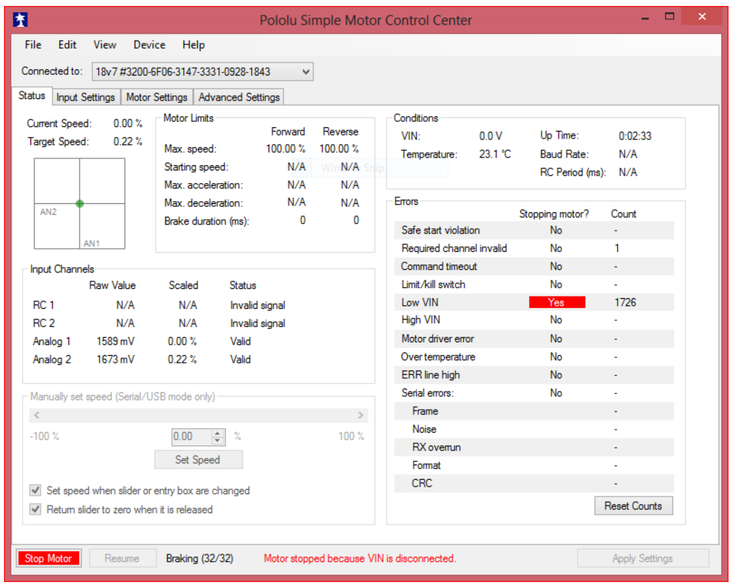



**Figure 13: The motor controller user interface, which is useful for troubleshooting – the red highlighting (above) indicates the error "Low Voltage In"**


**Figure 14: The control box**

At the control box the signal from the motor controllers connects to a 2-axis joystick with 2 5kΩ potentiometers. The vertical thrusters are wired to a DPDT switch. Inside the control box the wires are organized on terminal blocks.

A toggle switch is used as a main power safety shutoff.

### 5.6 Tether

In order to obtain precisely the right numbers and types of conductors, the tether was made by the company. It was designed to be compact, flexible and lightweight, all to reduce the effect of the tether's mass on the driving capabilities of the Rust Bucket. Inside 19.8m long sheathing from Techflex, the tether contains:

- 2 10AWG wires and 2 14AWG wires for power
- 10 16AWG wires for signal
- 1 coaxial cable for the camera

For the tether protocol, see Appendix 3.

### 5.7 Payload Tools

**Figure 15: A laser cut manipulator prototype**

**Figure 16: The manipulator**

The Rust Bucket has 2 versatile payload tools, the manipulator and the probe. The manipulator is built on the parallelogram principle in order to use all the provided gripping force effectively in parallel motion. For this reason, the manipulator has two moving joints (a single-jointed manipulator loses some of the gripping force to forward motion, and is therefore less effective).
This tool is constructed from aluminum, with high density polyethylene (HDPE) spacers for smooth functioning, and it is powered by a homemade linear actuator (a 500 Gph bilge pump replacement cartridge and a threaded rod). The manipulator is mounted on one of the skids. This tool transports the temperature sensor and the CTAs (tasks 1, 2, 3), opens the BIA (task 1) and removes biofouling (task 4).

**Figure 17: The probe**

The other payload tool is the probe, which, though stationary, is very useful and multi-purpose as well. Mounted on one of the skids, it is constructed from PVC pipe with an aluminum hook on the end. Strips of heat shrink on the aluminum provide a capable gripping surface.
The probe is used for task 3 (the mooring platform); transporting the SIA; removing and transporting the OBS and the pin; and for removing biofouling.

### 5.8 Sensors

Figure 18: The camera

The Rust Bucket has one onboard sensor, the camera, and one deployable sensor, the temperature sensor. The camera is a color board camera with the following features:

- 480 x 720 TVL of resolution
- 120º (wide angle) vision
- Low light capability – no lights are needed

Figure 19: The temperature sensor control box

The temperature sensor is based off a TMP36 analog sensor, chosen because it outputs in millivolts linearly to degrees Celsius, making equations much simpler. This sensor is potted in a piece of aluminum pipe and secured in a PVC pipe cradle. A cable with three wires (power, ground, and signal) connects it to the surface. At the surface, the control unit for the temperature sensor has its own control box. An Arduino microcontroller program controls the temperature sensor. The temperature readings are displayed on the screen along with the time. At the specified times (0, 1.5, 3, 4.5 and 6 minutes), the program stores the temperature on an LCD screen, accompanied by a buzzer. The temperatures can then be easily accessed later. For the schematic and flowchart, see Appendix 4. This sensor is used to measure the temperature of the water flowing from the hydrothermal vent (task 2).

## 6. Troubleshooting

The following flowchart was useful in sorting out any problems that occurred during the construction of the Rust Bucket – it made sure the troubleshooting process went smoothly and methodically. This eliminated unnecessary troubleshooting due to carelessness. Figure 21 provides an example of how the company used this careful approach

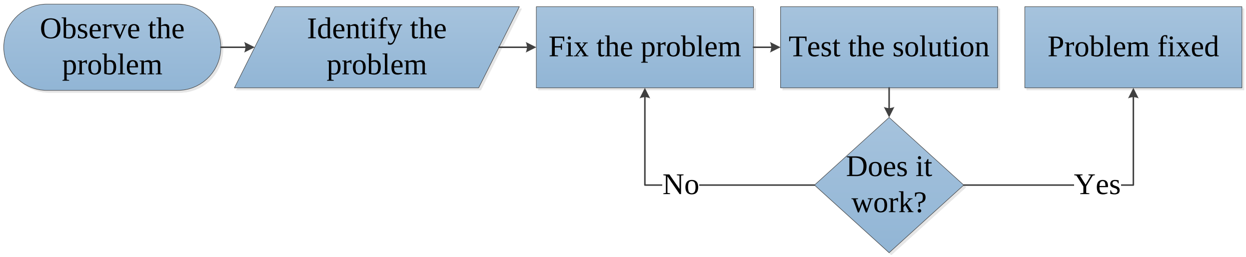



Figure 20: The troubleshooting flowchart

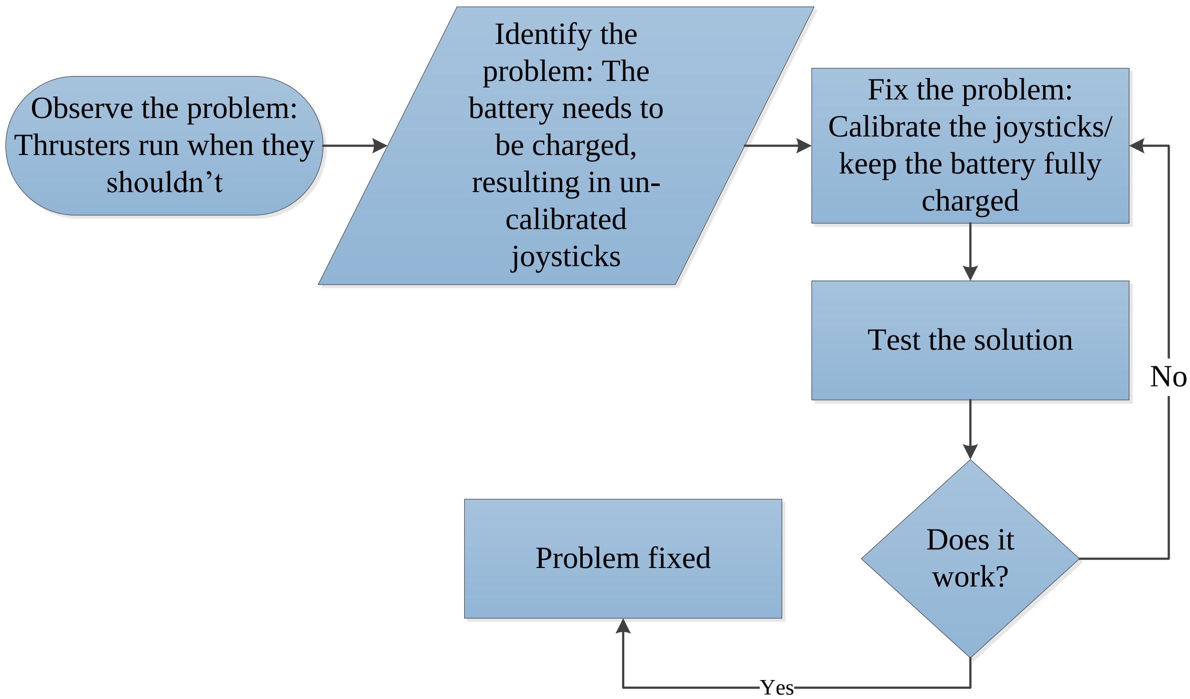



**Figure 21: The troubleshooting flowchart applied to a problem with the control system**

## 7. Challenges

### 7.1 Technical Challenge

During the project, there was some difficulty with the temperature sensor. Although it worked fine during testing sessions and was weighted substantially, the flow of water from the hydrothermal vent at the regional competition was too much and pushed the sensor off. Also contributing to this was the placement of buoyancy along the temperature sensor's cable. These problems were fixed: weight was added and the buoyancy was adjusted to correct the temperature sensor.

### 7.2 Non-technical Challenge

At the beginning of this project, measures were taken to ensure that the Rust Bucket could be completed successfully with a company of just three members. This was one reason for making the WEC removable (see section 5.2). This meant that one company member could work on the electronics while another member could work on the frame. Although having a small company can be a disadvantage (every person has to do more work), it also has its advantages: a smaller company means that coordinating meetings is easier, and every person can be completely familiar with every system of the ROV.

## 8. Future Improvements

Although the company has made significant progress over its history of competition, there is always room for it to improve on its designs and performance. AMNO & CO has come to realize that newly discovered technology becomes applicable at the speed that outpaces the speed with which it can be used. Many features proposed by team members for this ROV have not been used due only to the fact that there was not enough time to implement it. A few features we will definitely implement in the future are as follows.

- A smaller, lighter, and more compact frame. The current frame is heavy and difficult to transport.
- A WEC that closes with latches, as opposed to the time-consuming threaded rod system.
- Homemade thrusters or trolling motors. Bilge pump replacement cartridges, though waterproof and inexpensive, do not provide a substantial amount of thrust.

## 9. Teamwork and Organization

AMNO & CO is a small company, so every member was actively involved in every part of this project. The design process, the building process, the poster display, and the technical report were all worked on, edited, or reviewed, by every company member. Because the company is small, individual components of the Rust Bucket were dealt out to each member so most of the work could be done in between company meetings (see section 1, contributions). Before the Rust Bucket was built, a schedule was developed, (see the Gantt chart, appendix 5) and before systems were built or prototyped many donations were solicited and received in order to stick to a very limited budget. Because of this, AMNO & CO has money left over to use in prototyping a future vehicle.

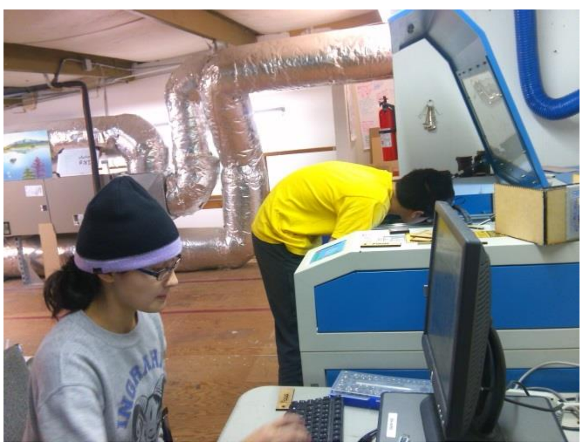


Figure 22: AMNO & CO laser cuts the frame

Very important to the project was that the work was done entirely by the team. Our mentors (who were very important for, among other reasons: trips to the hardware store; being patient with our long hours; and trusting us to build our ideas, however radical they may have sounded), the design and the building of every part of this project was done solely by the members of the company. In addition, a distinguishing feature of the Rust Bucket is that all the machining and programming was done by the company – we were given free use to a laser cutter that we operated ourselves, and a lot of time was spent learning/troubleshooting the software. For example, no significant knowledge of Arduino was available at the start of this project. The Rust Bucket was a self-taught, company-built project.

## 10. Lessons Learned

### 10.1 Technical Lesson

This year motor controllers and Arduino were used for the first time. Despite all the problems that were encountered and the troubleshooting that was required, learning all the lessons provided in software control will be valuable in all the rest of our experience building ROVs as well as in the field. All the Arduino code was self-taught, for example, which meant that in the troubleshooting process we learned to find other examples of similar programs and systematically work through the solutions.

### 10.2 Interpersonal Lesson

In a project like this it is important to listen to every company member's ideas. A skill that has been developed over the past 4 years of building ROVs is not to veto an idea right away. If a proposed system is debatable, the best solution is to ask the company member who proposed the system to build a prototype – There is no substitute for seeing a working model. This is often the best way to decide on a design.

## 11. Company Reflections

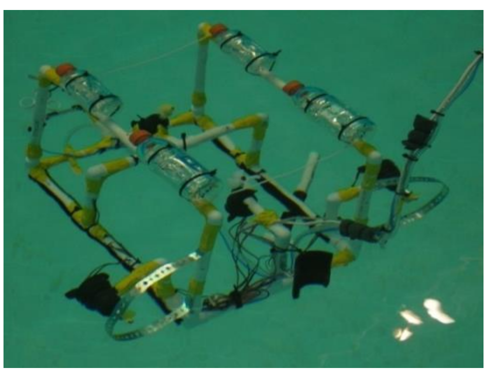


**Figure 23: Our first ROV (Scout, 2010)**

As a company we agreed that our four years of experience building ROVs has been nothing but helpful in our education. Throughout this experience, we have learned so much about ROVs – none of us knew what an ROV was before we started, nor did we imagine that we would qualify for an international competition – and how to build them. Not only this, but we have learned a lot about important engineering principles (for example, about buoyancy and drag), design and interpersonal skills (as expected, the company is a mixture of personalities), and how to use a variety of tools that we had never before had a chance to handle (including a drill press and a laser cutter). Also through the MATE ROV Competition, we have met professionals in the marine industry whose advice and insight gave us opportunities we had not before seen. In addition, for the first time we are proud to have raised enough money to have funds remaining for next year.

## 12. Budget

| System | Cost (USD) | Notes |
|---|---|---|
| Frame | $124.81 | *Discounted components[8]: all plastics* |
| Control System | $409.59 | *Discounted components[7]: joysticks, control boxes*<br>*Donated components[7]: front panel*<br>*Reused components[9]: Switches* |
| WEC | $523.19 | *Discounted components[7]: all plastics, underwater connectors* |
| Manipulator | $18.52 | *Reused components[8]: bilge pump replacement cartridge* |
| Tether | $0.00 | *Donated component[7]: tether sheathing*<br>*Reused componen[8]: wire, buoyancy* |
| Temperature Sensor | $15.25 | *Discounted components[7]: control box* |
| Propulsion | $313.54 | *Discounted components[7]: bilge pump replacement cartridges* |
| Camera | $0.00 | *Reused components[8]: camera* |
| Miscellaneous | $243.3 | - |
| **Total Cost of the Rust Bucket** | **$2,714.97** | *Does not include the value of donated, discounted, or reused components* |
| Income (awards) | $1,500.00 | *Sources: ASA, NAMEPA, gROVer, MTS* |
| Income (fundraising) | $570.88 | *Sources: bake sales* |
| Fair market value of donated or discounted parts | $1,101.57 | *Sources: see section 14* |
| **Total Income (with part values)** | **$3,172.45** | - |
| **Amount spent on the Rust Bucket** | **$ - 457.48** | - |

A goal of the company was to fund as much of the project as possible – it was a success. For a vehicle that cost $2,545.97, $457.48 of income were not spent. In addition, some components from previous competitions were reused to save costs, but only if they could be guaranteed to be in good condition.

[8] The costs of discounted or donated components are accounted for in the value of donated or discounted parts.
[9] The costs of reused components are accounted for in the budgets of previous ROVs; therefore, these costs are not included here.

## 13. References

1. "Primary Node." Interactive Oceans. Accessed 4 April 2013. http://www.interactiveoceans.washington.edu/file/Primary+Node
2. Stephen W. Moore, Harry Bohm, and Vickie Jensen. *Underwater Robotics: Science, Design, and Fabrication*. Monterrey, MATE: 2010.
3. "Ocean." NOAA. Accessed 4 April 2013. http://www.noaa.gov/ocean.html
4. "Sensors." Interactive Oceans. Accessed 4 May 2013. http://www.interactiveoceans.washington.edu/story.sensors

## 14. Acknowledgements

The Rust Bucket would not have been made possible without the following individuals:

- Mary Chang, Rachel Miller, Steve Miller, Robert Orndorff, Tonya Ricks Sterr, and Kate Sweeney
- Rick Rupan, Wes Thompson, and Fritz Stahr
- All the MATE officials and volunteers
- Everyone who purchased from our bake sales

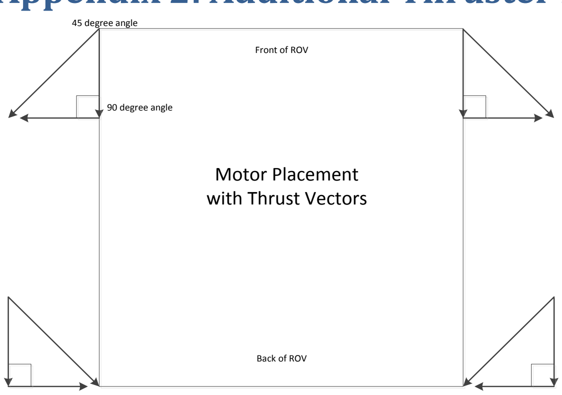
The following companies and organizations provided support, funds, and/or donated or discounted parts:

- MATE, MTS – the competition
- ASA, NAMEPA – funds
- StudentRND – tools
- ServoCity – joysticks
- TAP Plastics – plastics
- City of Shoreline – pool testing
- Global Diving – advice
- Pololu – motor controllers
- Keller America – pressure sensor
- Dassault Systémes - Solidworks™
- Supercircuits – camera (2012)
- Techflex – tether sheathing
- BinderUSA – underwater connectors
- O-Rings West – O-rings
- Harris Electric – wire (2012)
- General Plastics – buoyancy
- West Marine – thrusters
- Fisheries Supply – thrusters, heat shrink
- Polycase – control boxes
- Front Panel Express – front panel

## Appendix 1: Safety Checklist

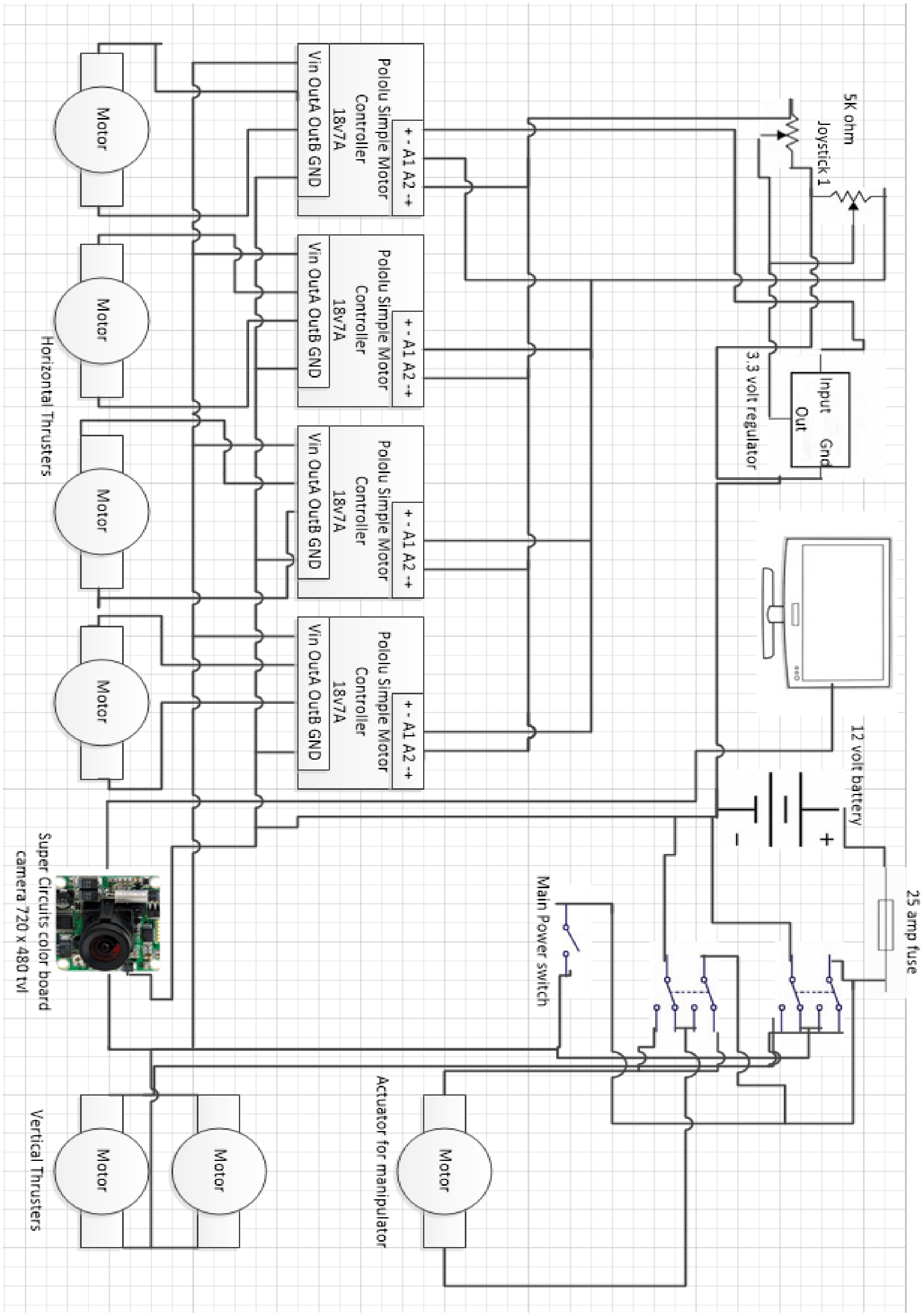
- Yes/no – safety glasses, closed toe shoes, gloves/masks if necessary
- Is the battery fully charged and in good condition?
- Are the thruster guards secure?
- Are all the underwater connecters properly fastened?
- Is the tether's strain relief in place on the ROV?
- Is the fuse new (not been blown)?
- Is the power switch off before connecting the ROV to power?
- Always observe the tether protocol: Do not pull on the tether, make sure it is untangled before use, let it out as the ROV leaves the mission station, and reel it in as it returns. Always coil the tether neatly and make sure the strain relief is secure.

## Appendix 2: Additional Thruster Information

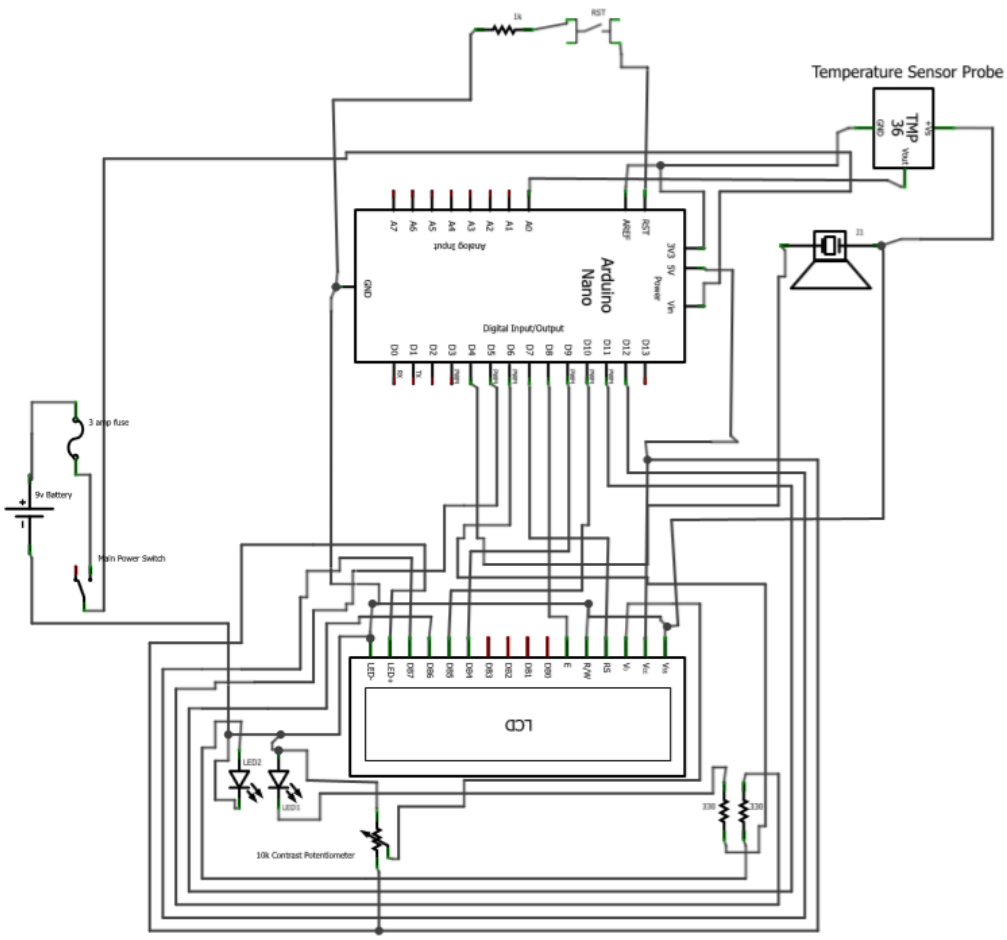


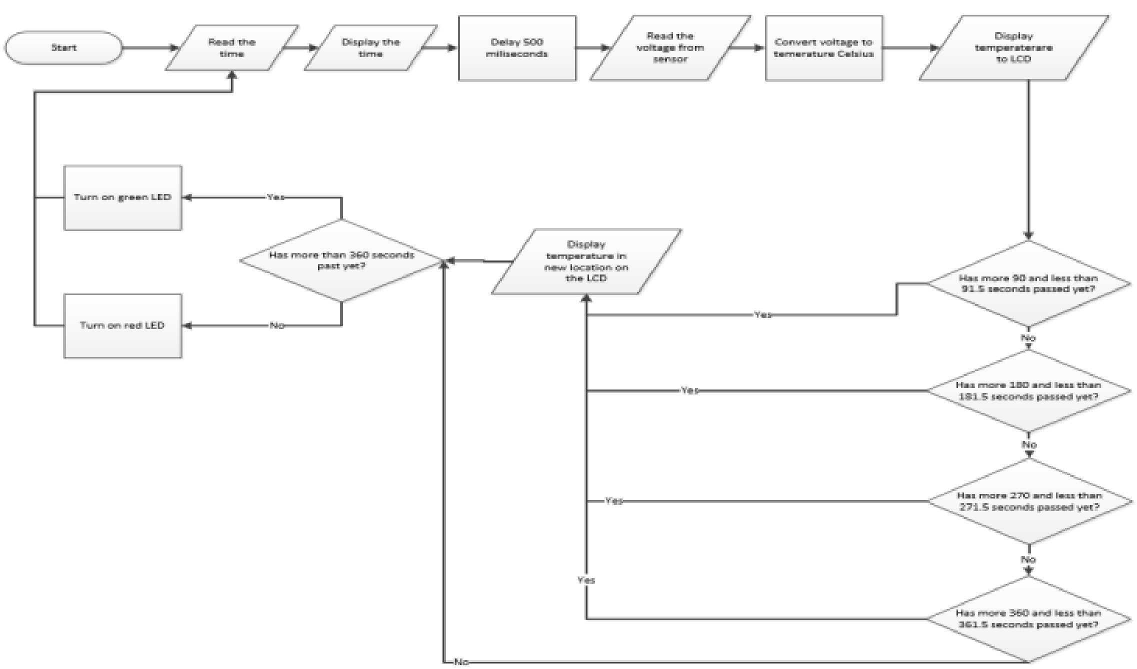

Thrust per thruster: 12N
Total forward thrust (due to vectoring of the motors): 34.3N
Horizontal acceleration: 0.006m/s$^2$
Horizontal velocity: 0.29 m/s
Vertical acceleration: 0.0165 m/s$^2$
Vertical velocity: 0.288 m/s

## Appendix 3: Electrical Schematic

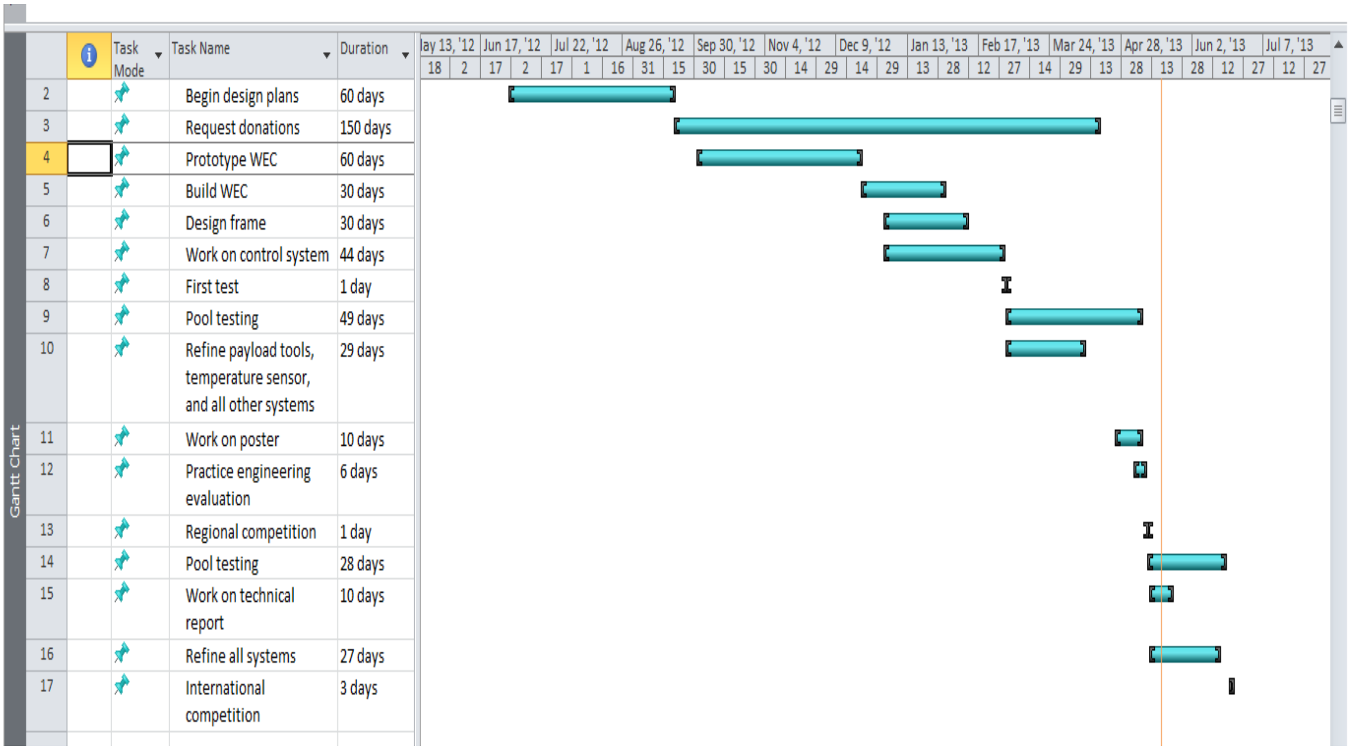


## Appendix 4: Temperature Sensor Schematic and Software Flowchart



## Appendix 5: Gantt Chart




| | Task Mode | Task Name | Duration |
|---|---|---|---|
| 2 | | Begin design plans | 60 days |
| 3 | | Request donations | 150 days |
| 4 | | Prototype WEC | 60 days |
| 5 | | Build WEC | 30 days |
| 6 | | Design frame | 30 days |
| 7 | | Work on control system | 44 days |
| 8 | | First test | 1 day |
| 9 | | Pool testing | 49 days |
| 10 | | Refine payload tools, temperature sensor, and all other systems | 29 days |
| 11 | | Work on poster | 10 days |
| 12 | | Practice engineering evaluation | 6 days |
| 13 | | Regional competition | 1 day |
| 14 | | Pool testing | 28 days |
| 15 | | Work on technical report | 10 days |
| 16 | | Refine all systems | 27 days |
| 17 | | International competition | 3 days |