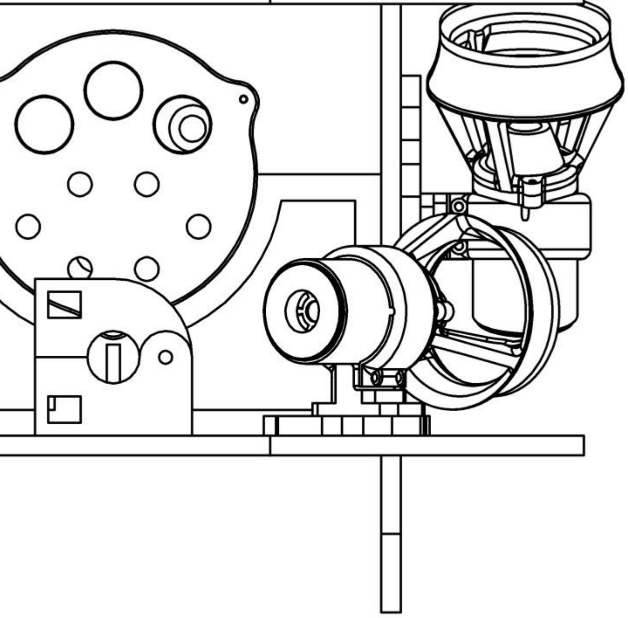
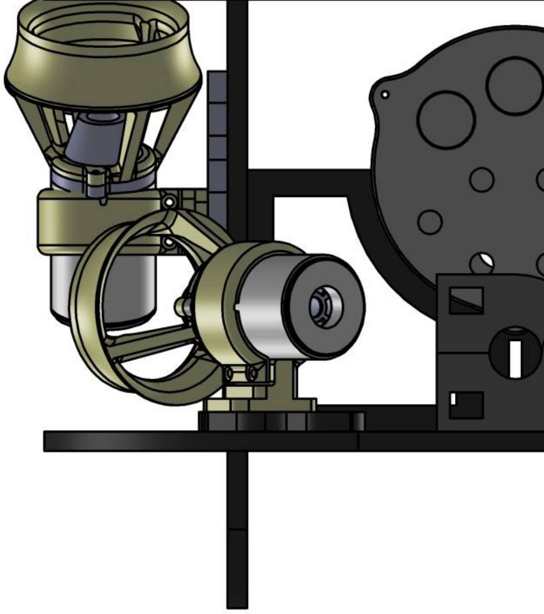


2015 MATE
International
ROV Competition

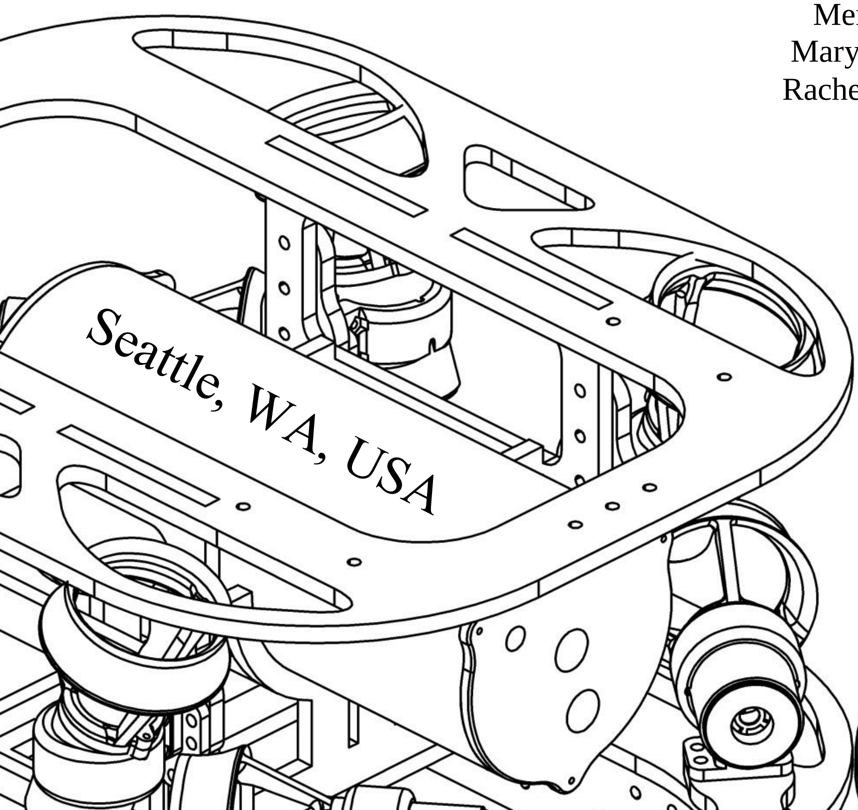


AMNO & CO

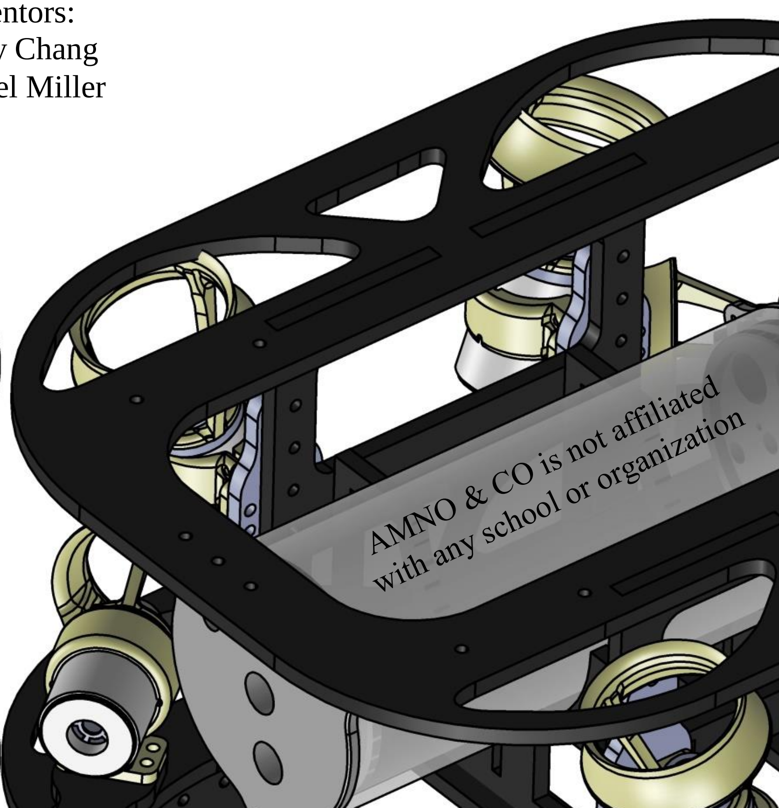
Technical Report

Alex Miller (10th grade): Chief Product Officer
Nicholas Orndorff (10th grade): Chief Technology Officer
Clara Orndorff (12th grade): Chief Executive Officer

Mentors:
Mary Chang
Rachel Miller



Seattle, WA, USA



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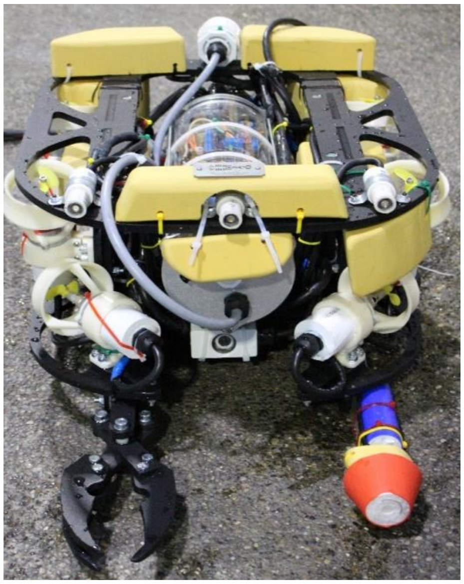


Figure 1: The ROV *(Credit: A. Miller)*

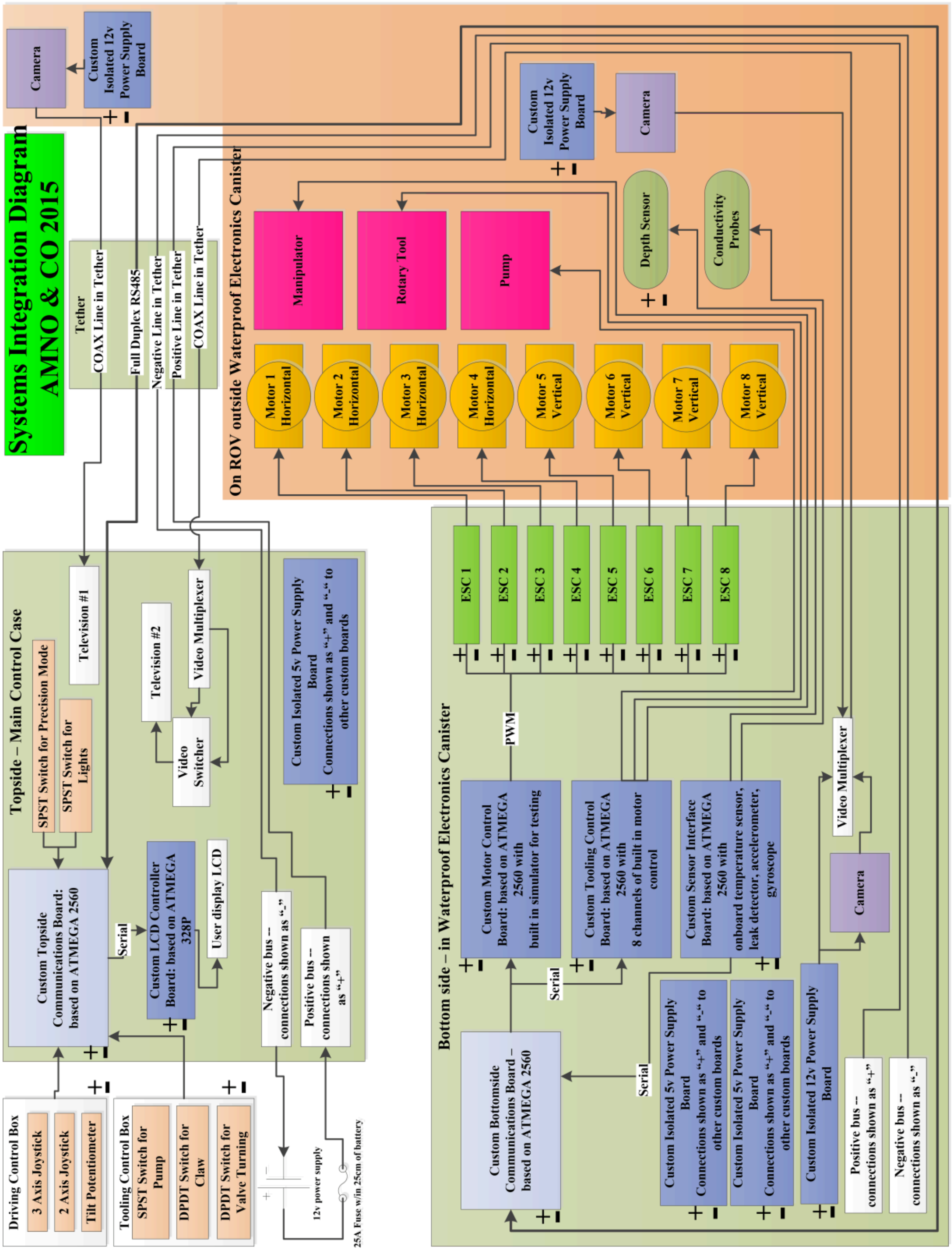
1. Abstract

AMNO & CO contributes six years of experience building Remotely Operated Vehicles to its goal of bringing state-of-the-art technology to the Arctic oil and gas industries.

This current vehicle is designed and tested for the purpose of analyzing, repairing and maintaining offshore oilfields in the Canadian Arctic. The complex process of designing, prototyping, optimizing, building, and final testing began last June. Since then, our goal has been to incorporate our six years' worth of learning (including prototyping, manufacturing and marketing skills) into a multipurpose, professional vehicle that can accomplish the mission tasks proposed by the MATE Center. Special features of this year's ROV include:

- Custom printed circuit boards that allow the control system to reach the optimal blend of sophistication, precision and reliability
- A total of 5 axes of motion, provided by innovative and cost-effective custom thrusters that use brushless motors and pump shaft seals to maximize the power-to-thrust ratio
- A 28-meter-long tether which is braided for ultimate flexibility
- A remote programming feature included to facilitate troubleshooting
- Built-in simulator LEDs that enable a real-time view of the control system and testing without being connected to the ROV
- An interlocking manipulator that can retrieve objects of various shapes in order to accomplish the majority of the 2015 MATE mission tasks

2. Systems Integration Diagram (SID)



3. Company Information

Alex Miller

Company role: Chief Product Officer, pilot

Alex is in 10th grade at Garfield High School in Seattle, Washington. This is his 6th year competing in the MATE ROV Competition, and eventually he would like to be an electrical or mechanical engineer.

Clara Orndorff

Company role: Chief Executive Officer, pilot, tether manager

Clara is in 12th grade at Ingraham High School in Seattle, Washington. This is her 6th year participating in the MATE ROV Competition, and eventually she would like to be some type of engineer.

Nicholas Orndorff

Company role: Chief Technology Officer, pilot, tether manager

Nicholas is in 10th grade at Ingraham High School in Seattle, Washington. This is his 6th year competing in the MATE ROV Competition, and eventually he would like to be a mechanical engineer.

Company Information photo credits: R. Miller

4. Mission Theme

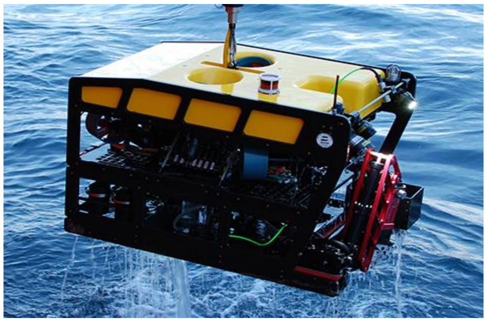


Figure 2: The MBARI Phantom ROV being deployed for exploration work in the Arctic[1]

Figure 3: The Royal Dutch Shell Arctic oil rig at the Port of Seattle
(Credit: C. Orndorff)

ROVs have recently gained attention for their use in research expeditions to explore the role of Arctic methane vents in global warming[2]. Most people do not know, however, that ROVs play a crucial role in the oil and gas industry which is the basis of many northern economies. It has been emphasized by industry professionals and energy experts that access to sustainable oil is a necessity for a secure economic future. The largely untapped Arctic oil fields are commonly believed to be a source of economic prosperity.

If the oil hidden within the Arctic can be extracted, much of the world will no longer be dependent on pipelines from other countries or continents. Several recent accidents have, however, questioned the safety of Arctic oilfields. Drilling in such extreme conditions does have risks, but luckily unmanned ROVs can do much of the hard work with less of the danger, and in doing so they can aid in ensuring economic security.

5. Safety

Safety features and practices are crucial components for a professional vehicle. Especially because ROVs use electricity in close proximity to water, the company made safety a high priority during the design process. Therefore, this year's vehicle has all of the required safety features including: no sharp edges, a 25amp fuse within 25cm of the battery on the positive line, caution labels for moving parts, strain relief on the tether and all other cables, and thrusters that are both inboard and shrouded. In addition to the required safety features, the team introduced several of their own, including a main power shutoff switch, surface voltage and amperage meters, a vacuum depressurization system to test for water leakage and DC-DC isolated switching power supplies to eliminate voltage spikes to electronic systems.

During construction of the ROV, the company followed a comprehensive safety protocol and Job Safety Analysis (JSA) which required proper Personal Protective Equipment (PPE). This includes the use of safety glasses, closed-toe shoes and gloves and masks (for potentially hazardous substances). The company complied with all Health, Safety and Environmental (HSE) standards in order to maintain a safe workspace.

Are we wearing closed toe shoes and safety glasses?
Is there a 25 amp fuse?
Is there (do we have) a Ground Fault Circuit Interrupter (GFCI)?
Is the airlock system on the ROV? Is the port closed? Has the ROV been airlock tested?
Is the tether strain relief in place?
Are the two control boxes plugged in correctly (check labels)?
Are the two banana plugs for power plugged in properly (red is + and black is -)
Are all the switches in the off position? (Main power)?
Is the tether/control case clamped to the table?

Table 1: The company's safety protocol

6. Design Rationale

There were many special considerations that went into the designing of a professional ROV capable of operating in extreme environments. Generally, there were environmental considerations to account for, such as the 75cm x 75cm hole in the ice for Mission 1 through which the ROV has to fit. More specifically, particular goals were created for the technical aspects of this ROV. One of these was to build custom waterproof thrusters. Another was to create a software-based system that allowed for multiple degrees of movement in both the horizontal and vertical planes.

Per necessity, the ROV needed to be compatible with the 2015 mission tasks. Due to the large number of tasks that have to be accomplished, the ROV's payload tools are designed to be not only capable but also interchangeable and time efficient, and the team created its own task order to reduce the number of trips to the surface (which is easily modifiable as necessitated by different pool conditions). Below is the order that was used for Mission 1: Science Under the Ice at the Pacific Northwest regional competition.

#	Initial Driver Plan	Task (Mission 1)	Points
1	C	Put measuring tee in claw	
2	N	Use tee to measure diameter of iceberg	10
3	N	Drop tee	
4	N	Measure keel depth of iceberg – depth sensor	10
5	N	Survey iceberg – show letters to judges	5
6	N	Bring tee back to pool station – tell Clara coordinates and heading	0 or else -5
7	C	Map the iceberg must be accurate to 1mm	10
8	C	Calculate volume of Iceberg V =	5
9	C	Determine threat level - surface	10
10	C	Determine threat level - subsea	10
11	A	Deploy passive acoustic sensor – assisted descent	10
12	A	Pick up sea urchin + bring to surface (o-ball)	10
13	A	Identify and count sea stars	10
14	A	Get algae from under ice + bring to side.	10
15	C	Present map, and calculations – before demobilization!	

Table 2: Efficient mission 1 task order

6.1 Frame and Flotation

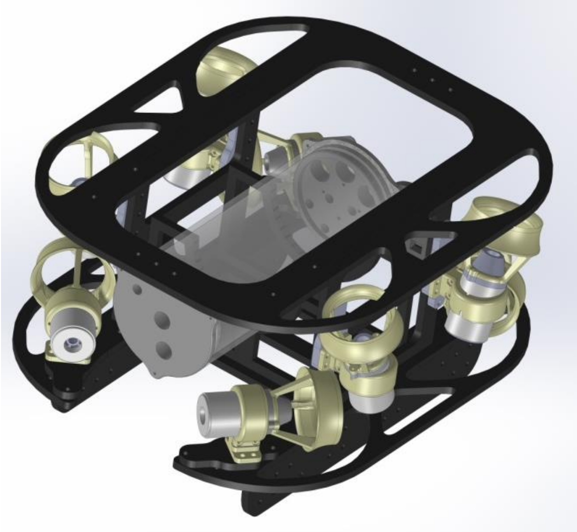


Figure 4: A Solidworks model of the major components of the ROV

The frame is made from laser-cut Starboard (a marine-grade version of high density polyethylene, or HDPE). Among its beneficial properties are its durability and its dimensional stability (it will retain its physical characteristics underwater). The frame was designed to have useful features including hemispherical cutouts to cradle the Waterproof Electronics Canister (see section 6.2), skids, integrated thruster mounting plates and cable control.

The frame was first designed in Solidworks to employ a unique slot-and-tab construction so the pieces fit together perfectly in a clean, rigid structure. Only eight bolts were needed for in its assembly, which both minimizes the weight load on the thrusters and conserves space on the frame for mounting other systems.

The goal was to achieve neutral buoyancy. Prior to vehicle construction, the required volume of flotation was calculated, based on the ROV's estimated final weight, to be 0.017m^3. This volume turned out to be correct, but achieving the correct placement required empirical testing.

Therefore, the necessary amount of flotation in the form of incompressible, closed-cell polyisocyanurate foam was mounted towards the top of the vehicle for the desired stability.

Figure 5: The frame with four of the 3D-printed thruster mounts *(Credit: A. Miller)*

6.2 Waterproof Electronics Canister (WEC)

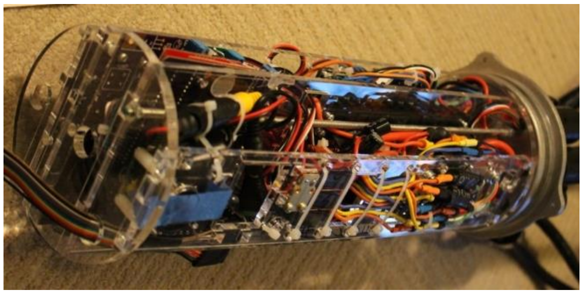


Figure 6: Bottom view of the compact electronics rack *(Credit: A. Miller)*

Figure 7: Top: a potted cable gland; Bottom: a female bulkhead *(Credit: R. Miller)*

The WEC is designed to safely and neatly contain the onboard electronics. For this purpose there is a 3-layer acrylic rack designed to hold the ROV’s printed circuit boards (PCBs) and other electronic accessories. It is based upon a 0.6cm-thick acrylic tube, which is clear to aid troubleshooting. An aluminum end cap, CNC-machined for accuracy, facilitates a watertight piston-type seal involving 0.5cm O-rings.

There are two ways in which cables enter and exit the WEC. On the rear end cap, there are six 6-contact bulkhead connectors as well as cable penetrators made from liquid-tight cable glands filled with epoxy resin. The cable glands are not only waterproof but also provide strain and bend relief.

On the front endcap there is an AirLock vacuum depressurization system. With a hand pump, air is removed from the WEC and a gauge is monitored for leaks. This test is conducted prior to every operation of the vehicle.

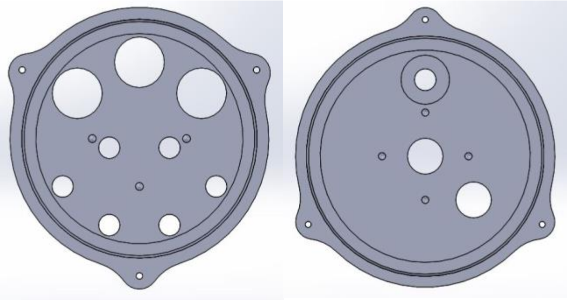


Figure 8: Solidworks models of the front (R) and rear (L) WEC end caps

6.3 Thrusters

The basis of each thruster is a hobby brushless motor, controlled via an Electronic Speed Controller (ESC). These motors were chosen for their high power-to-thrust ratio and their cost-effectiveness compared to similarly priced brushed motors. A CNC-machined aluminum end cap makes a reliable liquid-tight seal with an O-ring and is also compatible with a ¼in (6.35mm) pump shaft seal. Pump shaft seals were chosen because they require less accuracy and have low friction compared to O-ring or other elastomer seals. They are also good for use in water with a high particulate content.

The thruster assembly is housed in PVC parts, mounted to the frame and shrouded with 3D-printed acrylonitrile butadiene styrene (ABS) parts. There are eight thrusters total; four each for horizontal and vertical motion. The horizontal thrusters are vectored to allow for strafing (direct left-to-right motion) and the optimal amount of forward-backward motion (which, through research, was deemed more crucial than strafing motion). The vertical thrusters provide traditional up-down motion as well as forms of unstable motion such as tilting. Unstable motion can be beneficial as long as it is controllable, which is accomplished on this vehicle due to the nature of the control system (see 6.4).

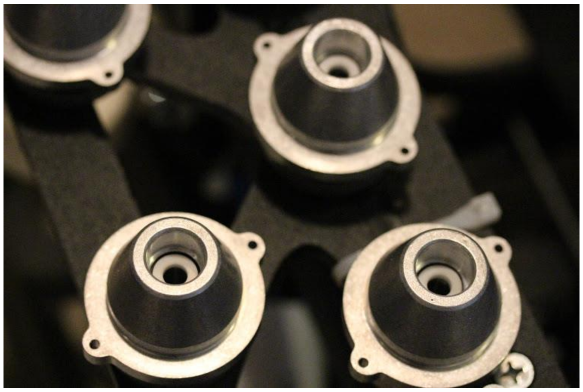


Figure 9: Several of the end caps immediately after machining *(Credit: R. Miller)*

Figure 10: The completed thruster assembly
(Credit: C. Orndorff)

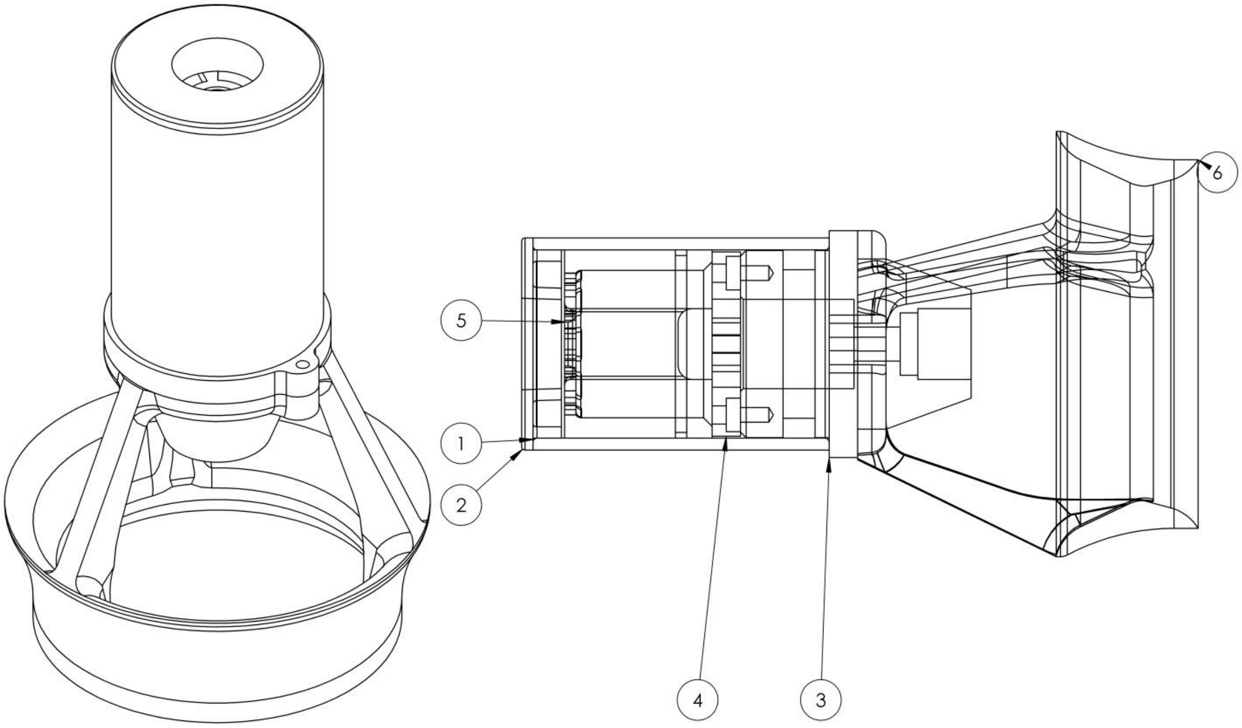


Figure 11: A Solidworks drawing of the thruster assembly
1: PVC coupler; 2: PVC reducer bushing; 3: CNC-machined aluminum end cap;
4: Delrin adapter plate; 5: 3D printed motor wire guard; 6: 3D printed propeller shroud

6.4 Control System and Tether

The control system was designed as a solution to intuitively integrate advanced user features and to allow for non-invasive prototyping with quick implementation of new systems. To do this, the system uses distributed control, meaning that two distinct custom printed circuit boards (PCBs), each based on an ATMEGA 2560 chip, are responsible for top and bottom communications which control the major functions of the ROV.

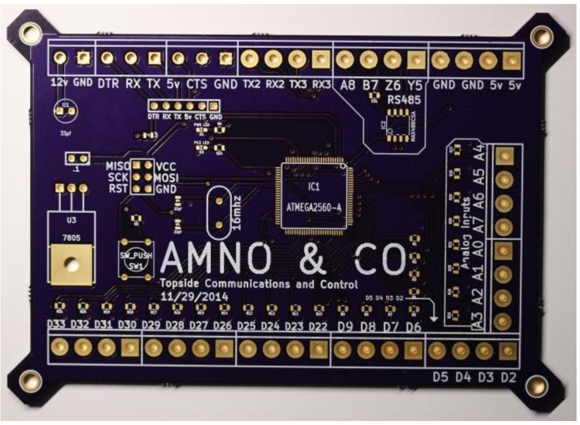


***Figure 12: The unassembled PCB for topside communications** (Credit: A. Miller)*

The decision to build custom PCBs stemmed from the need to fit a large amount of electronics in a small space and subsequent experimentation with the circuit board design program KiCad. This is accomplished through the use of surface-mount-devices (SMD), facilitating compact designs, more features, and newer and cheaper components. In addition, custom PCBs and SMD components combine to provide mechanical robustness and easy system integration.

Figure 13: The assembled PCB for sensor control *(Credit: A. Miller)*

In the control case at the surface, the topside communications board allows for reliable command of the vehicle. These commands are processed, and transmitted through the tether via a full-duplex RS485 communications protocol, created with a MAX488 transceiver. One benefit of the full-duplex network is that the topside communications board can simultaneously send and receive data from the ROV.

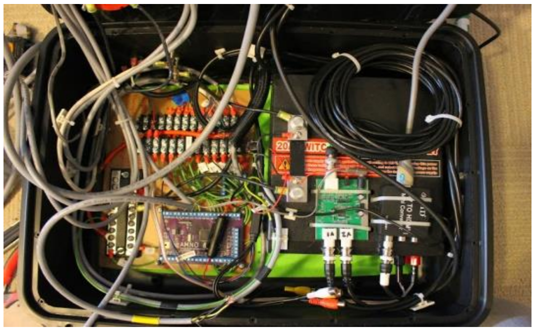


Figure 14: The topside control case, in progress *(Credit: R. Miller)*

Communications signals are then distributed to three other boards for sensors, thrusters and tooling. The sensor board features a 1-axis gyroscope, 3-axis accelerometer, leak detector and sensors for conductivity, temperature and depth. The thruster board allows for intuitive plug and play use of eight thrusters, and includes an LED-based thruster simulator, allowing for time-saving software testing when no thrusters are connected. Finally, the tooling control board includes built-in serial control for eight brushed thrusters.

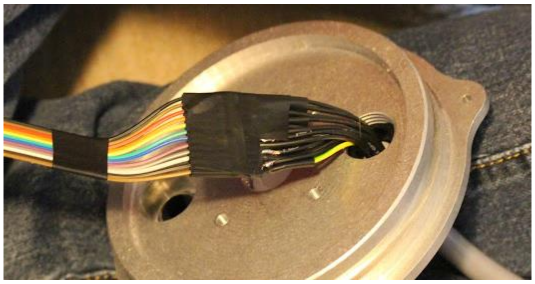


Figure 15: The remote programming cable with the WEC's front end cap *(Credit: A. Miller)*

At the surface, collaborative piloting is provided by two external user control boxes that plug into the main control case. The first box, for piloting, features a three-axis joystick for horizontal motion, a two-axis joystick for vertical motion and a potentiometer for tilt control. The second box features a toggle switch for the pump system and three double-pole double-throw switches for other systems including a manipulator and a rotary tool.

Figure 16: The surface control case *(Credit: A. Miller)*

The unique hardware supports sophisticated software that provides innovative features found on few working class vehicles. For example, the inclusion of an advanced sensor processing unit allows for the future implementation of proportional integral derivative depth and tilt hold. Another advantage is that the programming interface was designed to be extremely accessible – all of the boards can be remotely programmed while the WEC is closed.

The tether is 28m long, and braided for minimum size and maximum flexibility. It contains:

- Two 8-gauge silicone wires for power
- Five 18-gauge wires for signal
- Two coaxial cables for video

6.5 Cameras

The ROV is equipped with three cameras, all 700TVL resolution, 120º field of view and 0.1lux low light viewing capabilities. The first camera, for general driving purposes, is mounted looking forwards for viewing the primary tooling (see section 6.6). The second camera faces backwards, in order to provide another driving view and to be able to see the rotary tool (see 6.6). The third camera faces downwards and is mounted inside the bottom of the clear WEC. This is useful for mission tasks that require a wide perspective, such as counting the sea stars in Mission 1. While there are three cameras, a video multiplexer allows the signals to be sent up the tether on only two coaxial cables. At the surface, the forward camera is displayed on its own monitor while the two other auxiliary cameras share a second screen via a video switcher.

6.6 Mission Specific Tooling

Figure 17: The manipulator closed (top) and open (bottom) *(Credit: A. Miller)*

Figure 18: The interchangeable pump *(Credit: R. Miller)*

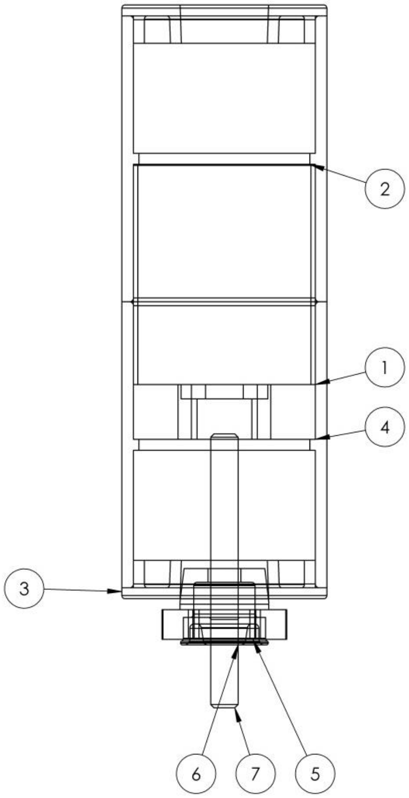
Figure 19: Tooling mounted on the front of the ROV *(Credit: R. Miller)*

Manipulator: In order to accomplish most of Mission 2 and select parts of Missions 1 and 3 (including retrieving the sea urchin and deploying the passive acoustic sensor), the manipulator was built around an electric linear actuator with 9kg of force. This drives three interlocking end effectors, which are made from Starboard (see 6.1) and shaped to be able to hold objects securely in any orientation.

In order to test the grounding of anodes in Mission 3, the manipulator deploys a magnet which attaches to the ground of the wellhead. The end effectors are plated with conductive copper strips (not pictured) that touch the different test points and complete a circuit with the magnet through the sensor PCB in the WEC. Data from this system is displayed on a Liquid Crystal Display (LCD) screen at the surface, alerting pilots to the improperly grounded anode.

Pump: In order to push water through the valve manifold in mission 3, an in-line pump connects to a 3D-printed fitting that mates with the manifold port. A plastic funnel helps direct the flow of water in order to guide the vehicle.

Rotary Tool: In order to turn the valves in missions 2 and 3, the rotary tool is mounted off the rear of the vehicle. It uses a planetary gearmotor that has 12.7N-m of torque and 60rpm. It is waterproofed using a u-cup seal that fits into standard PVC parts. From the shaft, 10cm-long bolts are attached to a lever with a clamping shaft collar. These protrude below the ROV’s frame in order to have uninhibited access to the valves.



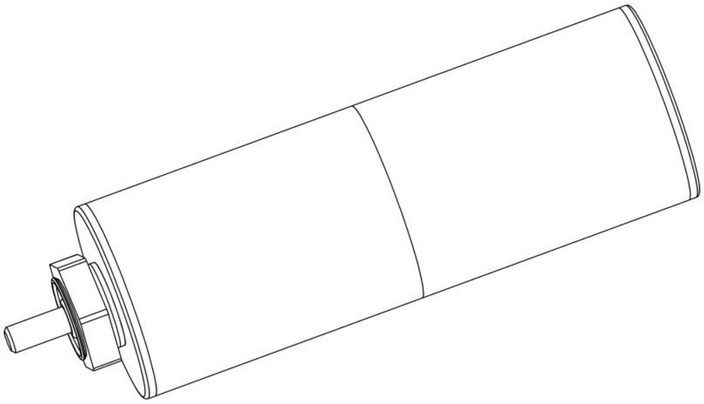


Figure 20: The waterproof PVC housing for the rotary tool
1: length of PVC pipe; 2 & 3: PVC reducer bushings;
4: gearmotor; 5: PVC threaded reducer; 6: u-cup seal; 7: motor shaft

7. Troubleshooting

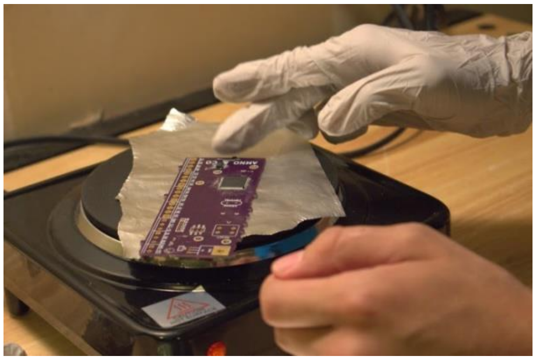


Figure 21: Using a hot plate to solder a miniscule Arduino chip onto a custom PCB, with gloves for safety *(Credit: A. Miller)*

A specific instance of troubleshooting involved the chips used on our control boards. These chips measure 1.4cm by 1.4cm and have 25 contacts per side for a total of 100 pins that have to be perfectly soldered onto very small, 0.5mm pads on the PCBs. From our research, we decided that the way to do this would be to put a thin layer of solder paste over the contacts on the board, carefully align the chip on top, and place the whole setup on a hot plate which would melt the solder – excess solder could later be removed with a knife. This method appeared to work and we implemented the boards into our control system, where we realized that this type of soldering led to unreliable connections. To fix this, we came up with our own solution to small-scale soldering. First, a substantial amount of solder was placed over the pins, covering them thoroughly. Next, we used solder wick to remove the excess. Finally, we were able to use a multimeter to test the majority of the pins to make sure the connections were correct.

Extensive prototyping was done for each individual system, primarily using 3D printers which are known for rapid prototyping. Using this technology enabled the company to make more models quicker and for a lower cost than any other method. On a larger scale, however, testing and piloting the entire ROV was essential and in fact a form of troubleshooting. Every vehicle pilots somewhat differently and requires a learning curve – since we had a completely new vehicle this year, we had different types of joysticks along with our other new features. In order to do well at the regional competition, we had to be able to pilot the ROV well, and this came from the extensive pool testing sessions we were able to have. Therefore part of our success comes from how familiar we are with our ROV's handling under different conditions.

8. Teamwork and Organization

Figure 22: Clara, Alex and Nicholas collaborate to launch the ROV at the regional competition *(Credit: R. Miller)*

Figure 23: Alex, Clara and Nicholas work together to braid the tether for minimum size and maximum flexibility *(Credit: A. Miller)*

We made task assignments chiefly at the design level by assigning particular team members to do research on how best to accomplish a specific mission. After the research phase, however, we all had to agree on the design and then we built, tested, implemented and went through the troubleshooting process together. Since there are only three people on our team, we value the fact that each of us is directly involved with every aspect of this project. Instead of having, for example, a "lights expert" or a "control system specialist," we all worked through every step of every system together. Therefore, when we are asked questions about specific systems, we all have a complete knowledge about our ROV. Also, our goal was to learn as much as possible: for example, to do the machining we reached out to local companies, who were generous enough to donate their expertise by teaching us to use their machines for our own parts.

9. Project Management

This year's design process began in June of 2014, after the 13th MATE International ROV competition, because we build a completely new vehicle every year. While in past years we reused some components, the last vehicle we built was highly specialized and still functional so were reluctant to remove components, leading to our decision to build our current vehicle from scratch. In addition, we like the challenge of being able to fully display all the skills we've learned over the last six years in an entirely new ROV.

In order to achieve everything we wanted this year, we made deadlines for ourselves. When we wanted to make something complicated and time-consuming, we made limits so we would not spend inordinate amounts of time, effort and money. Having the deadline of the regional competition was another motivating factor – as the date got closer and we realized that some aspects still had to be finished, we reorganized our priorities to focus on the ROV instead of our other commitments.

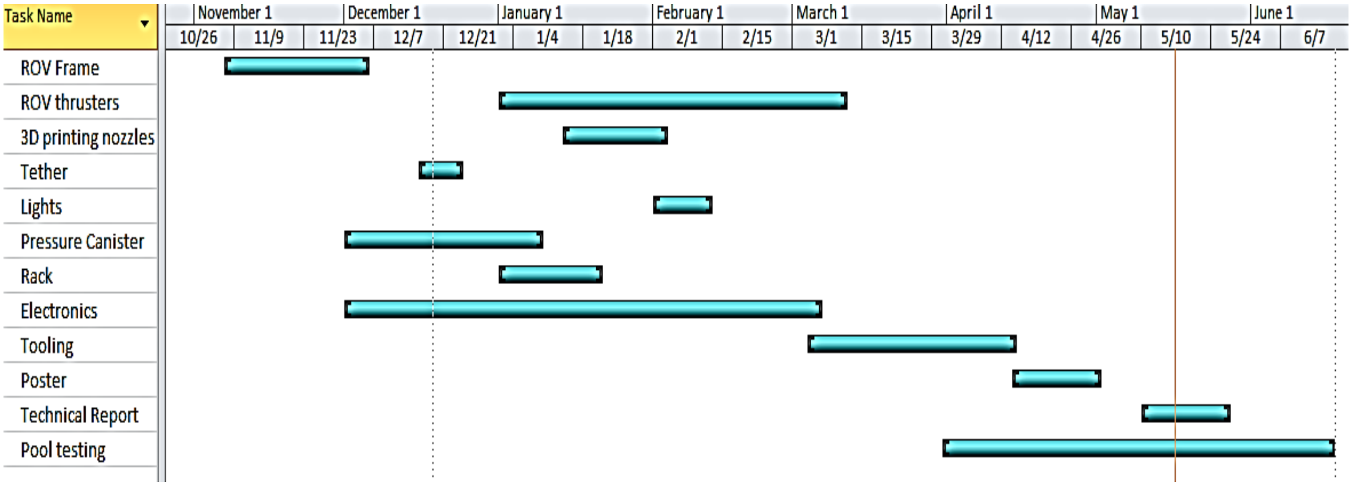


Figure 24: A Gantt chart for the essential elements of this year's design process

10. Challenges

10.1 Technical Challenge

Figure 25: A brushless hobby motor
(Credit: R. Miller)

One challenge we faced was learning how to use brushless motors for our thrusters. We had never used brushless motors before, and therefore had to figure out all of their particulars, often by iterative testing. We learned, for example, that for the motors chosen it was not possible to run two motors from the same ESC (the vertical thrusters were originally designed to run in pairs). When our systems did not work, we did in-depth research and learned that this is theoretically possible, but only with more expensive ESCs and high-precision motors (ours were not). Fortunately, we had extra ESCs and were able to integrate these into our system with little difficulty.

10.2 Non-technical Challenge

Occasionally, multiple team members felt that they had created the best design for a particular task and were reluctant to compromise. However, since we had to eventually decide on a single solution, we found that the best way to find the best one was to prototype and test all the possible designs so as to have physical evidence as a basis for our important team decisions.

11. Lessons Learned

11.1 Technical Lesson

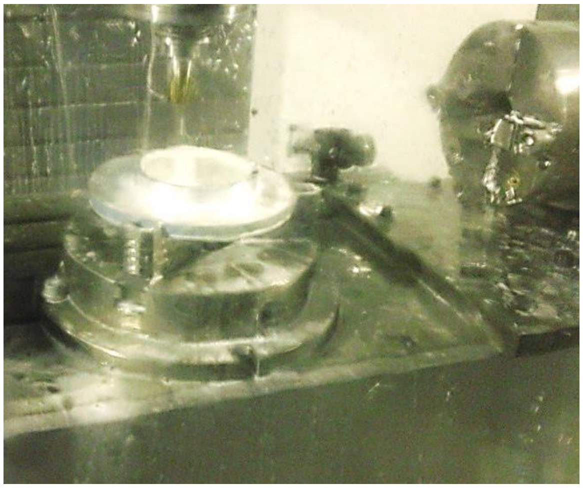


Figure 26: Partway through the machining process of one of the WEC end caps *(Credit: C. Orndorff)*

A local product development company, Claroworks, has been helping us learn how to make more professional vehicles and systems. We were eager to learn how to do CNC machining and programming as they are necessary skills for us as future engineers, and for fun. We expanded on our knowledge of the CAD program Solidworks to learn how to use the machining program HSMWorks and were fortunate enough to be trusted on their Haas 3-axis CNC machine. We eventually used these new skills to machine our own WEC and thruster end caps.

11.2 Interpersonal Lesson

Figure 27: Nicholas, Alex and Clara explain their ROV *(Credit: R. Miller)*

This year, we learned how wonderful it is to be able to share our ROV building with others and inspire younger children to join the MATE ROV competition. The Seattle Aquarium held a Discover Science Weekend, and we brought our previous ROV for what was intended to be a static display for the MATE booth. A professional Seabotix ROV demonstration had been planned, but it experienced unexplained failures and the event coordinators asked us if we would pilot ours instead – our answer, of course, was yes! We therefore had a fantastic time figuring out their fast-paced safety approval processes and piloting our ROV in the aquarium’s 50,000 gallon main tank for an audience of several hundred fascinated families.

12. Future Improvements

Many times, mission specific tooling becomes an afterthought – only after we have designed and built the rest of the ROV do we seriously consider tooling design and placement. This year, however, we learned so much in terms of design, prototyping and machining and we would want to apply all of these in the future to make improved tooling systems that can accomplish the mission tasks in a smooth manner yet still be versatile and multipurpose. More specifically, we would like to make a mechanical arm instead of just a fixed manipulator, as this would provide more degrees of motion.

13. Company Reflections

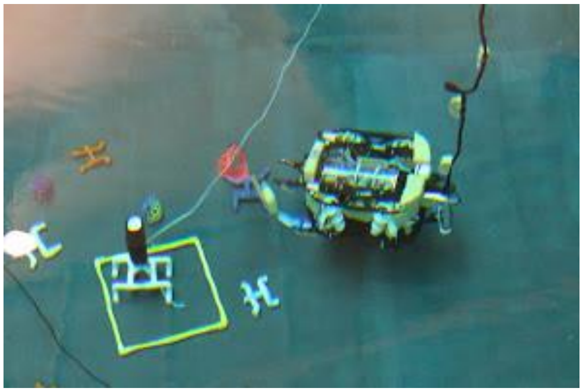


***Figure 28: The ROV operates in the 5m pool at the PNW Regional** (Credit: R. Miller)*

We realized that, although simple systems can work well enough for the task at hand, as a company we get a larger benefit out of working through more complex solutions. To us, the challenge of troubleshooting difficult problems is more beneficial than simple systems that work but have less learning value. This motivated our decision to design our own circuit boards for the control system. As we expected, it was difficult to troubleshoot the control system because there weren't very many resources we could look to for solutions. In the end, however, this more complicated approach was definitely worth it: our control system works exactly as we originally intended, and we gained many useful skills throughout the process.

14. Budget

AMNO & CO is not associated with any school or organization so does not have institutional support in the form of funds, equipment, or materials. Therefore, we must be thoughtful and careful in order to control how much money we spend. To do this, we considered several factors in setting a budget. First, we considered the amount we spent on the vehicle we built for the 2014 MATE competition - approximately $2000. Second, we estimated that in order to build a more sophisticated vehicle we would need to spend more money, largely for prototyping more designs and for using higher quality parts. Third, we dedicated the amount of prize money/income we received from last year's achievements to cover these extra costs - $1150. Therefore, our final spending budget allows for more sophistication by combining last year's costs ($2000) with prize money/income ($1150), for a total budget of $3150. In order to stick to this budget, we had to make conscientious design and purchasing decisions. While we often might have liked to use professional, high-precision parts, their costs were prohibitive. In those cases we used a successful letter-writing campaign requesting discounts or donations of products.

As can be seen in the Project Costing section, our out-of-pocket costs were $3194.25 (very close to our budget) and the value of donated parts and services was $4586.75, for a total value of $8931.00.

15. Project Costing

Category	Amount Spent (USD)	Total Value (USD)	Donated/Discounted/ Reused
Frame	**191.84**	**267.6**	
Laser cutting	0	60	Donated
Starboard	141.84	157.6	Discounted 15%
Misc.	50	50	
Flotation	**0**	**50**	Reused
Polyisocyanurate foam	0	50	Reused
WEC	**89**	**1804**	
Machining	0	500	Donated
Tube	0	150	Donated
Aluminum stock	0	50	Donated
Acrylic rack	89	89	
Cable glands	0	15	Donated
Bulkhead connectors	0	1000	Donated
Thrusters	**558.2**	**1878.2**	
Machining	0	800	Donated
Aluminum stock	0	100	Donated
Seals and O-rings	0	320	Donated
ABS filament	50	150	Discounted
Motor drivers (ESCs)	166	166	
Motors	240	240	
PVC fittings	11.7	11.7	
Hardware	30	30	
Misc.	60.5	60.5	
Electronics	**1916.85**	**3138.06**	
Printed Circuit Boards	700	700	
Electronic components	700	700	
Topside control case	0	200	Donated
Small control cases	27.44	41.16	Discounted 50%
Front panels	0	50	Donated
Surface connectors	28	56	Discounted 15%

Joysticks	0	900	Donated
Misc.	461.41	490.9	Discounted 10%, 15%
Tether	**275**	**286.65**	
Silicone wire	200	211.65	
Other wire	50	50	Discounted at cost
Sheathing	25	25	
Cameras	**204.99**	**234.99**	
Cameras	180	180	
Epoxy	24.99	54.99	Donated
Tooling	**928.51**	**1091.64**	
Actuators	290	440	Discounted 50%
Bearings	120	120	
Misc.	518.51	531.64	Donated, Discounted at cost
Misc.	**179.86**	**179.86**	

Value of Donated Parts (USD)	4586.75
Income (USD)	1150
Amount Spent (USD)	3194.25
Total Value (USD)	**8931**

Other costs include travel and ROV transportation to Newfoundland, which currently have not been finalized. However, AMNO & CO estimates $4000 will cover transportation for the team, shipping costs for the ROV, and hotel rooms for the duration of the competition.

15. References

1. "Expedition to Study Methane Gas Bubbling out of the Arctic Seafloor." MBARI. September 21, 2012. Accessed May 2, 2015.

2. "Subsea Industry: Drilling on the Floor of the Arctic Ocean." Alberta Oil Magazine. October 21, 2013. Accessed May 2, 2015.

16. Acknowledgements

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- All the MATE Competition officials and volunteers

MATE

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Appendix 1: Sample electrical schematics

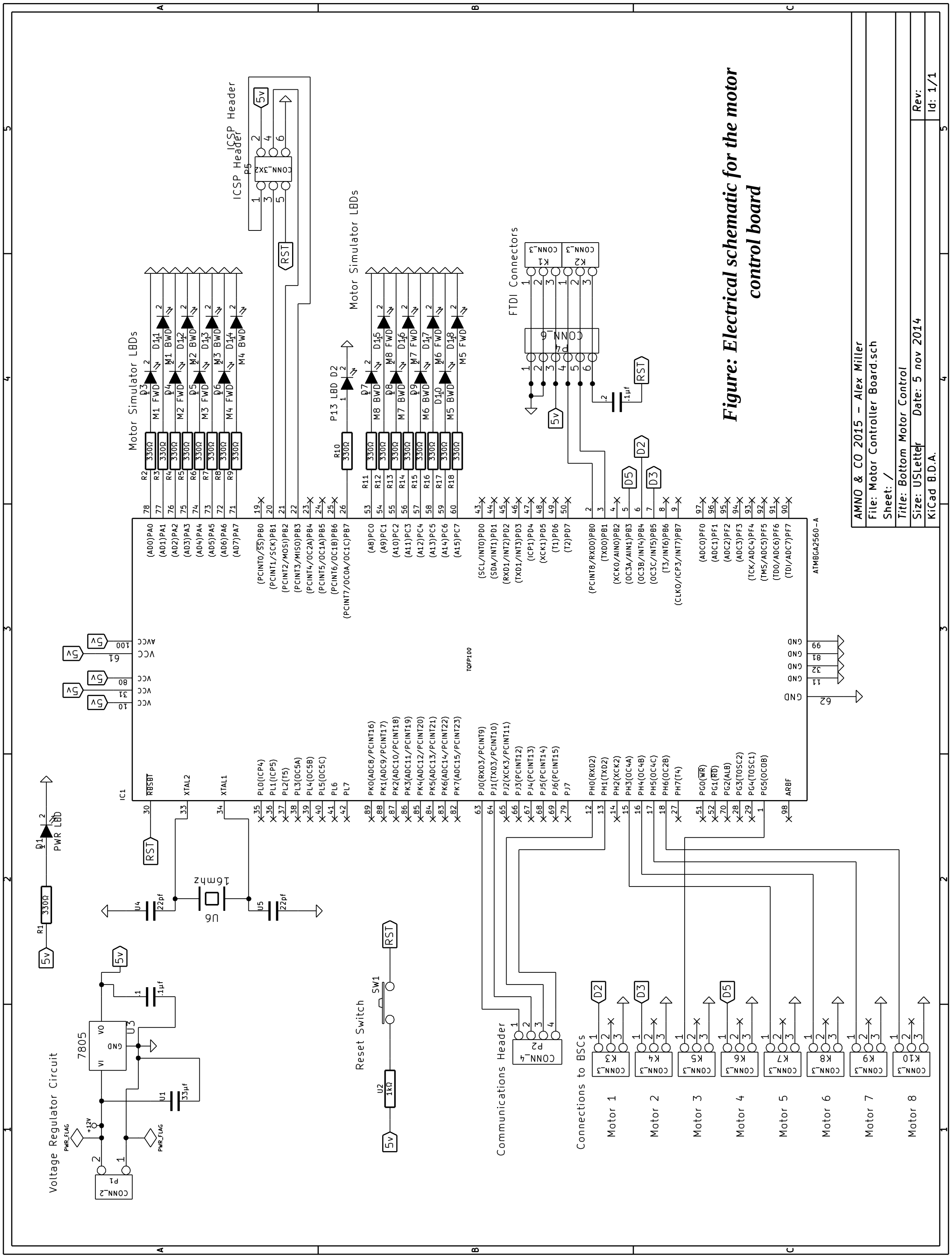

Figure: Electrical schematic for the motor control board

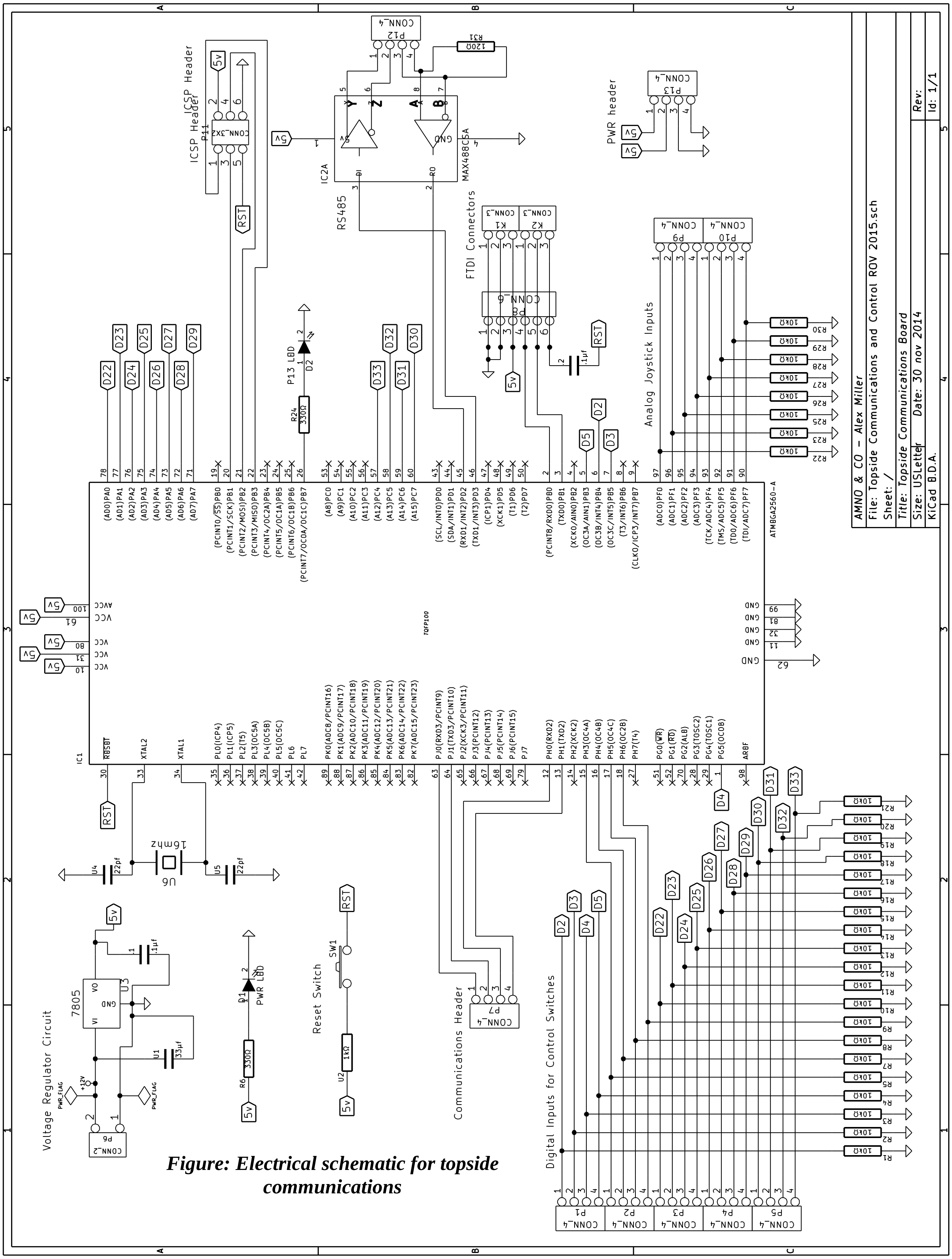

Figure: Electrical schematic for topside communications

Appendix 2: Sample software flowcharts

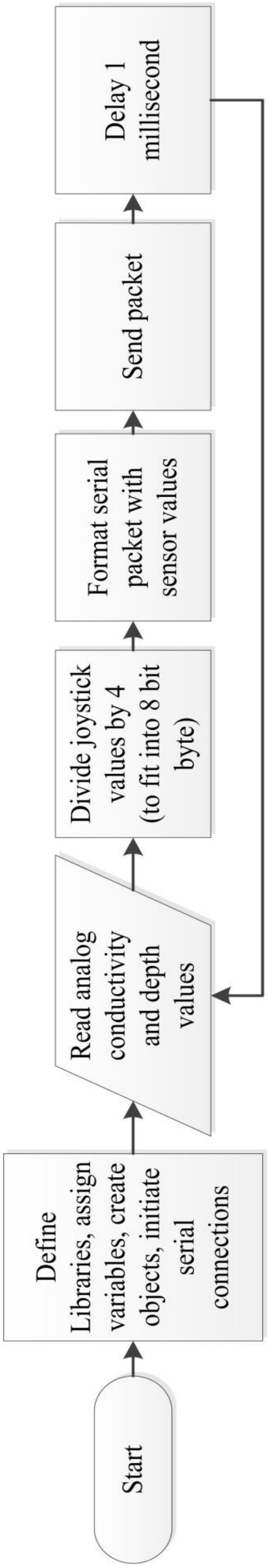

Figure 29: Software flowchart for sensor data

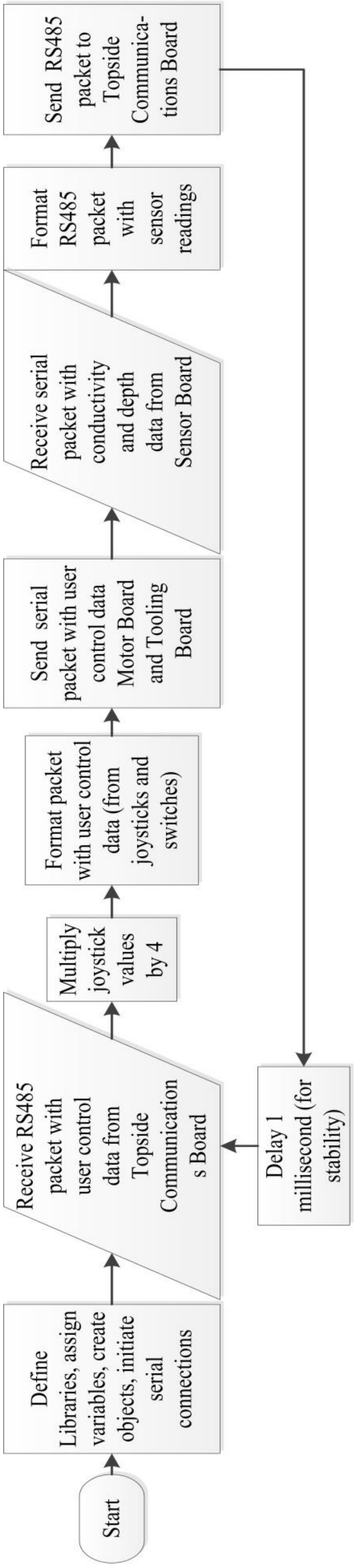

Figure 30: Software flowchart for bottomside communications

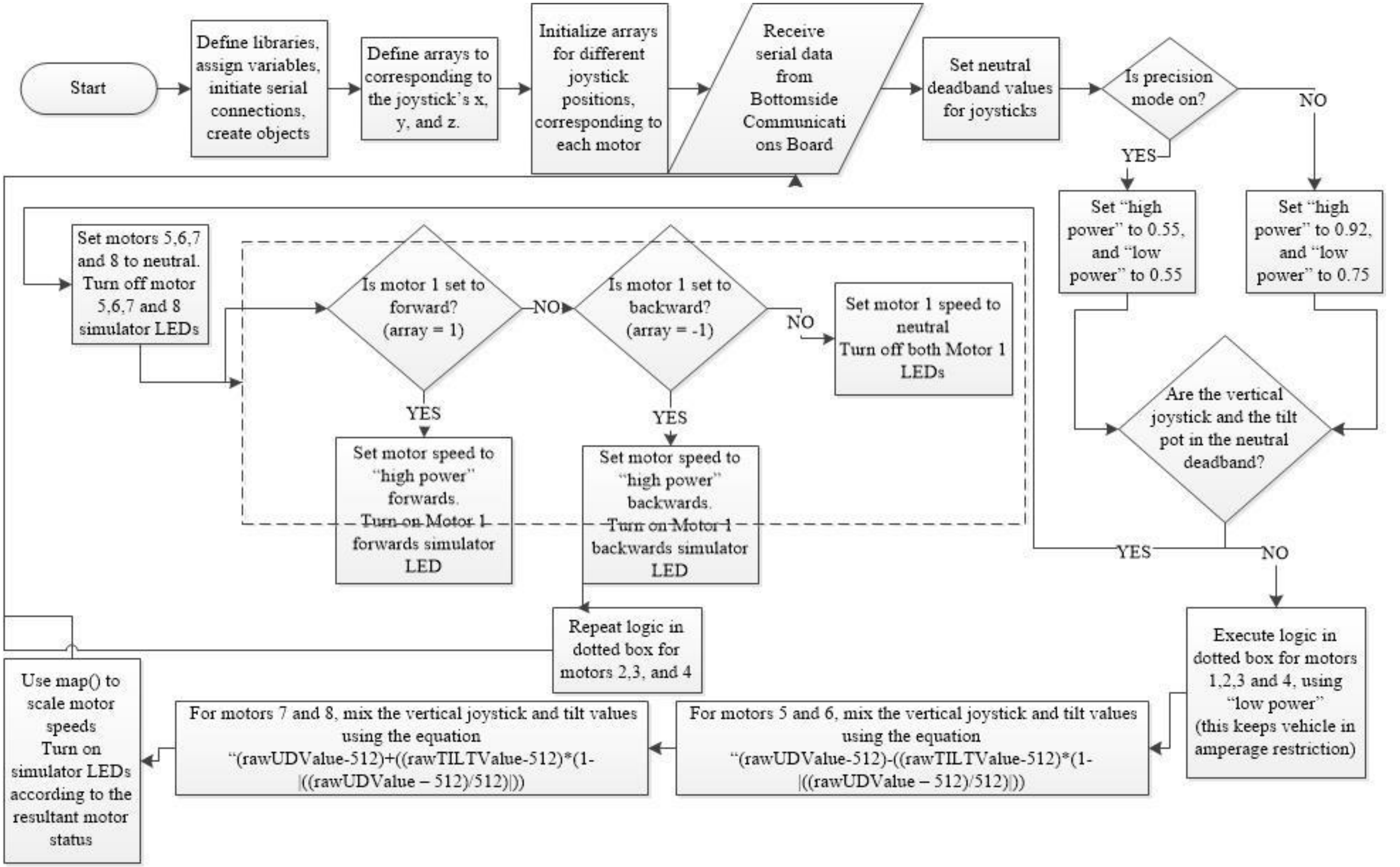

Figure 31: Software flowchart for thruster control