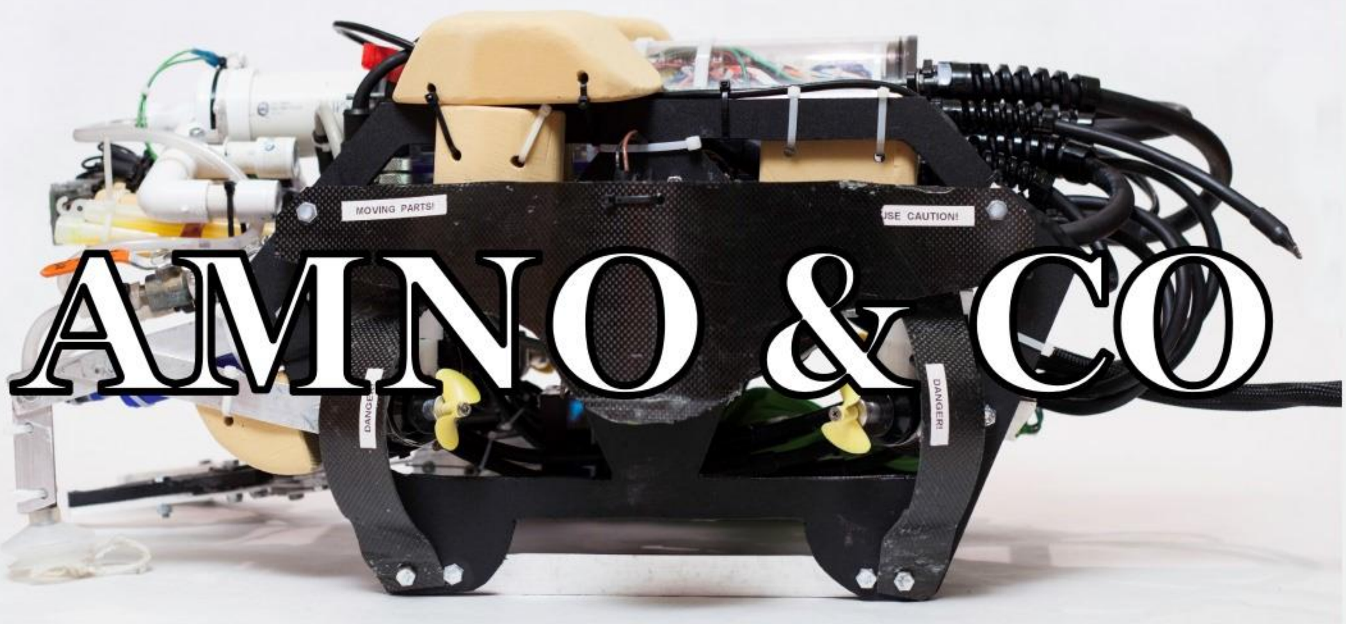
2014 MATE International ROV Competition
Ranger Class
Alpena, Michigan

AMNO & CO



Alex Miller (software specialist) GARFIELD HIGH SCHOOL*
Nicholas Orndorff (mechanical engineer) INGRAHAM HIGH SCHOOL*
Clara Orndorff (CEO) INGRAHAM HIGH SCHOOL*

Mentor: Mary Chang
Seattle, Washington, USA

*AMNO & CO IS NOT AFFILIATED WITH ANY SCHOOL OR ORGANIZATION

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1. ABSTRACT

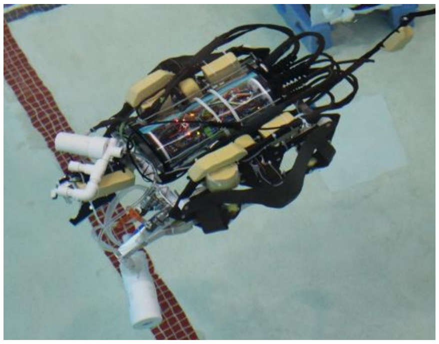
As a company this is our fifth year of building specialized Remotely Operated Vehicles (ROVs). For this year's competition our ROV is intended to assist in analyzing and recovering shipwrecks in the Thunder Bay National Marine Sanctuary.

Throughout this process our goal has been to build a sophisticated yet rugged ROV while at the same time learning many new skills. In light of this our research was crucial, leading us to experiment with carbon fiber for the first time and to develop machining skills.

This year, we are excited to have created an ROV that includes an Arduino/RS485-based control system with depth hold and strafing motion, an electric actuator-driven manipulator with limit switches, and a durable Starboard frame with carbon fiber elements.

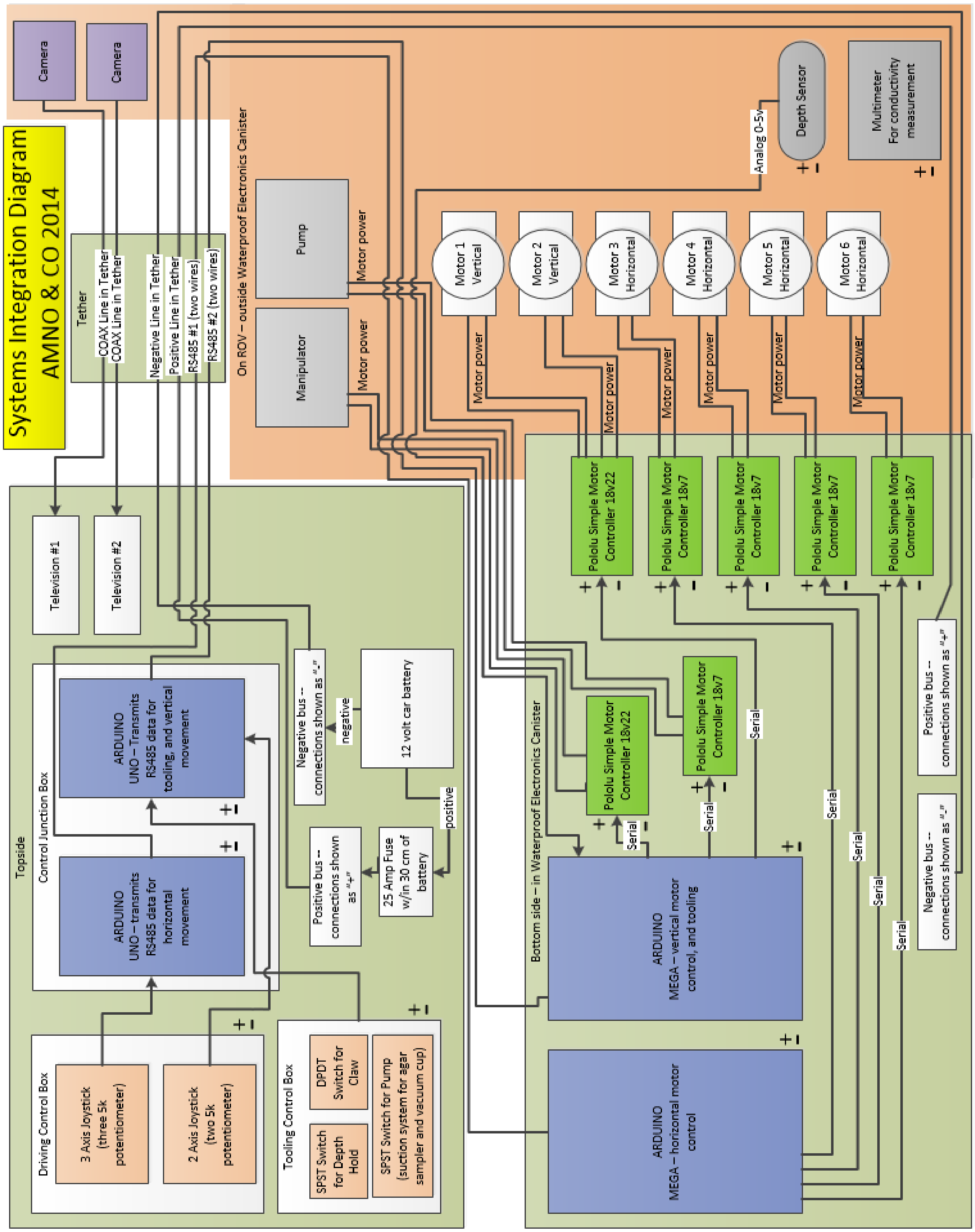
In addition to all of the abovementioned features, we are most proud of all the new skills we researched and acquired along the way. We feel that this year's ROV represents the work of many years' research and lessons.

Now, approaching this year's international competition, we are confident that all of our research, experimentation, and practice will pay off during our missions.



The ROV

2. SYSTEMS INTEGRATION DIAGRAM (SID)



3. COMPANY INFORMATION

Alex Miller

Alex is in 9th grade at Garfield High School in Seattle, Washington. This is his 5th year of participation in the MATE competition. On the team, he is a software specialist as well as a pilot. He devotes a significant amount of his time to skiing, playing cello, and mentoring an elementary school robotics team.

Clara Orndorff

Clara is in 11th grade at Ingraham High School in Seattle, Washington, where she has just completed the final year of the IB program. This is her 5th year of participation in the MATE competition. On the team, she is the CEO, machinist, and tether manager. She spends her free time volunteering, running and participating in a local youth symphony.

Nicholas Orndorff

Nicholas is in 9th grade at Ingraham High School in Seattle, Washington. This is his 5th year of participation in the MATE competition. As part of AMNO & CO, he is a mechanical engineer as well as a pilot. When he isn't working on ROVs, he enjoys playing soccer and playing trumpet in the All-State orchestras.

(Photo credits: M. Chang, R. Miller)

3. MISSION THEME

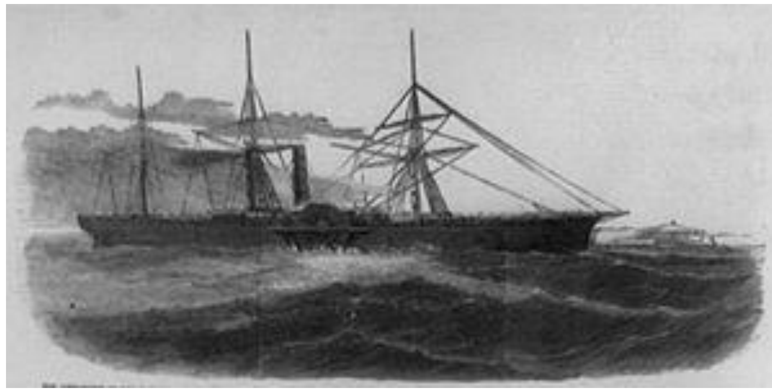
Notorious for its bad weather and conditions, the Thunder Bay region of Lake Huron is home to so many shipwrecks that it is known as Shipwreck Alley[1]. Now, the Thunder Bay National Marine Sanctuary (TBNMS) provides refuge for these wrecks as a learning experience. The TBNMS is 1,867 square kilometers, and encompasses over 200 shipwrecks. Unique to Thunder

The *FT Barney*, a wreck in the TBNMS[1]

[1] "Science Highlights." TBNMS. http://thunderbay.noaa.gov/pdf/science_highlights_tbnms&20202013.pdf (accessed March 16, 2014).

Bay is the wide variety of shipwrecks; such as a steamer sunk in 1844 and a 152m long German freighter.

Despite the efforts of TBNMS and other marine sanctuaries, shipwrecks around the world are in danger. Human activities and the natural events of the Great Lakes are hazardous to the valuable wrecks. Among these factors with the potential to destroy these treasures are ice, waves and invasive species such as zebra mussels[2] (seen in the 2014 mission tasks). This is where ROVs come in, providing the technology to safely analyze and preserve the wrecks. As can be seen from the 2014 mission tasks, ROVs can take samples from the sea bed in order to better learn how to preserve underwater environments, and their role in retrieving artifacts is important for the future of current and future shipwrecks and marine sanctuaries around the world.



The recently newsworthy *SS Central America*, containing 30,000 lbs of gold now being recovered by ROVs[3]

5. SAFETY

Among other things, the close proximity of electricity and water was one reason that safety was taken very seriously. As a result this ROV is packed with safety features, many of which also increased the vehicle's performance. In addition, the MATE competition requires certain safety features, all of which appear on this vehicle:

- A 25A fuse within 30cm of the battery on the positive line (during pool practices, a power supply displayed the current amp draw at all times)
- Inboard thrusters and danger labels on moving parts
- Strain relief on all cables

Unique to this ROV are the following safety features:

- A leak detector and vacuum test system for onboard electronics
- Error LEDs on the custom PCBs – these also were key for troubleshooting the programs
- A main power shutoff switch

Clara wears safety glasses to make one of the frame pieces (*credit: R. Miller*)

[2] "National Marine Sanctuaries Condition Reports – Thunder Bay." National Marine Sanctuaries Condition Report. http://sanctuaries.noaa.gov/science/condition/tbnms/ (accessed March 16, 2014).

[3] America's Lost Treasure. http://www.sscentralamerica.com/history.html (accessed May 19, 2014).

SAFETY PROTOCOL:
When working on the ROV, always do the following:
Wear closed-toe shoes and tie back long hair
Wear safety glasses
Never operate the ROV without fuse and GFCI plug
Always charge the battery properly
Use gloves and masks for potentially hazardous materials
Cover over all sharp edges

6. DESIGN RATIONALE

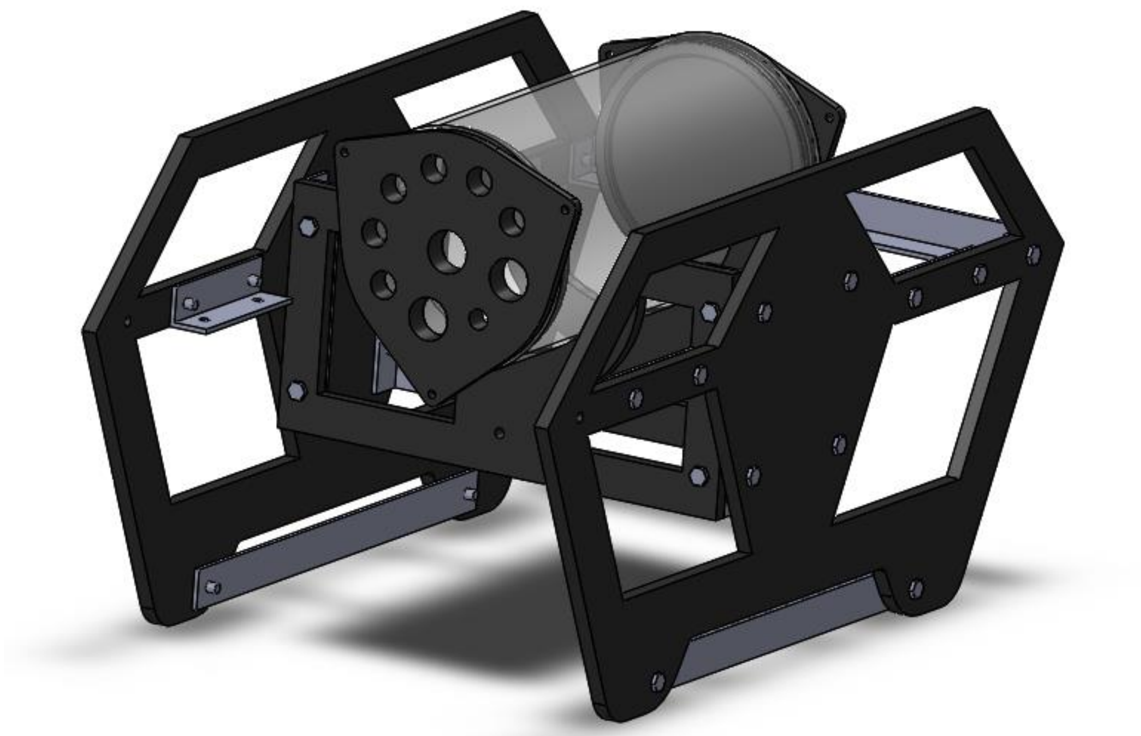
For this year's vehicle there were several crucial design considerations. First, the entire vehicle had to be less than 60 cm wide and less than 60 cm tall in order to enter the shipwreck (for example, the team's previous vehicle would not have fit). Second, in order to be more efficient, the mission tools were designed to be as compact as possible to reduce the number of trips to the surface. Third, for the control system, one of this year's design goals was to create a software-based system that allowed for every degree of movement in the horizontal plane.

As mentioned above, the goal was to build an ROV that would be compatible with the 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 time efficient, and the team designed their own order for the tasks in order to get more done. This reduces the number of trips to the surface but pool conditions make that subject to change. Below is the order used to get 250 out of 300 mission points at the Pacific Northwest regional competition.

Efficient task order:
Go down w/ quadrat, place on shipwreck, count zebra mussels
Pick up glass water bottle
Bring glass water bottle to surface
Place new sensor string in claw, and drop it off in target location
Pick up plastic water bottle
Pick up anchor line rope
Bring anchor line rope and plastic water bottle to the surface
Cargo container
Scan three targets (at 6:00 move on)
Enter shipwreck
Read date
Pick up plate
Exit shipwreck, and bring plate to the surface – ID home port
Put agar/conductivity sensor in the claw
Test conductivity – ID which one is venting groundwater
Retrieve agar
Find type of ship
Identify shipwreck based on known info

6.1 Frame and Flotation

The primary material of the frame is 0.9 cm (0.375 in) Starboard. This durable plastic has dimensional stability which makes it an excellent material for underwater applications. Parallelogram-shaped cutouts allow for water flow and decrease drag for some directions of motion. Aluminum angle and bolts anchor the side pieces to the middle pieces, also Starboard, which have semicircular cutouts to hold the Waterproof Electronics Container (section 6.3). The final dimensions, including tooling, are as follows: 0.31 m wide by 0.76 cm long by 0.36 m tall – small enough to enter the shipwreck.

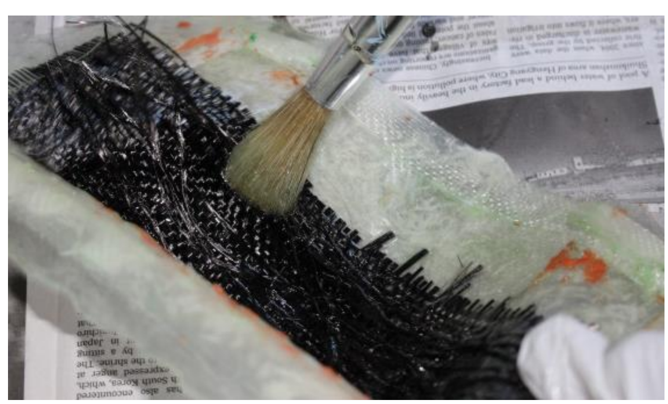


A Solidworks rendering of the frame

With all its systems aboard, the ROV has a mass of approximately 22.7 kg. This means that flotation is necessary (Archimedes' Law was used to get a rough estimate), although some is provided by the Waterproof Electronics Container (filled with air and the onboard electronics). The additional buoyancy is provided by closed-cell, polyisocyanurate foam (also used on the tether), mounted on the top for stability, which renders the ROV neutrally buoyant.

6.2 Propulsion

This year's ROV employs six 4732 Lph (1250 Gph) bilge pump replacement cartridges as thrusters, chosen for their widespread availability and their high thrust to cost ratio. Two of the bilge pump cartridges are used for vertical motion and are mounted on the center of each side of the vehicle. The remaining four are



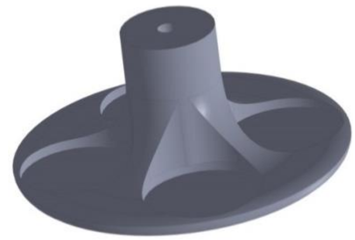
Making the carbon composite layup
(*credit: A. Miller*)

vectored at the corners, which enables strafing and crabbing motion as well as conventional movement, both using all four thrusters. Strafing motion in particular was a design consideration essential to complete the mission tasks: it reduces the time required to complete the scans of the shipwreck (rather than having to turn, drive, and turn again to reach the next target, the ROV can simply move sideways). All six thrusters are mounted securely to the frame with PVC pipe and pipe clamps, and are shrouded with custom carbon fiber composites designed and fabricated by the team.

Theoretical current (A)	3
Actual current (A)	3.5
Power (W)	42
Resistance (Ω)	3.4
Forward thrust of ROV (N)	34.3
Horizontal velocity of ROV (m/s)	0.29
Vertical velocity of ROV (m/s)	0.288
Horizontal acceleration of ROV (m/s^2)	0.006
Vertical acceleration of ROV (m/s^2)	0.0165

Specs for the thrusters and ROV (these measurements were made by the team prior to the addition of all the subsystems)

Before deciding on bilge pumps, the team prototyped other methods, including magnetically coupled thrusters. These would result in a thruster without dynamic seals - a lower chance of leaking. As a concept, the prototypes function well, but in their real applications these prototypes had too much friction to be a viable option.



A CAD rendering of a prototype part for a thruster

The team decided on the type of bilge pumps (4732 Lph) due to tests they conducted, seen in the table above right. Similar tests were conducted on bilge pumps of lower powers, with unsatisfactory results.

6.3 Waterproof Electronics Container (WEC)

In order to safely house our onboard electronics, we have created an O-ring sealed Waterproof Electronics Container (WEC). The team CNC-machined sturdy aluminum end caps that are accurate and contain liquid tight cable gland bulkheads, waterproof to a maximum depth of 46 m (10.2Kpa). They also provide strain and bend relief for all the cables. The body of the WEC is polycarbonate, chosen due to its impact resistance, as well as the fact that it is clear, which aids troubleshooting. Inside, the electronics are mounted on a laser-cut two-layer rack that provides excellent space efficiency (it was designed with considerations for every board and holes for every screw). Before each dive, the WEC is depressurized through a vacuum test to ensure a good O-ring seal. In order to do this we use an AirLock vacuum test system designed for submersible camera housings. With this system it takes under five minutes to make sure that the electronics are consistently well protected.

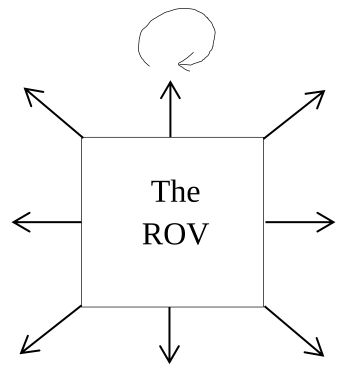
The WEC before electronics (*credit: R. Miller*)

Heyco cable glands help create waterproof seals around the connectors (*credit: D. Diblik*)

6.4 Control System and Tether

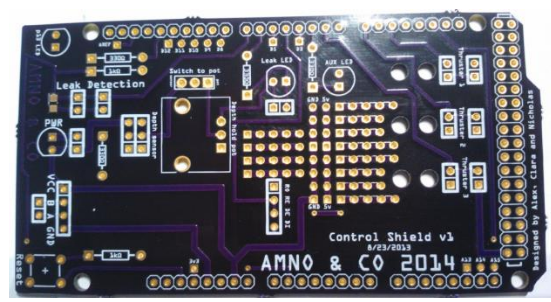
This year, the goal was to design an advanced, software-intensive system in order to achieve intuitive, user-friendly controls. The result is based on four Arduino microcontrollers connected in two pairs, each with its own RS485 communications line down the tether (RS485 was chosen for its reliability and noise resistance). The RS485 communications are made possible through custom designed daughter boards that contain the necessary MAXIM485 chips along with serial breakout headers to communicate with each of the motor controllers. The first pair of microcontrollers controls the vertical thrusters, tooling and the depth hold feature (facilitated by a simple PID (proportional integral derivative) algorithm, it helps to count the zebra mussels and scan the shipwreck). The second pair of microcontrollers solely carries out vector based calculations to control the four vectored horizontal thrusters (see the software flowcharts on the following page). This gives the ROV the unique ability to strafe and crab at diagonals as well as to obtain standard turning functions. This wide range of maneuverability makes it relatively easy for our ROV to function in and around the shipwreck. Strafing in particular helps with the mission task involving sonar scans.

Some of the electronics mounted on one of the onboard racks (*credit: M. Chang*)



The ROV's range of horizontal motion

Some of the potential downsides of a more advanced control system are the inherent complexity and possible confusion. This year's system, however, is complex but easy to prototype, program, build and understand – made possible by the custom PCBs (designed by the team). Not only do these PCBs reduce confusion, but they also look professional and can better withstand real world conditions.



One of the custom PCBs

The sophisticated, driver-friendly surface controls consist primarily of one 2-axis 5kΩ joystick to control vertical motion and one 3-axis 5kΩ joystick to control horizontal motion. There are two SPST switches (for depth hold and the suction system) and one DPDT toggle switch (to control the manipulator). The tooling controls and joysticks are located on separate control boxes, which is ideal for the two-driver configuration used by this team.

The 23 m long tether is responsible for successfully transporting all of the signals that are neccesary for such a complex control system. To do this there are:

- Six 20 AWG wires for signals
- Four 10 AWG wires for power
- Two shielded coaxial cables for cameras

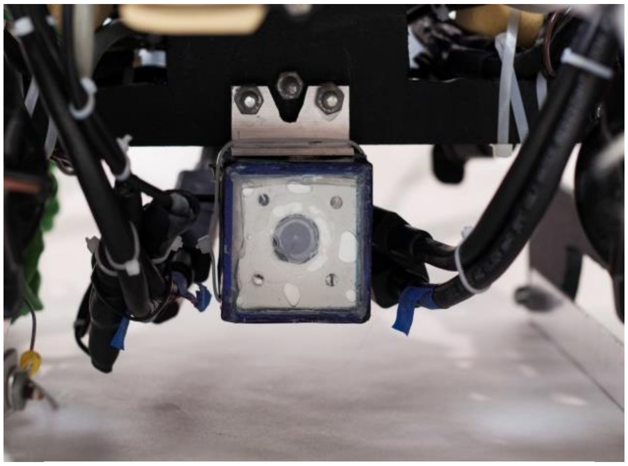
All of the wires are held together in a single cohesive bundle with braided cable sheathing. Polyisocyanurate foam reduces the impact of the tether's mass on the performance of the ROV by making the tether neutrally buoyant. Other ways of reducing the tether's impact are through the tether protocol to the right and an experienced tether manager.

TETHER PROTOCOL:
Always do the following:
Coil tether neatly (only uncoil during mission, pool practices or necessary maintenance)
Store under table or near wall
Recoil tether after every use
Warn people of tripping hazard
During a mission:
Let out tether during descent and forward motion
Reel in tether (do not pull) during ascent
Keep the tether going straight out the back as much as possible

6.5 Cameras

The mission tasks necessitate the need for a good imaging system so that an ROV pilot can accurately gauge distances and speeds in order to better accomplish the tasks at hand. The ROV has two potted board cameras; one facing forwards, the other facing downwards. The choice of two cameras follows the team's belief in using the bare minimum of cameras necessary in order to keep an intuitive natural system that requires low cost and effort to operate.

The cameras both have 480 TVL resolutions and 0.5 lux low light capabilities that eliminate any need for lights, even inside the shipwreck. Both these features enable good driver feedback despite being in dark viewing conditions such as the simulated shipwreck.



The forward-facing camera (*credit: D. Diblik*)

In addition to basic driving purposes, the cameras and their positioning are key in allowing the team to do the following of the mission tasks:

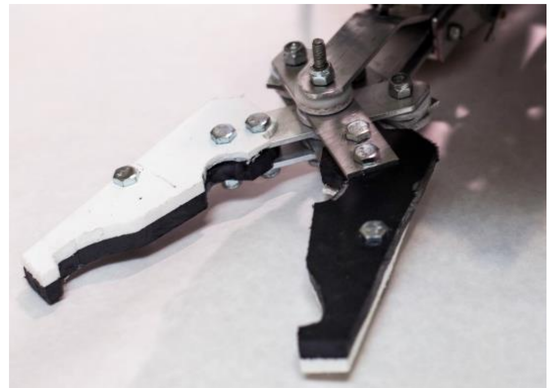
- Reading the date and identifying the shipwreck
- Counting the zebra mussels
- Locating the microbial mats and conductivity sample sites

6.6 Mission Specific Tooling

Manipulator

In constructing a manipulator, the goal was to produce a strong and versatile design. Both of these goals were completed.

The durability results from the rugged aluminum and plastic components. The design revolves around an electric linear actuator with limit switches that provides 84.5 N of force yet draws only 1 A. The actuator is waterproofed in the arm section of an arm-length rubber glove. Sturdy Starboard grippers with cutouts make possible the following mission tasks:



The manipulator (*credit: D. Diblik*)

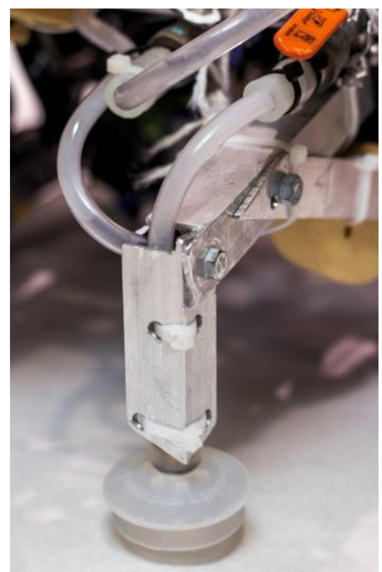
- Retrieving and deploying the sensor string
- Opening and closing the cargo container
- Transporting the conductivity sensor and microbial mat sampler
- Transporting the quadrat
- Removing the anchor line rope

Suction System

The suction system consists of an in-line pump with various valves. This is not hydraulic; rather, it is an open system with two possible attachments, facilitating the following mission tasks:

- Retrieving the glass and plastic water bottles, and the plate
- Taking a sample of the microbial mat

The suction system connects to a single-bellow silicone suction cup with enough gripping power to attach to a contoured surface.



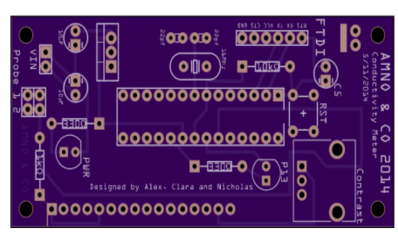
The suction system with the suction cup attachment (*credit: D. Diblik*)

Microbial Mat Sampler

To return a sample of agar (a simulated microbial mat) a cluster of three tubes is held together and inserted into the agar. At the top of each tube a check valve lets out the water already in the tubes and creates suction that keeps the agar in the tubes – the valves are one-way. This is held in the manipulator, and at the surface the agar is collected by removing the valves.

Conductivity Sensor

To determine which of the samples is groundwater and which is freshwater, two probes are connected to a custom microcontroller



The custom PCB for the sensor

board. This board is based on an ATMEGA 328P and is programmed with an FTDI chip. This device takes a conductivity reading and outputs it to an LCD display which is seen by the camera. Despite its small size, the sensor has onboard power regulation, testing features, and a crystal for timing. This system is transported by the manipulator and is backlit for ease of reading.

Quadrat

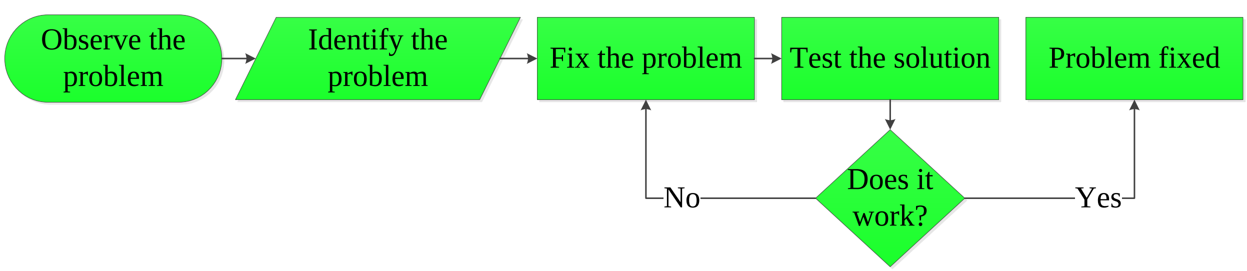
To count the number of zebra mussels the ROV deploys a 0.5 m x 0.5 m PVC pipe square. Holes are drilled to allow for water flow and a handle is made out of PVC fittings that can be held by the manipulator. A vertical pipe comes from one corner to help with measurement of the wreck (see below).

Measurement System

To measure the shipwreck the team utilizes a no-cost, unique, innovative and surprisingly accurate method. The approach to the mission tasks was to accomplish them in the most efficient manner, which led to this method of measurement. Having already deployed the quadrat (of known length, 0.5m) in an orientation aligned with the sides of the shipwreck, the wide angle cameras allow the drivers to measure the shipwreck and the quadrat on the monitor with only a ruler. All that remains is simple calculations using the quadrat as a scale factor in a proportional relationship. Below is a sample calculation for how this is applied (this is for a length measurement, the same procedure applies to the width and height measurements).

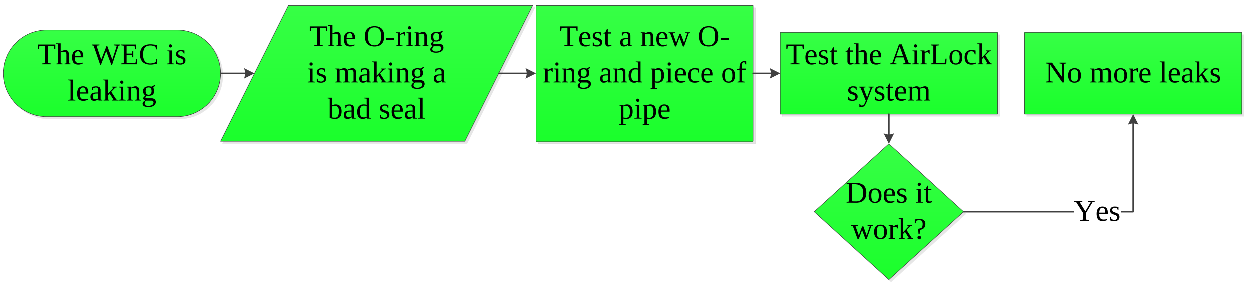
Length of the quadrat (real): 0.5m
Length of the quadrat (on screen): 4cm (0.04m)
Length of the shipwreck (on screen): 19cm (0.19m)
Length of the shipwreck (real) $= \frac{0.5}{0.04} = \frac{x}{0.19} \quad 0.04x = 0.085 \quad x = \frac{0.085}{0.04} = 2.125m$

7. TROUBLESHOOTING



The troubleshooting flowchart

The team developed the above flowchart as a straightforward, rational way of solving problems. It also eliminates mistakes due to carelessness and panicking. Below, this formula was applied to a real problem with this year's vehicle.



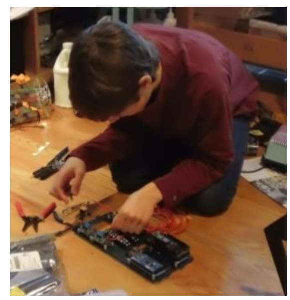
The troubleshooting flowchart applied to this ROV

In the above problem, the pipe had become slightly warped, which interrupted the O-ring seal. After diagnosing the cause of the problem and potential causes for the warped pipe, a new pipe was cut and future problems were prevented through the addition of a larger O-ring.

8. CHALLENGES

8.1 Technical Challenge

One of the goals for this ROV was to have a full range of translational movement – meaning not only turning but also an intuitive system that included strafing motion. We first tried to do this using a prototype system based on relays and switches. This did not work. After realizing that this would need to incorporate the joystick, we decided to run the system through the ROV's onboard microprocessors. While this was a significant improvement, there were still problems, and only after a long troubleshooting process were we able to write the necessary array for each axis of the 3-axis joystick. This type of challenge was new to us, but has left us satisfied with the results.



Alex wires up electronics for the onboard rack (*credit: M. Chang*)

8.2 Non-technical Challenge

Having a team of only three members can be challenging, but it is also our greatest strength. Unlike a large team on which a single person specializes in a single system, every member of AMNO & CO is deeply immersed in the brainstorming, prototyping, and development of every part of the ROV. This raises challenges, primarily due to the difficulties raised by time constraints and scheduling, which requires flexibility and sacrifices so that we can all be present at team meetings. To build a capable vehicle with only three people requires extraordinary amounts of time and commitment from each member. We are pleased to say that through time management and planning we successfully overcame this obstacle.

The team works together (*credit: R. Miller*)

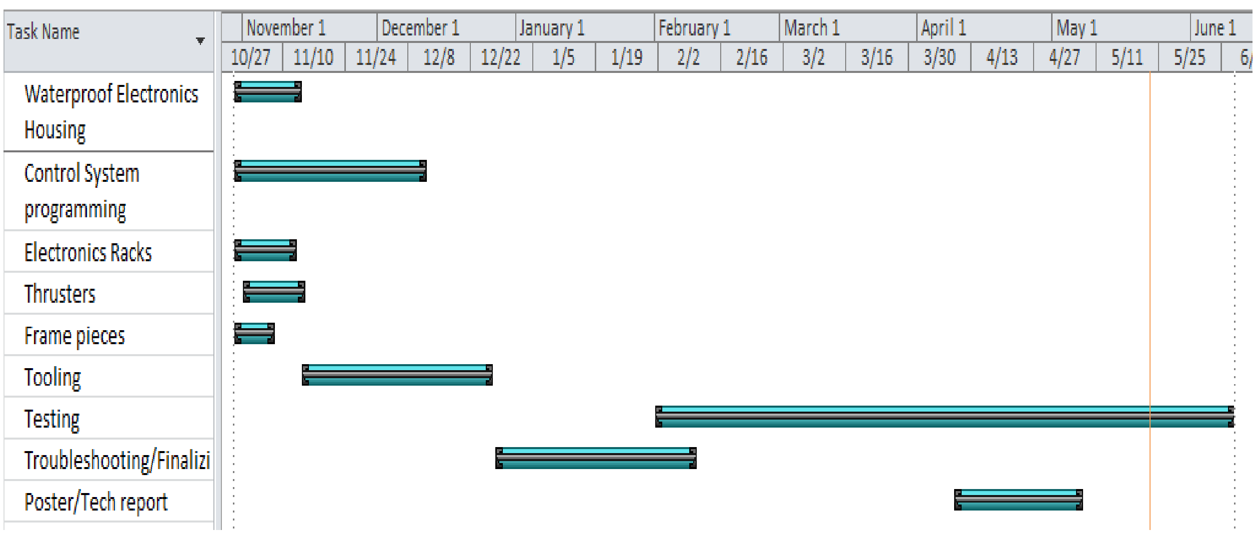
9. TEAMWORK AND ORGANIZATION

As mentioned above, the entire design process was inherently a team effort. Each member had a part in brainstorming, prototyping, building, testing and in writing and editing. None of this year's project would have been possible without the contributions of every person.

Our team's philosophy is that we should do everything ourselves, even and especially when that involves learning new skills (which to us is what makes the whole project fun). Obviously in some cases we asked for professional help, but never did we let anyone else do the work for us. For example, the end caps for our WEC were CNC machined, but as a team we designed and reviewed the parts on Solidworks, and we were fortunate enough to be taught the use of CNC machines – we programmed the machines and pushed all the buttons ourselves.

Operating a CNC machine (*credit: C. Orndorff*)

While each team member has some specific assignments (for example, Alex is listed as the software specialist), we would like to acknowledge once again that the whole team made valuable contributions to every system. We used a Gantt chart to manage our time efficiently, and while troubleshooting disrupted the process, we were mostly successful in adhering to it.



A Gantt chart showing the most crucial aspects of the design process

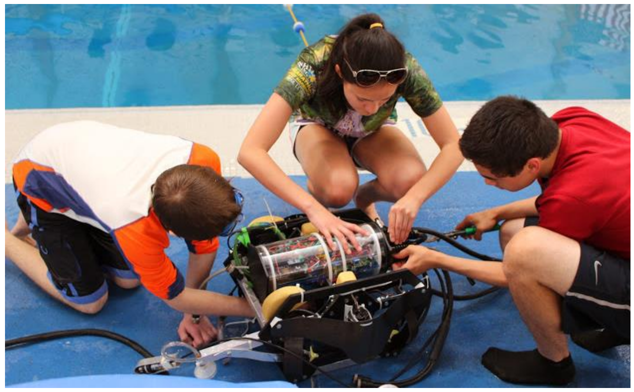
10. LESSONS LEARNED

10.1 Technical Lesson

For this year's ROV we mastered many valuable skills, including: successfully modeling and designing parts on CAD programs, particularly Solidworks. In past years we haven't used these programs to as large an extent as we did this year when we modeled the entire frame. We know that this is a skill that will have uses in many future projects or jobs.

10.2 Interpersonal Lesson

Because every team member comes up with good ideas, a lesson we learned was how to choose the best method and to be open to all the available ideas. We learned that the best way to do this is to have each person prototype all their ideas – in choosing the one that visibly works the best, this is often the most effective.



Left to right: Alex, Clara and Nicholas prepare for a pool practice
(*credit: R. Miller*)

11. COMPANY REFLECTIONS

Alex Miller: "In 5th grade, when I first worked on an ROV, I looked up to the older teams, their technology and their designs; over the years, through gradual improvement and learning, we have been able to increase our level of engineering substantially. It has proved to me that anyone, through incremental skills development and hard work can be capable of being part of a significant long-term achievement. Now when I look at real world ROVs, I can see myself building something similar."

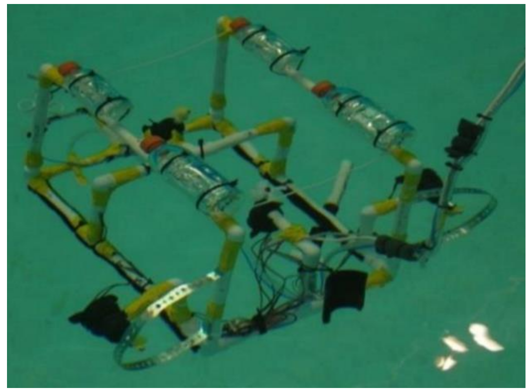
Clara Orndorff: "This year we learned more than we ever have. We made PCBs, used laser cutters and CNC machines, made most of designs on Solidworks, and wrote a lot of programs for our control system. This is more that we would have dreamed of being able to do 5 years ago. I think we're all proud of how much of this ROV is of a quality that would work in the real world."

Nicholas Orndorff: "When I started on AMNO & CO, we were in the Scout level, with a PVC ROV. Since then the amount of progress the entire team has made has been incredible, from advanced control systems to CAD/CAM manufacturing. The amount of failure and success has provided me with a good background in applied technology for the rest of high school and college.**"**

12. FUTURE IMPROVEMENTS

One of our biggest accomplishments every year is the amount we have learned and the fact that we did it all ourselves. Despite this, there is more we can do. Yet again we came up with more design ideas that we could possibly use or implement in the time we had. Next year, we hope to use some of these and to come up with many more. Here are just two of the things we have thought about that will lead to a more sophisticated vehicle.

- Over the past few years we have used bilge pumps as thrusters due to their low cost and availability. Now we feel that we have the knowledge and skill to move beyond these already waterproof thrusters. Next year, we plan to waterproof our own thrusters.
- We are proud of the WEC that we made, but for next year's vehicle we would like to have a WEC that is easier to remove and program separate from the frame.



Our first-ever ROV – which took third place for the Scout level regional competition five years ago (*credit: M. Chang*)

13. BUDGET

AMNO & CO is not only a small team but also unaffiliated with any school or organization. This means that the team strives to fund the project by itself. First, summer bake sales were a significant contribution in terms of monetary income, as was a technical report competition. Early on, the team agreed to stay away from overly expensive parts unless a donation or discount was given, and in terms of the budget, AMNO & CO was extremely successful at this. A full list of sponsors can be found in the Acknowledgements section of this report. In the table below, all costs include estimated costs of donated, discounted or reused components.

System	Cost	Other
Frame	$300	*Discounted components: Starboard* *Reused components: polyisocyanurate foam*
Propulsion	$440	*Discounted components: bilge pump cartridges*
WEC	$2096	*Donated components: pipe, end caps, fittings, O-rings* *Donated services: machining*
Control System and Tether	$1,926	*Discounted components: control boxes, miscellaneous electronics supplies, cable sheathing, joysticks* *Donated components: underwater connectors, heat shrink, depth sensor* *Reused components: motor controllers, wire, underwater connectors*
Manipulator	$227	*Discounted components: actuator*
Cameras	$110	*Discounted components: cameras* *Reused components: cameras*
Other Tooling	$110	*Includes: quadrat, conductivity sensor, suction system*
Miscellaneous	$1,217	*Donated components: power supply* *Donated/Discounted services: pool time*
Travel and Accommodation	$2,225	*Donated funds: travel costs*
Total Cost	**$8,661**	*Includes travel and accommodation*
Income	$3,000	*Sources: individuals, bake sales, competitions*
Fair Market Value of Donated Components	$4,179	*Sources: see acknowledgements*
Amount Spent	**$1,482**	

14. REFERENCES

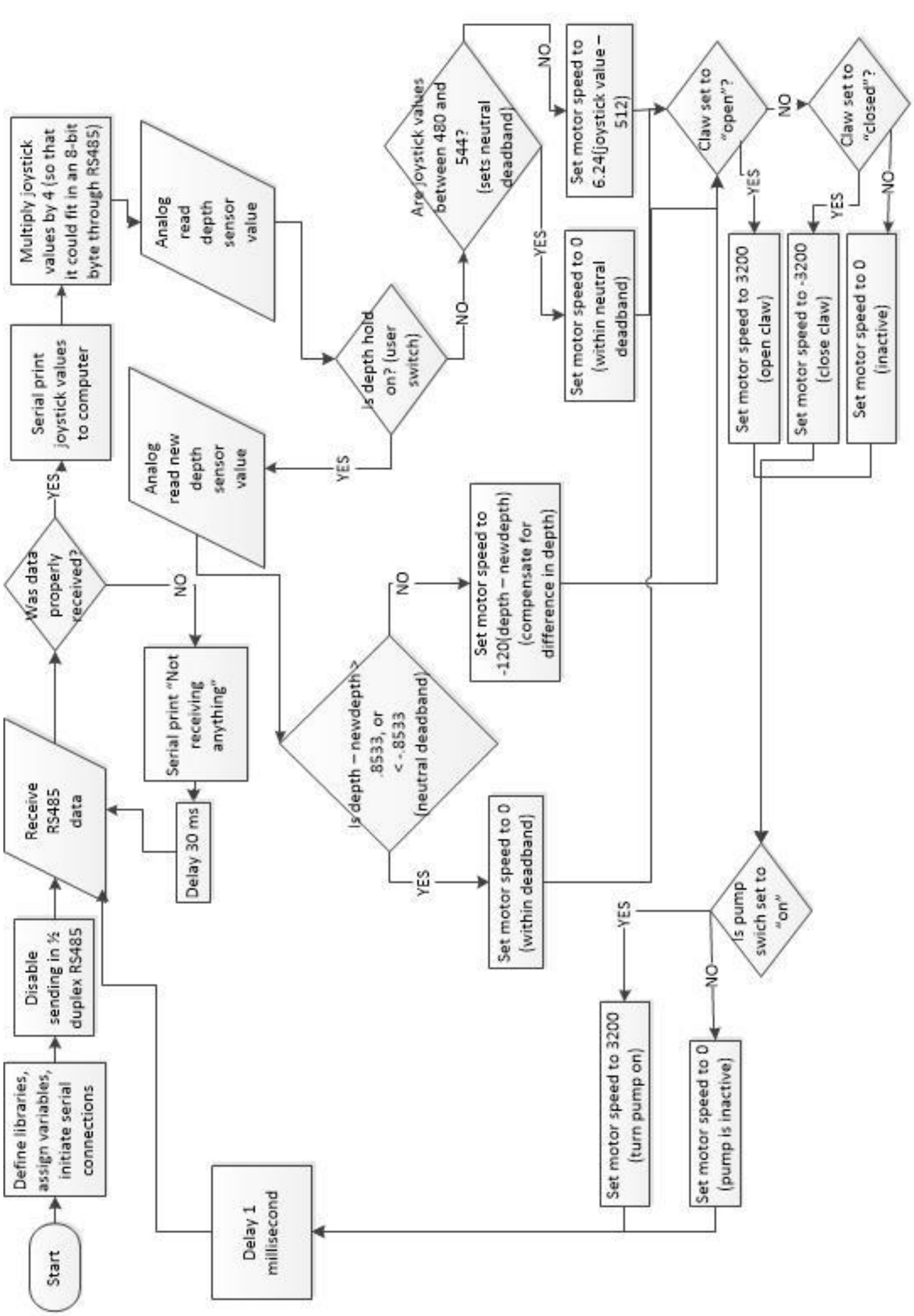
1. "Science Highlights." TBNMS. http://thunderbay.noaa.gov/pdf/science_highlights_tbnms&20202013.pdf (accessed March 16, 2014).
2. "National Marine Sanctuaries Condition Reports – Thunder Bay." National Marine Sanctuaries Condition Report. http://sanctuaries.noaa.gov/science/condition/tbnms/ (accessed March 16, 2014).
3. Wikimedia Foundation. "SS Central America." Wikipedia. http://en.wikipedia.org/wiki/SS_Central_America (accessed May 19, 2014).

15. ACKNOWLEDGEMENTS

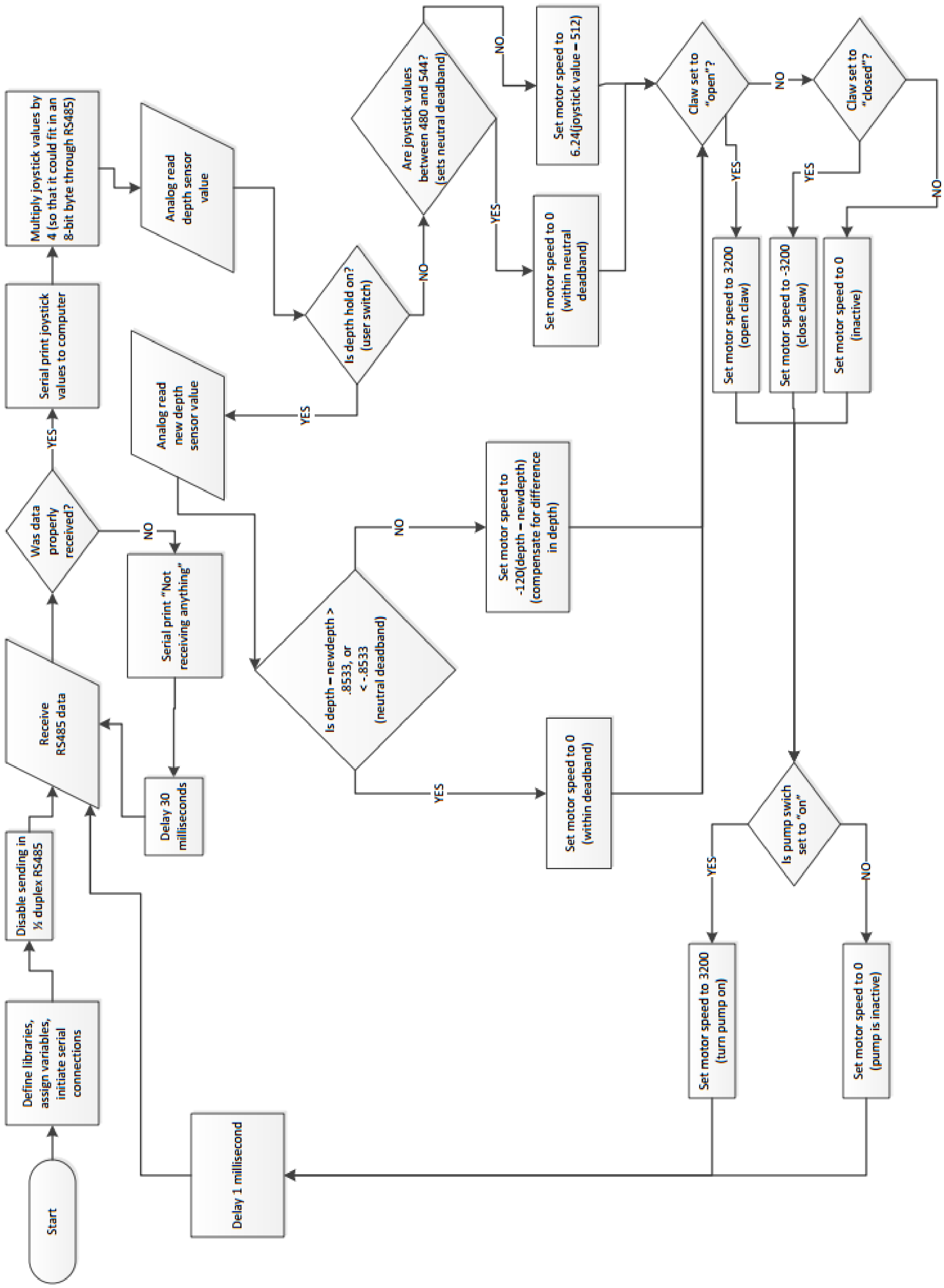
As with any of our previous ROVs, this one would not have been possible without the support of the following companies and individuals that provided support, funds and/or discounted/donated components.

- Rachel Miller, Steve Miller, Mary Chang and Robert Orndorff
- Rick Rupan, Wes Thompson and Fritz Stahr
- Dylan Diblik and Pete Orndorff
- Nick Gammon
- All the MATE Competition officials and volunteers
- Everyone who purchased from our fundraisers

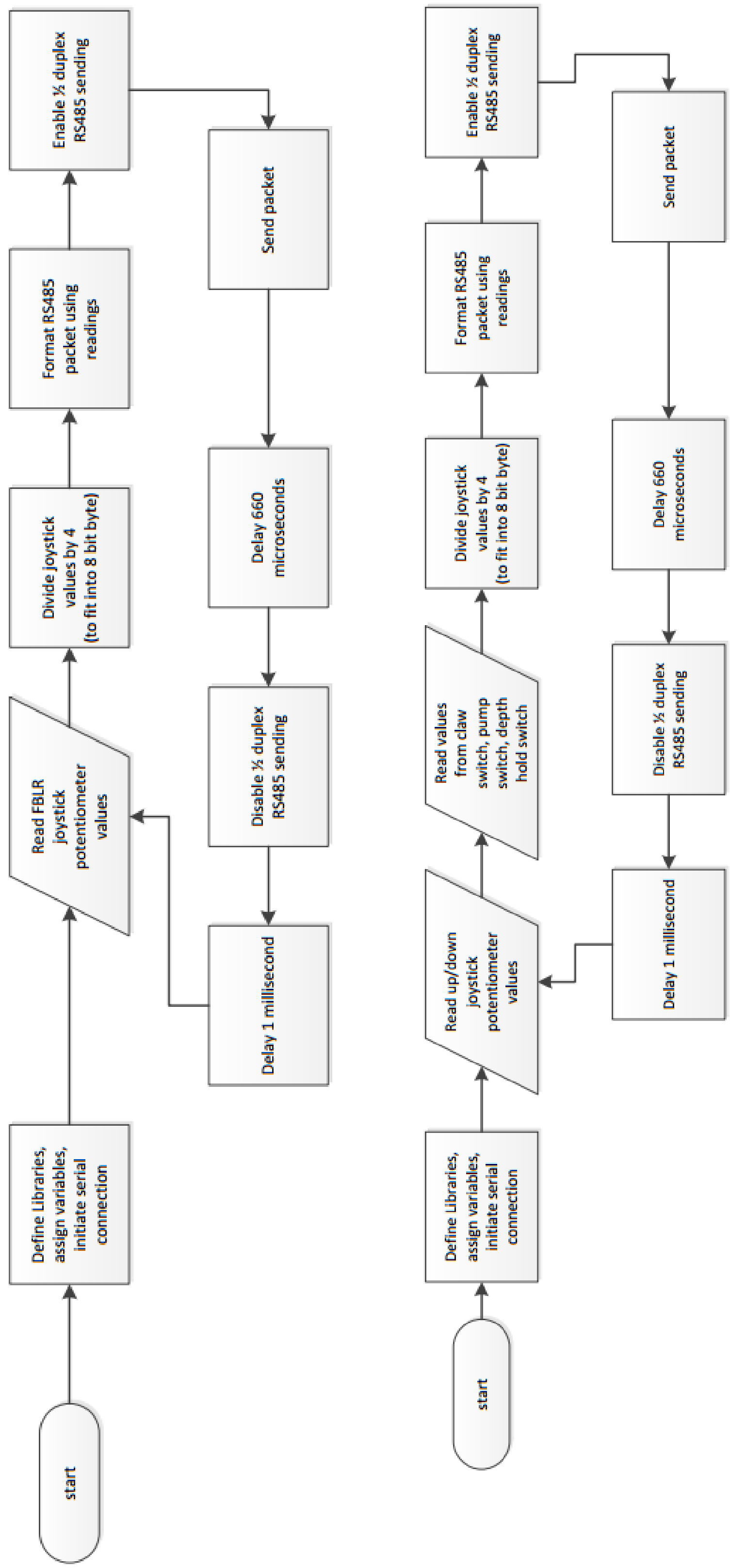
16. SOFTWARE FLOWCHARTS



The software flowchart for the bottom Arduino's control of horizontal motion



The software flowchart for the bottom Arduino's control of vertical motion



The software flowcharts for the top Arduino's control of horizontal (left) and vertical (right) motion