WENTWORTH INSTITUTE OF TECHNOLOGY, BOSTON, MASSACHUSETTS

Team and Members & Roles		
CEO/Head Engineer	Connor Boris	Sophomore
CFO/Head Engineer	Benjamin Waltuch	Sophomore
Programmer/Pilot	Joe Jevnik	Freshman
Electrical Engineer	Nathaniel Dube	Sophomore
Engineer/Documenter	Christopher Stewart	Freshman
Mechanical Engineer	Joshua Mandelbaum	Sophomore
SolidWorks Engineer	Thomas Chiarelli	Sophomore
Mechanical Engineer	Brent Cornwall	Sophomore
Design Engineer	Marcus Grandinetti	Sophomore

Mentor
Professor James McCusker

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1 Abstract

The great lakes have a unique environment as well a long maritime history that is well worth preserving. The Great lakes form 21% of the world's surface fresh water supply and due to the Erie canal, are a large vessel of ship traffic. The large amount of ship traffic combined with the severe storms prominent in early winter makes the great lakes a ship graveyard. With the vast amount of research and conservation efforts necessary to maintain its health, and to find these shipwrecks, comes the need for technology to get the job done. This technology needs to be effective, durable, and adaptable. C-Turtle Underwater Robotics has the capabilities to provide such technology to satisfy the needs of environmentalists and researchers.The members of C-Turtle Underwater Robotics work collaboratively to engineer underwater robots that can successfully accomplish given tasks in simulated and real world environments in a safe, creative, efficient, and effective way by focusing each individual's strengths as a cohesive team and delving into unfamiliar subject areas to better ourselves with hopes of ultimately benefiting the community and environment.

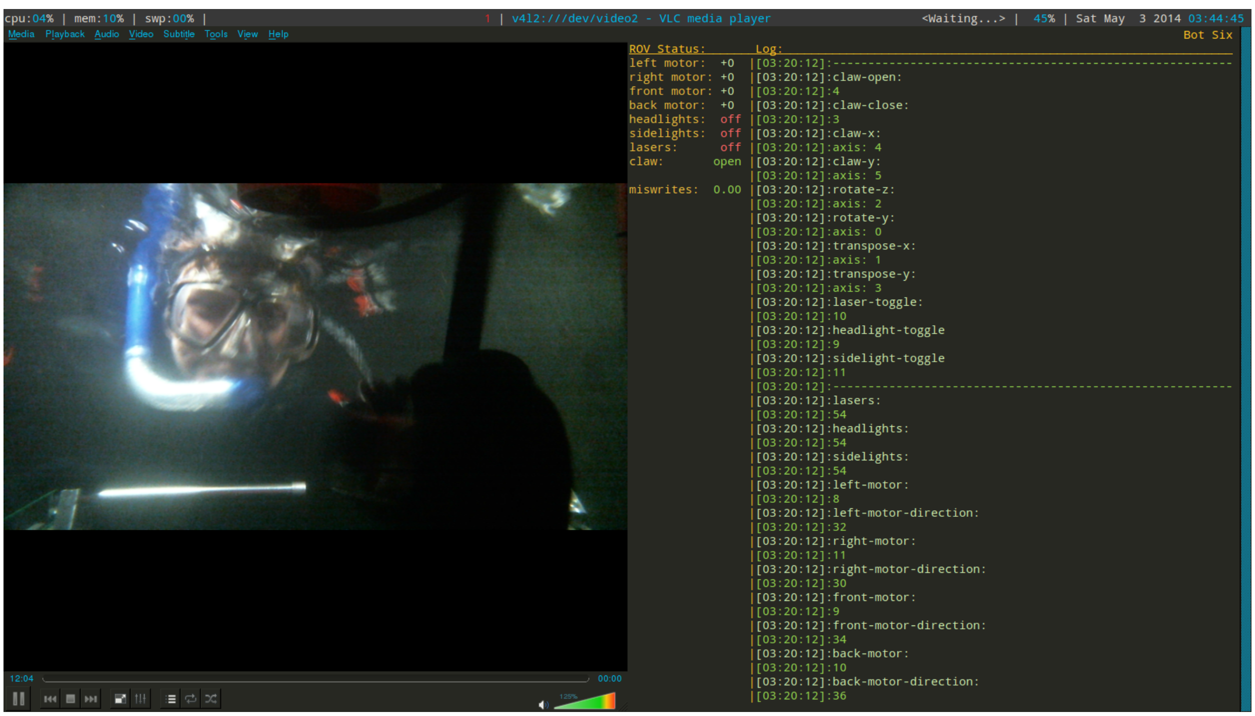


Figure 1: A screen shot of one of the testing versions of the user interface

2 Mission Summary

2.1 Task 1

Mission task one consists of four main parts. Measuring the shipwreck, scanning the shipwreck, photographing the shipwreck, and determining the type of ship.The first part of this mission is exactly as the title describes. There are markers at each corner of the shipwreck and the ROV must determine the distance between each of the marker. By doing this it will determine the length, width, and height of the shipwreck. The second part of this task is acquiring three targets on the shipwreck. To do this one of the ROV cameras must stabilize on a target on the shipwreck from a particular angle. This completes one of three sonar scans. The third part of this mission is to create a photomosaic of the shipwreck. To do this the ROV must take multiple pictures of the side of the shipwreck and stitch them together to create a complete detailed image of the wreck. The fourth part of this task covers a more significant part of the mission than the previous three. To identify ship the ROV must determine the type of ship, determine what type of cargo the ship was carrying, determine the date the ship was built, and determine the homeport of the ship. To determine the type of ship the ROV must find the ships propulsion mechanism by looking around the outside of the ship. To determine the cargo that the ship was carrying, the ROV must open the cargo container, determine the type of cargo in the container, and close the container. To determine the year that the ship was built, the ROV must enter the wreck and find the plaque showing the year the ship was built. To determine the name of the ship the ROV must find the ceramic plate inside the ship and return it to the surface. The plate will have the ship's homeport marked on it. These four criteria will identify the ship and complete mission task one.

2.2 Task 2

Mission task two consists of four main parts. Measuring the conductivity of the groundwater, retrieving a sample of the microbial mat, replacing the sensor string, and estimating the number of muscles on the wreck. To determine the conductivity of the groundwater the ROV will insert a test probe into the sinkhole long enough to sample the water. To retrieve a sample of the microbial mat the ROV will collect a sample in its beak and return it to the surface. The ROV will collect the old sensor string with its beak and replace the old one in the same fashion. To estimate the number of zebra mussels on the wreck the ROV will use its beak to place the quadrat on the wreck and the camera to take an image of the quadrat. This will conclude task two.

2.3 Task 3

Mission task three consists of three main parts. Removing bottles, removing the anchor line rope, and removing the Danforth anchor. To remove the two bottles the ROV will grab them in the beak, flip them into the depository along with the plate and bring them to the surface. To remove the anchor line rope, the ROV will grab it with the beak and return it to the surface.The danforth anchor will be retrieved by the hooks on the back of the ROV.

3 Design Rationale

The main focus behind the design of the *Annamaria* was cost effectiveness and overall efficiency. It was not only designed to complete the mission tasks given by MATE, but with the intent of having a universal design which could be applied in a multitude of different scenarios. Having a cost effective design allows for easy repair or replacement in case of failure or demand.

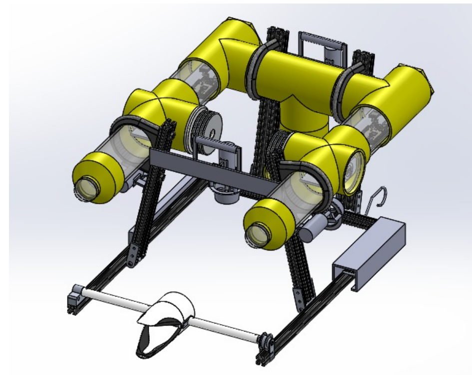


Figure 2: The full solidworks drawing

3.1 Bouyancy Vessel

The buoyancy vessel is mostly comprised of both white and clear schedule 40 PVC pipe and fittings. The pipe and fittings were fastened together using PVC solvent as well as 5200 marine sealant to ensure a watertight seal. The shape chosen for the buoyancy housing, as seen in Fig.2 was chosen for several reasons. The U-shape design is to allow for objects of a height of 35 centimeters or less to be placed in the collection depository area. A closed, square shape design would restrict the height of potential objects that could be harvested. Four inch PVC pipe was chosen to provide both an ample amount of buoyancy to support the weight of all the components as well as a housing for the two electronics plates used to operate the vehicle.

3.1.1 Component Integration

Moving from the head of the ROV to the tail, the following will describe the reasoning behind every implemented component of the buoyancy housing. The two, four-inch to two-inch reduction caps were used to seal the front of the PVC housing and also house two custom made printed circuit LED boards with a brightness of 630 lumens each. These can be seen in Fig.4. These front facing LED's provide a wide angle of lighting to provide visibility of any object within the front facing cameras field of view. The clear PVC pipe was selected to allow any user the capability of seeing inside of the buoyancy housing. This is beneficial for some degree of troubleshooting if the ROV ceases to work. The electronics plates are easily visible, so any main component can be optically analyzed to determine if it is functioning or not. Also, the user can visually inspect if there are any leaks due to a breach in the housing. This can be seen in Fig.3. Two, four-inch PVC cross union fittings were used for several key reasons. Instead of implementing longer PVC pipes for the electronic housing, the cross unions were utilized for the two available openings. As seen in Fig.5b, The openings on either side of the *Annamaria* facing outward are used as windows for HD 720p webcams. These cameras allow the user to view what is on either side of the ROV at all times. There are LED rings fitted around each camera so that vision is still possible in dark situations. On the other side of each cross union are fitted heat sinks to provide heat transfer from the electronics plates inside of the housing to the outside environment. This prevents the inside of the housing from overheating

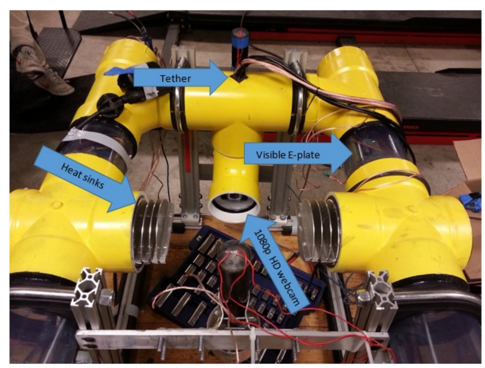
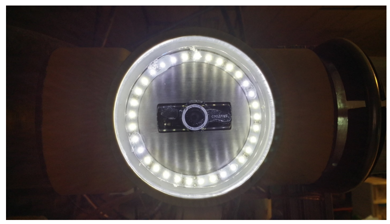


Figure 3: An overview of the bouyancy vessel

(a) How the tether was mounted into the bouyancy vessel



(b) The side view camera, showing the ring leds

Figure 5: Tether / Side view camera

and keeps the electronics from failing. The two T-unions located towards the back of the ROV serve as connector pieces to complete the U-shape as well as provide an entrance and exit for the electronics plates. These openings are threaded on the inside, so they are sealed tight by means of threaded caps screwed down onto large O-rings fitted to the inner wall of the unions. This feature allows for easy access to the electronics as needed. Cemented in between the T unions is another, non-threaded T-union that is oriented 90 degrees downward so that the middle opening is facing the bottom of the ROV. The tether enters the top of this T-union where each wire component is fed to its designated side of the housing. One end of a 90 degree elbow is connected to the middle opening of the T-union where the other opening is facing the front of the ROV. A 1080p HD web cam is epoxied to a polycarbonate window which is sealed to the inside of the PVC elbow. For clarity, please refer to Fig.3. The rationale behind the placement of the front facing camera is based on the location of the beak and collection depository. Having the camera set back in the ROV allows the user to see what is inside of and in front of the ROV, as well as aim and maneuver the beak into correct positions while collecting samples. This design has an added advantage over other ROVs in the fact that the camera's view grants the pilot awareness of the vehicles height and width while maneuvering in close quarters.

3.1.2 Wires & Pneumatic Tubing

All wires and pneumatic tubing that are run to or from the housing are routed through holes drilled in the PVC to the exact diameter of the specific wire. Holes were drilled in groups on the bottom of each cross union and at the top of the middle T-union. After all wires and pneumatics were fed through their assigned hole, small cylinders surrounding the group of holes on the inside of the housing were filled with epoxy to create an airtight seal between all wires and their holes, as seen in Fig.5a. To ensure a complete airtight seal, 5200 marine sealant was caulked around each wire on the outside of the housing.

3.2 Frame

3.2.1 Vibration Damping

The ROV's modular frame is composed of 10-series 80/20 extruded aluminum and is attached to the buoyancy housing using vibration damping U-bolts. The vibration damping is key in isolating any vibration of the thrusters from the cameras for the sake of maintaining image clarity. Without this, vibration could render the added resolution of the HD cameras virtually useless. Shock absorption is another benefit of these U-bolts as they reduce the chance of any damage to be done to the housing or its contents in the event of a collision on land or in water.

Figure 4: The headlight fixtures

3.2.2 Slotted Design

The slotted design of the 80/20 allows for easy and fast modification of instrumentation and ballast. In addition, it is also relatively easy to change the height of the ROV as the situation demands by shortening the upright 80/20 sections. A taller frame may be desired if larger objects are being contained in the ROV and a shorter frame may be desired if operating in more confined spaces. A model of the ROV frame can be seen in Fig.6.

3.2.3 Thrusters

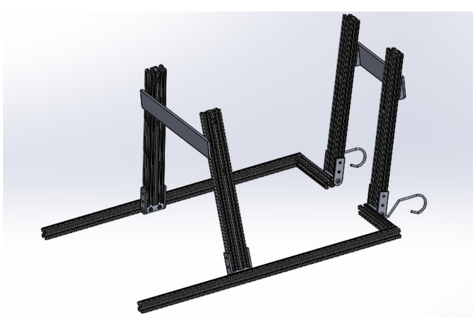


Figure 6: The solidworks drawing of the 80/20 frame

Easy and secure attachment of the ROV's four thrusters is an added benefit of the 80/20 aluminum frame. Two Crustcrawler thrusters are fastened laterally to the front-upright sections. These each provide a maximum of 6.8kg of thrust to control forward and reverse movement, as well as rotation about the vertical, y-axis. The other two custom made thrusters each provide a maximum of approximately 2.8kg thrust for depth and attitude control.

This number of thrusters, in the described configuration, is optimal considering both economy and functionality. A major focus was to minimize production costs for this vehicle and thus it was decided that the four thrusters would provide adequate degrees of freedom for the given mission. Also, it would be approximately \$1400.00 less to produce than alternative configurations. One such considered alternative is commonly referred to as a vector drive configuration that utilizes 4 thrusters for horizontal plane translation and rotation. This would add z translation, however, it would not greatly improve our robots ability to complete mission tasks to a degree that would be fiscally reasonable or significantly more marketable.

3.3 Beak

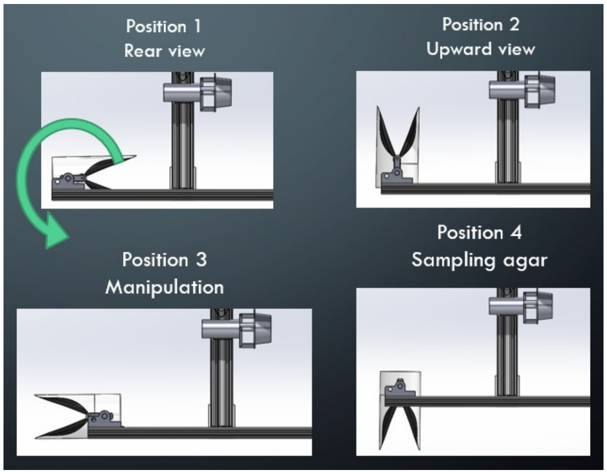


Figure 7: The beak positions

The ROV utilizes a 270° range of motion grasping mechanism to conduct sample and object gathering. Instead of separating the tasks of picking up solids and viscous materials, the ROV implements a beak specifically designed to complete both of these desired functions. The beak is constructed primarily of PVC to ensure structural integrity and allow the beak to sturdily grasp solid objects. The beak also contains a rubber "gum" lining, cut from neoprene rubber, which is elastic enough to conform to solid objects but rigid enough to create a seal around viscous liquids. Neoprene rubber was chosen due to its capability of maintaining flexibility over a wide range of temperatures, as well as its resistance to tearing. The beak also houses a CMOS camera. This gives the operator a view of exactly what the beak is picking up and allows the operator to make precise corrections for delicate extractions. The range of motion of the beak also allows for the CMOS camera to act as a surveillance device and cover area other cameras can not, such as beneath, above, and behind the ROV.

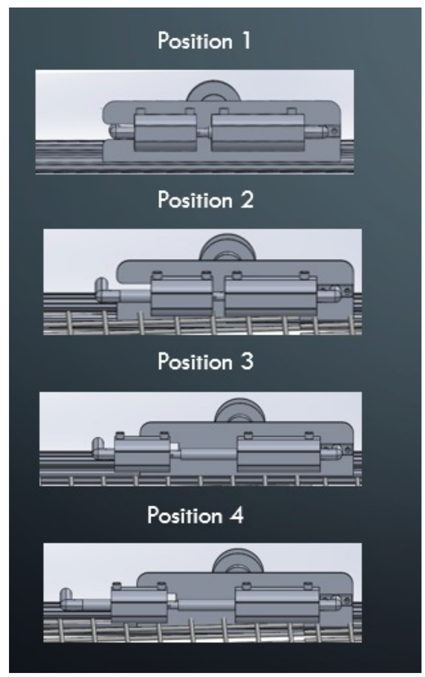


Figure 8: The piston positions

The actuation of the beak is done through two double acting pneumatic pistons in series, along with a pulley system. When the larger piston actuates, with a stroke of 40 millimeters, the beak rotates 180 degrees.The smaller piston is exactly half the stroke length of the larger one, 20 millimeters. Therefore, this allows the beak to rotate 90 degrees when this piston is actuated. Between the two pistons, there are four positions the beak can move to, as labeled in Fig.8 and Fig.7. The rationale behind indexed control of the beak instead of variable angular control was due to the main functions of the beak and the tasks given. Due to its design, the beak can secure hard objects as well as the microbial mat in its mouth as it were with the beak in the downward position. Having the beak in the forward position gives the user a better idea where objects are in relation to the beak. Actuating the beak in the upward position allows the ROV to hold on to the microbial mat as it resurfaces for the user to extract the sample. The backward position allows the beak to place any solid objects into the collection depository for storage while it completes the rest of the given objectives. Having angular control of the beak would have added complexity and time to the overall function. Every movement would have to be very precise to guarantee accuracy. With indexed control, the user knows exactly the orientation of the beak whether its through hot keys on the control board or examining the CMOS camera display.

3.4 Collection Depository

While collecting samples and other objects at the pool bottom, it is possible to store them in the collection depository. This is located at the base of the ROV frame, directly behind the beak mechanism. It is comprised of tightly woven chicken wire that is fastened around the 80/20 extrusions. The contour of the depository is slightly deeper toward the back of the ROV than the front. This is to allow all objects to stay seated toward the rear of the ROV so there won't be any interference with the beak while it is in the backward position. The collection depository was implemented to remove the need for multiple trips to the surface as objects are collected, both in competition and real-world environments. Considering the fifteen minute window to complete the mission tasks, it was concluded that collecting objects while completing other tasks was a more efficient use of time than returning to the surface every time an object was gathered. In water with less light or clarity, being able to remain in a location and pick up multiple items is a huge advantage as well. When visibility is low, it may be difficult to quickly find an underwater location again after leaving it.

3.5 Anchor Hooks

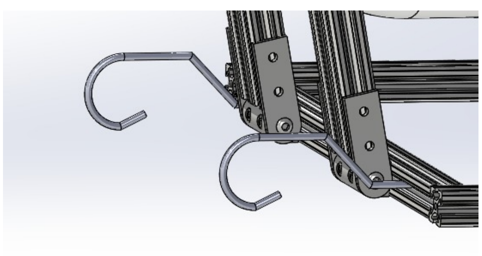


Figure 9: The anchor hooks

Two anchor hooks as seen in Fig. 9 are located at the rear of the ROV fastened to the bottom frame of the 80/20. The hooks are oriented with the open profile facing downward. This allows the user to maneuver the ROV along the bottom of the pool floor and scoop the danforth anchor up by the two bars protruding outward. The hooks are set at a distance apart from one another that ensures the anchor will be secure during transport, with a negligible chance of it falling off.

3.6 Software

For the software side, the driving factor behind all decisions was modularity. The robot's codebase was built from the ground up, limiting the library dependencies to `pthread`, `ncurses`, `guile-2.0`, and because of `guile-2.0`, `gc`. The intention was to build it all in order to have the most control over the system while eliminating unneeded abstraction or cruft. The reason for choosing a modular system was so that work could be done while the design was still subject to change. Also, this worked towards the goal of providing a standalone service that would allow users to exchange simple modules to control completely different robots. In essence, it is a system that facilitates in the programming of a robot, which was used to build the specific system needed for the *Annamaria*.

3.6.1 Client Server Model

The communication is based on a client server model, such that the robot acts as the server, and the computer acts as the client. By deferring all computation to the client, the complex logic is executed faster and is easier to debug. The server runs custom arduino server code that allows for flexible runtime control over the hardware. The connection to the client is through a serial port, and as such, the server was inspired heavily by hardware terminals such as the VT100. One place this can be seen is in the buffer overflow manager that sends a `Please Wait` command back to the client when the buffer is half full; this command tells the client to stop sending messages until the server has had enough time to process them all. When the buffer falls below one quarter full, it will send a `Please Start` command, signaling that it is now okay for the client to send messages again. For this reason, an asynchronous messaging queue was built to handle the client's message passing. The reason that the message queue is asynchronous is that when a large amount of data needs to be sent in a short time, it is preferable that the message queue waits as to not overflow the server, yet also does not block on the logic processing thread. This leads to smoother control that more accurately reflects the desired results when sending bulk messages, preserving the desired order of execution. To improve the processing time, only a very small set of variable width instructions are sent to the server. These instructions consist of one of seven opcodes, and a variable amount of arguments, such that the longest instruction is three bytes wide. As a heuristic, it checks for the most commonly sent opcodes (ppm writes) first, allowing for a faster lookup time, where the least commonly used opcodes are checked later. This helps reduce the extent to which the hardware interface acts as a bottleneck in our system. In order to form these messages efficiently, while still maintaining the goal of being modular required the design of a solid framework for users to work with that did not require, or required very little, understanding of the underlying system. For this purpose, it was decided that scheme should be used for user facing configuration with bindings to the underlying c backend.

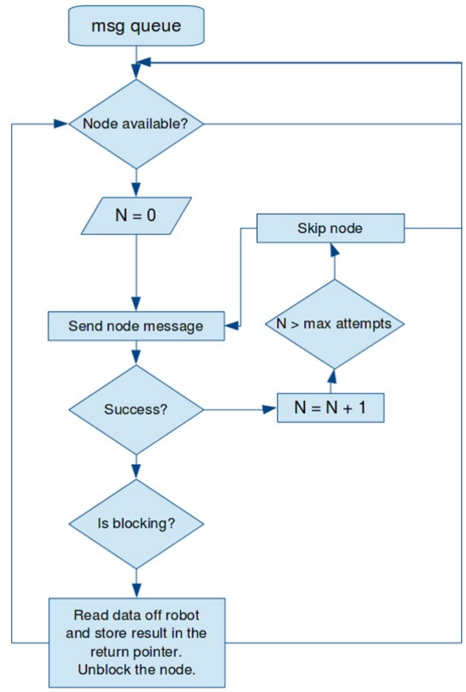


Figure 10: The message queue thread

3.6.2 Modular Logic

For the modular configuration, users must provide three files that will be evaluated at runtime. The first is the `.keybinds` file, specifying the keybindings to the joystick. This allows users to bind any button or axis to a particular action, and even allows them to bind more than one, or none at all to a single action. This concept is carried over to the `.pins` file which is the bindings for each hardware device to arduino pins. Again, users may bind more than one or no pins to a single device, allowing for complete customizability. Finally, the most important file that the user must provide is the `logic.scm` file. This is the file where users get to work with the provided robot abstraction, which is that the robot in inheritly stateless, where all state must be explicitly passed around. The user is provided with two data types to work with, the `<ctrl-state>` which represents the state of the arduinio's pins (meaning the power going to motors, the state of the relays, etc. . .) paired with an extra field that the user may populate as they wish, and the <input-state> which represents the state of the inputs (sensors and joystick). The input state does not have the raw joystick, but instead preprocesses the joystick by mapping the users key bindings to their values. The user is required to provide two particular scheme procedures (yet are free to define as many as they wish), where the first is initialize, a function that takes the null <ctrl-state> and returns the <ctrl-state> they wish to start with, and logic-step, the procedure where the logic is done. logic-step is a pure function that takes the current <input-state>, an integer delta-t representing the number of micro seconds since the last call to logic-step or initialize, and finally, the <ctrl-state> returned from the last call to logic-step or initialize. Users simply provide algorithms that analyze the states and determine the next state to return. This abstraction was chosen for a host of reasons. One important reason is that it provides a safe way for users to interact with the robot without worrying about race conditions or hidden side effects. Another is that it is mathematically sound, as you can think of the <ctrl-state> as a category of one object, and the functions that are created by passing logic-step the first two parameters act as morphisms of the category by mapping that object onto itself. Internally, the c backend takes the ctrl-state returned at each step and syncs any changes to the robot. Because scheme is so commonly used in AI and machine learning research, it is the perfect language for such a task.

3.7 Electrical Systems

The electrical system was designed from the ground up, and each of the components sourced or constructed was incorporated with mission objectives in mind. It is divided into three basic subsystems: power, logic, and control. Power modules consist of a variety of voltage regulators and blocking diodes to direct flow. The logic subsystem consists of the arduino hub, our sensors which interface directly with it, and the logical portions of the Electronic Speed Controllers (ESCs) and relays. Finally, the control subsystem incorporates relays to actuate our solenoids and ESCs which actuate our thrusters. The lighting system is mainly external to these categories, though it is subject to the control of the logic subsystem. A detailed overview of the entire electronics design can be found in our Systems Integration Diagram, which represents a layout faithful to the actual placement of the ROV's components.

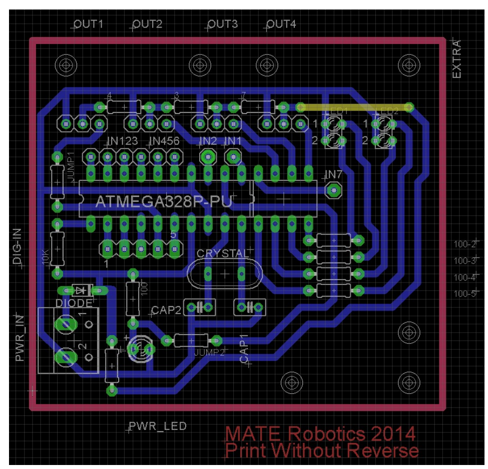


Figure 11: The control board

3.7.1 Modularity & Heat Dissapation

Modularity was a key principle in the design of the electronic systems, just as it was for the rest of the hardware and software. Each electrical component was incorporated and connected in such a manner that they could be easily swapped out or reinserted should any issues arise. Towards this ideal, incorporated are a pair of electronics plates which act as the foundation for our components to rest on, as well as a heatsink for improved reliability. These plates can easily be removed in whole from the robot, providing easy access for repairs or modifications; additionally, when docked inside the robot they attach magnetically to our external heatsinks. This gives all the benefits of water-cooling to counter the inherent thermal insulation provided by the PVC body.

3.7.2 Custom Work

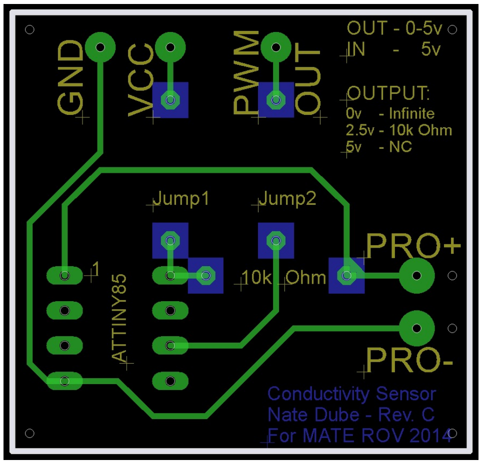


Figure 12: The conductivity probe

Where possible, custom printed circuit boards were designed by the team, printed, and acid etched so that the ROV could utilize components tailored to its specific needs. Among these custom boards are sensing modules (for conductivity, acceleration, etc), a high amperage 5v regulator (designed to be capable of sourcing up to 6 amps), headlights, and general-purpose controller boards which can communicate with the Arduino hub to outsource some processing tasks. Each custom printed circuit board was designed with electrical standards in mind, with properly and efficiently routed traces and shaped to suit the space they were designed for. The custom PCBs were acid-washed, drilled, and populated by hand, allowing the team to become intimately acquainted with the workings of the system.

4 Safety

4.1 Electrical

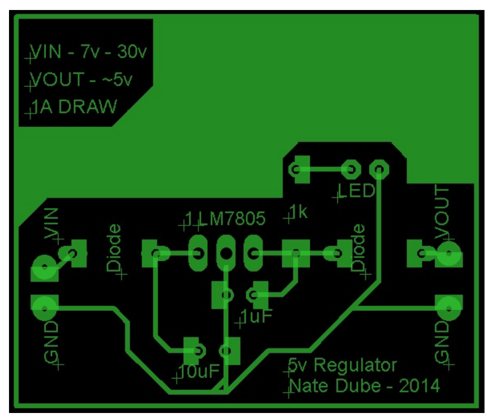


Figure 13: The voltage regulator

The ROV was constructed, programmed and designed with safety as a top priority. The design allowed for slight buoyancy to ensure safe ROV retrieval in case of power failure. All motors contain deadman switches, which are triggered by any loss of signal from the surface. All fuses and the direct cutoff switch are located on the surface if any catastrophic failure occurs under the water. Apart from the expected fuses, several features which increase the reliability and overall safety of the system were incorporated. Blocking diodes are installed strategically to direct the power flow to each module, so that a number of components can share power lines in parallel without the risk of introducing unexpected back voltage. This protects the components and ourselves by increasing the predictability of the system. Regulators are used onboard the ROV to provide 24, 12, and 5 volt sources, resulting in a smaller, simpler tether and a more integrated system. A more tightly integrated system makes for fewer wires and connections, and therefore fewer points of potential failure. In the event of a power cut, the logical components will maintain power as long as the communications cables are intact, allowing the system to continue collecting data and potentially re-initialize the systems without excessive downtime. No other systems can draw from this power, however, so it is safe not worry about unanticipated movement in this state. With all motor controllers and electronics being confined to a small space, external heat sinks were manufactured and implemented as a precaution to prevent overheating.

4.2 Mechanical

The attenuation of light through water is due to absorption of the colors' wavelengths. Turbidity of the water and particulate concentration are other factors that make visibility even more difficult under water. After researching this matter, it was concluded that the color yellow is among the most popular colors to be used for visibility under water due to its wavelength. To ensure the safety of the ROV and any person near the vehicle during operation under water, the housing was spray painted with a bright yellow color. This feature, coupled with the lights on the front and sides of the ROV, creates a safe environment for all. The safe transportation of the ROV was addressed by the construction of handles located in the front and rear that limit the risk of injury while launching and retrieving the ROV from the water. As another safety measure, a custom made housing was manufactured to protect the pistons that operate the rotation of the beak. The housing reduces the overall risk of something or someone being pinched by the actuating pistons.

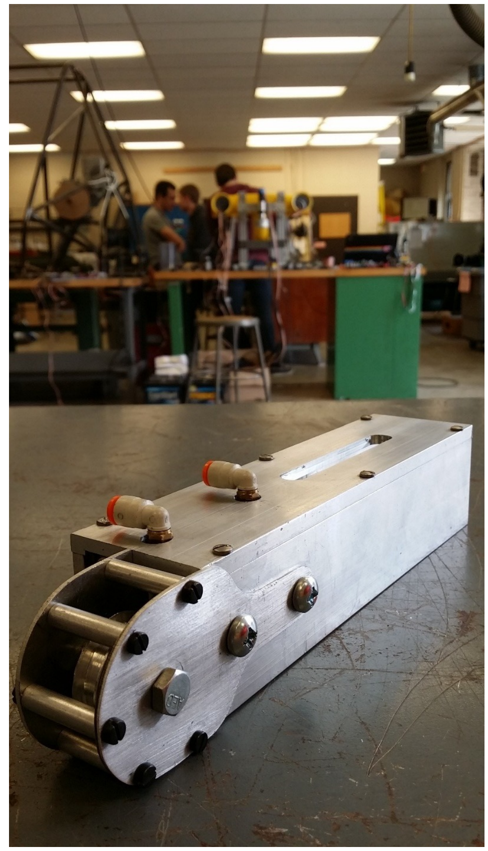


Figure 14: The housing for the pistons that control the beak

5 Challenges

5.1 Non-technical

Due to the inconvenient fact that Wentworth's campus does not have a testing facility for the ROV, a nearby pool had to be used, when available, to conduct testing. Specific windows of time were granted for tests to be run and so it was critical that the time be used wisely. A problem that was faced because of this was the number of unexpected problems that would arise upon arrival of the test site that would eat up a large portion of test time. On one particular critical test day, a lot of time was lost fixing small hardware and wiring issues such that the pool was going to close before there was a chance to gather the test results that were needed. While this was unfortunate, it was decided that it was no time to call it a night. Thus, arrangements were made to bring the ROV to a pond and complete testing there. The first location that was visited did not have a stable launch or control area. Also, the water was shallow and filled with plant life. The second location that was tried, had much better conditions that allowed for easier testing in deeper and cleaner water. One team member had a full wetsuit, so there would be someone in the water with the ROV in case manual recovery was required. After a number of hours, the necessary testing was complete and the ROVs propulsion system was able to function as desired.

5.2 Technical

A more technical challenge that was faced was having to theoretically design the majority of the robot before funding and physical parts arrived. Since this was the team's first year competing in MATE Robotics, there was no designated funding for the undertaking of such a project. As a result of this, combined with the need to keep developing the ROV, it was necessary that a lot of design had to be done without having physical components to manipulate or experiment with. This was a certainly a valuable exercise in using one's imagination but not necessarily the most time efficient manner of forming results or functional prototypes. While it was not easy, we stuck to the method for a number of weeks until we allocated funds to begin construction.

6 Lessons Learned

6.1 Fine Print

Throughout the building and testing process of the ROV, many valuable lessons were learned that have sculpted each team member into a more thorough thinker and better engineer. One big issue the team had run into was the purchase of the motor controllers for the Crust Crawler thrusters. The motor controllers purchased were the exact model recommended on the Crust Crawler website, but were purchased from a different seller at a cheaper price. Later on, it was discovered that these motor controllers are typically sold as mono-directional. Crust Crawler had a contract with the makers of these motor controllers to install a special firmware that enabled them to be bi-directional. As a temporary fix, relays were implemented into the design which electromechanically switched the thruster wires to change the direction of the motor. Moving forward, further research will be done to ensure all electrical parts perform the way they are intended to. This was quite a learning experience that cost us both time and money as a result of less time spent researching in the beginning.

6.2 New Team

Another learning experience we encountered was outside the realm of technology. Since this was the first year C-Turtle Underwater Robotics has entered the MATE competition, everything had to be done from the ground up. Not only was an ROV designed and engineered, but funds were raised and materials were allocated to move The *Annamaria* from the paper to the pond. This competition encompassed many skills and tasks not necessarily taught in the engineering curriculum that all members of the team had to learn as the project progressed. Budget management, planning for practice time and organization were among many other tasks that were instrumental in making this ROV a success. The challenge of acting like an engineering company has strengthened each team member in areas outside the scopes of engineering or technology alone and has added to each individual's professional repertoire.

7 Reflection

Overall, this entire competition has been a very exciting and humbling experience. Being a first year team, C-Turtle Underwater Robotics had to overcome many obstacles both technically and commercially. Many team members had to work outside of their comfort zone to handle expense reports, fundraising, organizing and many other foreign tasks. This was a learning experience one can not possibly take from a classroom. After analyzing the progress over the entirety of this project, it is concluded that the first year was a success. Adequate funds were raised to complete the manufacturing and assembly of the ROV, the design was sound and functional and the team was able to work collaboratively to complete all required objectives. Learning from the bumps in the road this year, C-Turtle Underwater Robotics will come back again, even stronger and more determined than before.

8 Systems Integration Diagram

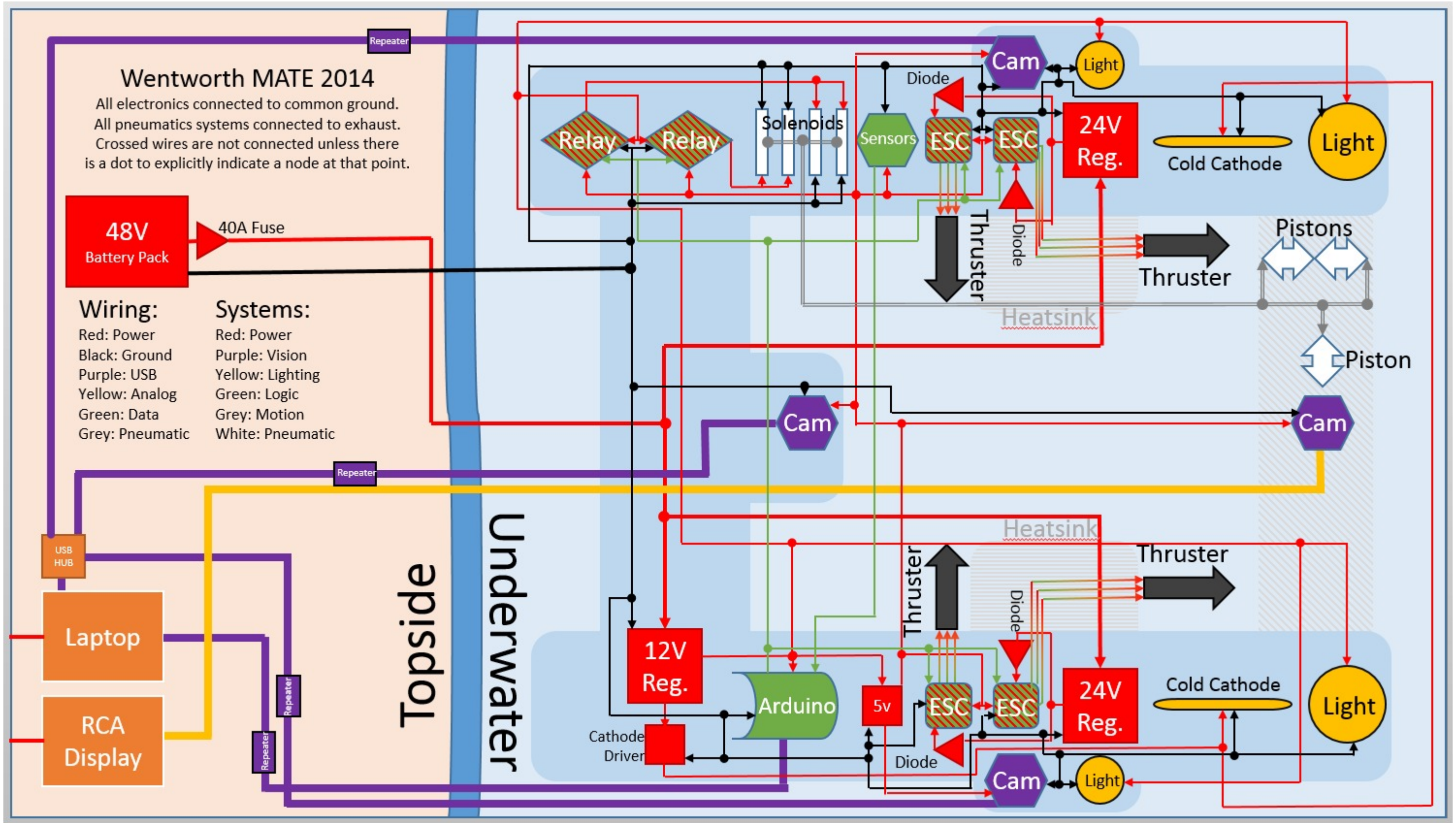
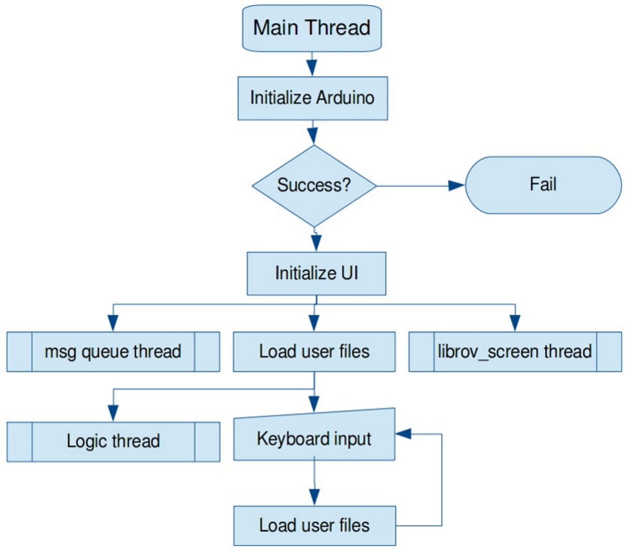
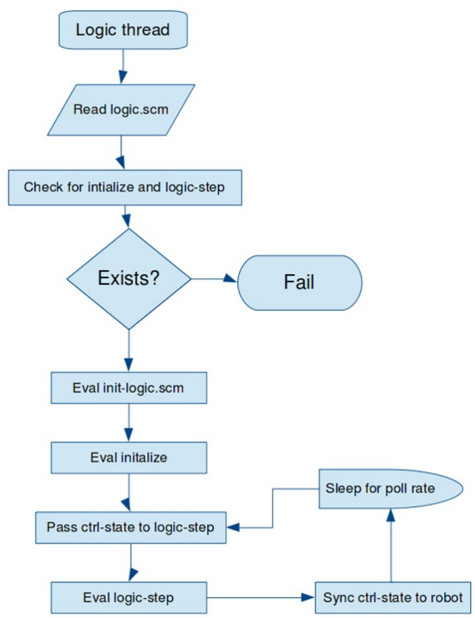


Figure 15: The full systems diagram outlining both surface and underwater controls

9 Software Flowcharts





10 Expense Report

		ORDERED PARTS				
	Part	Description	Quantity	Price/Unit	Total	Source
Beak						
	PVC pipe (3" x 2')	Main beak material	1	$ 6.56		The Home Depot
	1" stroke pneumatic double acting piston	manipulate upper bill of beak	1	$ 22.00		donated
	40 mm stroke pneumatic double acting piston	beak rotation	1	$ 40.40		SMC
	20 mm stroke pneumatic double acting piston	beak rotation	1	$ 34.80		SMC
	4 way- 2 pos. solenoid	manipulate upper bill of beak	3	$ 40.70		SMC
	pneumatic tubing	manipulate upper bill of beak	1	$ 7.00		ebay.com
	stock aluminum	arm		$ 20.00		donated
	bronze bushing	allows rotation	2	$ 2.24		ebay.com
					$ 237.75	
Thrusters						
	crust crawler thrusters	for movement	2	$ 599.00		donated
	donated thrusters	for movement	2	$ 600.00		donated
	thruster mounts	stock aluminum	1	$ 20.00		donated
					$ 2,418.00	

Frame						
	80x20	single extrusion	1	$ 14.20		donated
	80x20	double extrusion	1	$ 22.98		McMaster Carr
	U-bolt	to secure 80x20	5	$ 15.35		McMaster Carr
	pivot fasteners	to secure 80x20	1	$ 10.00		manufactured
	corner connector	to secure 80x20	2	$ 6.83		McMaster Carr
					$ 137.59	

Electronics						
	ATtiny85	Conductivity Sensor	1	$ 2.99		ebay.com
	10k Resistor	Conductivity Sensor	100	$ 0.01		Donated
	PCB + Wiring	Conductivity Sensor		$ -		Donated
	End Mill	Motor Controller Parts	2	$ 20.92		Donated
	Castle Motor Controllers	Motor Controller Parts	2	$ 89.00		castle.com
	ATMEGA328P-PU	Custom PCB Parts	4	$ 4.45		ebay.com
	10uF 450v Electrolytic capacitors	Custom PCB Parts	10	$ 2.20		ebay.com
	16Mhz Oscillator Crystals	Custom PCB Parts	10	$ 4.18		ebay.com
	22pF capacitors	Custom PCB Parts	20	$ 2.69		ebay.com
	car regulator (12v 10a)	48v to 12v Regulator	1	$ 19.99		ebay.com
	LM7805	12v to 5v Regulators	10	$ 2.50		ebay.com
	0.33uf to 10uf Capacitors	12v to 5v Regulators	10	$ 1.70		ebay.com
	1000V Diode	General/Safety	100	$ 3.50		amazon.com
	40A Fast-Blow Fuse	General/Safety	5	$ 3.68		ebay.com
	SMC 12v SY3000 Solenoid	Control	2	$ 81.40		SMC
	Sunfounder 4-Channel Relays	Contol	2	$7.05		amazon.com
	Bullet Connectors	Cabling	100	$ 7.50		amazon.com
	JST Connectors	Cabling	20	$ 6.58		ebay.com
	Screw Terminal Connectors	Cabling	25	$ 8.25		ebay.com
	DHT22 Sensors	Temperature Sensors		$ 16.00		ebay.com
	ATtiny85	Temperature Sensors		$ 6.00		ebay.com
	PCB + Wiring	Temperature Sensors		$ -		Donated
	MMA7361	Accelerometer	1	$ 6.00		ebay.com
	Sunfounder Acrylic Arduino Mega Case	Central Hub	1	$ 5.00		amazon.com
	Sainsmart Arduino Mega	Central Hub	1	$ 22.88		ebay.com
	usb cable (64 feet)	Tether Cabling	4	$ 34.99		amazon.com
	laser pointers	range finding	4	$ 7.11		ebay.com
	Logitech camera		1	$ 39.99		ebay.com
	.5 Watt LEDs	Lighting	50	$12.00		ebay.com
	Cold Cathode Tubes	Lighting	2	$ 14.65		amazon.com
	CMOS camera	gripper	1	$ 35.88		Sparkfun
					$ 469.09	

Buoyancy Vessel						
	4" clear PVC pipe	for waterproof housing	1	$ 117.79		McMaster Carr
	4" T-connector	for waterproof housing	2	$ 13.86		McMaster Carr
	4" PVC cross connector	for waterproof housing	2	$ 16.11		McMaster Carr
	4" PVC hex end cap	for waterproof housing	2	$ 9.14		McMaster Carr
	4" to 2" reduction cap	for waterproof housing	2	$ 6.66		The Home Depot
	4" PVC elbow	for waterproof housing	1	$ 3.90		The Home Depot
	polycarbonate	for camera windows	1	$ 40.00		donated
	PVC cement	to hold PVC together	1	$ 8.99		donated
					$ 262.22	

Miscellaneous						
	Asst. nuts and bolts		1	$ 20.00		True Value
	stock alminum	for manufacturing	1	$ 100.00		donated
	wire		1	$ 50.00		donated
	soldering materials		1	$ 7.00		donated
	epoxy	for waterproofing	10	$ 5.00		True Value
	wire netting	collection depository	1	$ 17.99		True Value
	teflon tape	for waterproofing	6	$ 2.50		The Home Depot
	logitech 3D pro	controls	1	$ 24.99		amazon.com
	nitrile gloves	protection		$ 3.98		The Home Depot
	plasti-dip	for waterproofing	1	$ 7.50		The Home Depot
	5200 marine sealant	for waterproofing	1	$ 21.00		The Home Depot
	black spiral loom	tether	1	$ 33.23		amazon.com
Subtotal:					**$ 354.69**	
TOTAL					**$ 3,879.34**	

11 Safety Checklist

11.1 Power On

1. Area is quiet during start up
2. Thrusters are lubricated
3. All people and objects are clear of thrusters and pistons.
4. No extraneous conductors touching electrical components or batteries

11.2 Launch

1. Visual inspection of housing
2. Housing caps are tightly secured
3. Safe handles are used
4. All tripping hazards are clear of area

11.3 Recovery

1. Safe handles are used
2. Power is turned off
3. visual inspection of housing

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