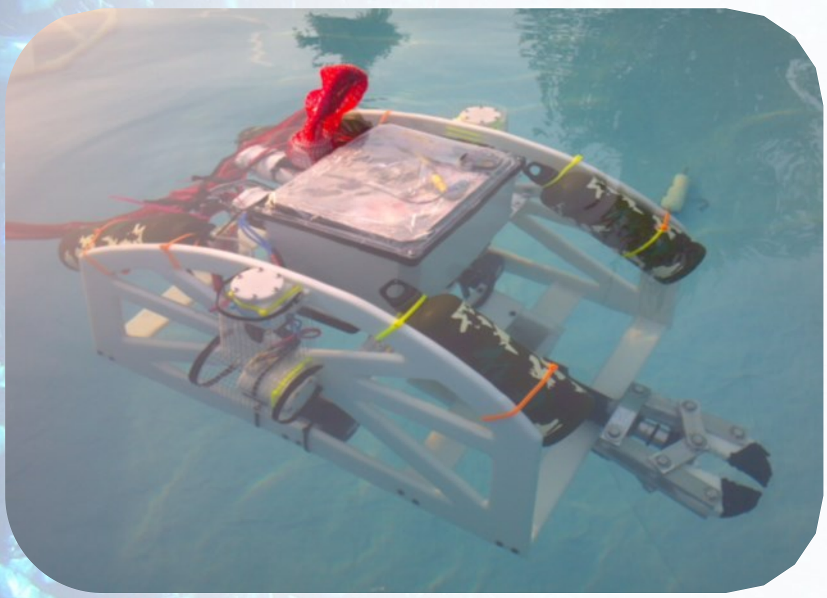
MSOE Underwater Robotics

Milwaukee School of Engineering, Milwaukee, Wisconsin

The Systems and Design Philosophy of *Bubbles*



Bubbles the ROV

Team Members

- Seth Opgenorth—CEO
- Nick Vogt—VP, Pilot
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- Akshay Kiritisharma—Secretary
- Lindsay Vogt– Accountant, Technical Writer
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Mentors

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Abstract

MSOE Underwater Robotics is a first year company and student organization at the Milwaukee School of Engineering. This company is made up of a small team of engineers, each bringing something new to the table and each striving to use the education they have gained to benefit this hands-on experience. The engineers decided that it would be unacceptable to build anything less than the best. Although some of the members have experience on high school robotics teams, there was no ROV to build on and improve, so the new company had to start from scratch. Having no base to work off of was challenging, but was probably for the best as it allowed for far more creativity and ingenuity when designing electrical, software, and mechanical systems on the ROV. The team's corporate structure allowed every aspect of the ROV to be broken down into separate systems that could easily interface and synergize with each other creating a well performing, fine-tuned machine.

The ROV, *Bubbles*, was designed, built, and tested specifically to undertake the underwater tasks involved in observing and sampling ocean activity. While spending many hours together the members learned to work as a team, think creatively, and be open minded to each other's opinions. *Bubbles* was created with an HDPE frame, a dry housing that encloses the electronics, five wide angle Aqua-Vu cameras, five high efficiency brushless motors, a waterproof manipulator, an Arduino microcontroller operated with a PS3 controller, motor drivers, and the always useful zip ties.

Table of Contents

Competition Mission

The Ocean Observatories Initiative (OOI) is an important project that will have an effect on every living creature on earth. This Initiative is working to collect information on the ocean to better understand how changes in the largest ecosystem (the ocean) affect such things as climate, biological assortment, and other ecosystems. Scientists' goal is to find a way to record and document continuous data from the ocean floor. Because humans cannot remain in the ocean for extended periods of time, sensors are being placed in the ocean with direct connection to computers in labs on the surface. This allows professionals to continuously monitor ocean activity in real time.

The current system contains nodes on which data gathering instruments are located. Scientists plan to use all of the information collected to find the effects different ocean activity has on the weather, specifically severe weather; ocean ecosystems; and plate tectonics. This is a new age of ocean monitoring that has been ten years in the making. This advanced technology will be helpful for generations to come.

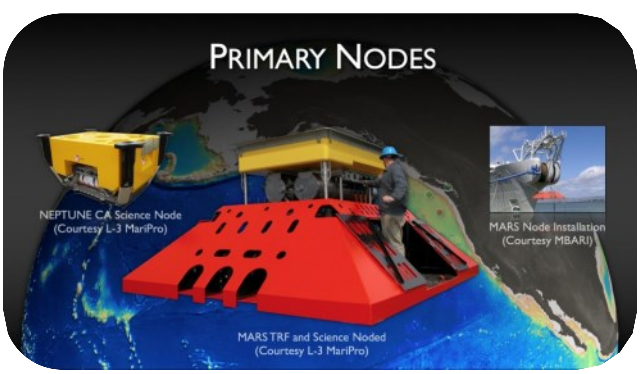


Figure 1—Credit: OOI Regional Scale Nodes program and the Center for Environmental Visualization, University of Washington

The Team

The MSOE ROV team began with a small group of motivated students who participated in the MATE ROV competition as high school students. To date, the team has worked hard on becoming an official student organization at MSOE, reaching out to companies for materials and funds, along with designing and engineering an ROV that will be best to compete in the 2013 MATE ROV International Competition.

There are many advantages to having several experienced members on a new team. This mixture allows the team to make design decisions based on previous experiences while being able to gain a different perspective on the design with help from new members. This has also allowed for large amounts of originality since there is not an old ROV to work on. The MSOE ROV team has used this to their advantage by making custom thrusters, a hydrodynamic frame that has many places to grip for transportation, and a powerful custom made gripper.

Figure 2—MSOE ROV 2013 Team t-shirt

Design Rational

One great thing about the MATE ROV competition is the wide variety of directions a team is able to take in order to complete the mission for the year. However, this also means that there are a lot of decisions to make as a team. This lead the team decision to design and manufacture an ROV that would be an efficient, robust, powerful, and versatile machine capable of handling anything thrown at it. This mindset and careful planning led to the design and creation of the thrusters, frame, gripper, tether and software.

Frame

Originally many frame designs were brainstormed on the blackboard and with cardboard models. Using past experiences, the team was able to make an educated decision on the frame design. The design chosen is big enough to allow for future improvement and additions, small enough to carry easily, and strong enough to handle anything the team might put it through. Several holes are cut in the sides of the frame to allow for a convenient place to place your hands when carrying the ROV, while reducing overall dry weight and increasing hydrodynamics. The material chosen was 1.25cm thick HDPE, which is plastic having a specific gravity of .95 g/cm^3. This makes it nearly neutrally buoyant and a perfect choice for constructing the frame.

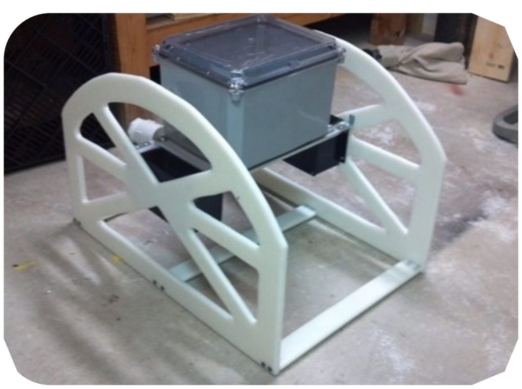


Figure 3—ROV Frame

Dry Housing

Water likes electronics a little too much and has the tendency to cause unwanted shorts and corrosion. To battle against this, a 10" x 8" x 6" dry housing was obtained from Integra Enclosures for free, with the team's promise of sending performance evaluations of the product. The dry housing chosen has an Ingress Protection (IP) rating of 68, meaning it is capable of keeping all dust out and is rated to be continuously submerged in water greater than 1m deep. Finally, the dry housing provides 77kN of flotation to counteract the weight of the motors, electronics, manipulator, and fasteners allowing for a neutrally buoyant ROV.

Figure 4—Integra 10x8x6 IP68 enclosure

The dry housing chosen was a perfect fit for all of the electronics and leaves no wasted space. As a result, the dry housing is broken into 3 layers (power distribution, power conversion, and cameras/other logic devices), with wires running between each layer. Individual layers of electronics can be easily removed and serviced if needed. Finally, before placing the dry housing in water, electrical tape is stretched and wrapped around the seam of the lid to reduce the possibility of water leaking in. This precaution has prevented water from leaking in and is considerably faster to replace in comparison to an RTV silicone seal that would need to be redone every time the lid is removed.

Bulkhead Connectors

The team's business department attempted to make contact with several commercial bulkhead manufacturers, but was unable to get any water rated bulkheads donated. To overcome this challenge, the team designed their own connectors to allow electrical signals and power lines to move in and out of the dry housing. The team knew that it would need, at minimum, 2 wires for main tether power, 12 for motor power, and at least 32 signal wires. Each power wire for the motors uses 10 AWG wire, while the main power comes in through 6 AWG wire. Each signal wire uses 22 AWG wire. The wires chosen allow for maximum power transfer, without having to worry about excessive heat along with allowing many wires to be fit in a small area.

Figure 5—Bulkhead Connectors

The bulkheads are made of PVC, RTV silicone, and a thermoplastic adhesive. The PVC caps are used as the body of the bulkhead and all have screw connectors to allow for additional wires to be added on in the future. Wires are then secured on the inside of the cap using an RTV silicone to form a watertight seal. On top of the silicone, a high strength thermoplastic adhesive is added to provide stress release which prevents the seal from breaking. Each female portion of the bulkhead is attached to the main dry housing using a plastic primer and cement to bond the two plastics together. This joint is then sealed off with JB KwikWeld epoxy to fill any remaining voids and provide additional strength. Finally by using standardized PVC screw connections, bulkheads can easily be replaced with new ones that have different wire setups.

Tether

Two runs of colored 6 AWG, stranded marine grade wire were chosen to transmit power to *Bubbles*. The wire chosen has a type 3 ultra flexible rating which provides it with protection from fatigue due to flexing or vibration. The vinyl casing on the wire is resistant to salt water, battery acid, and ultraviolet radiation. The individual strands, made from 30 AWG wire, are individually tinned to prevent copper from corroding over the years as it is exposed to water. According to Ohm's Law at a maximum allowed load of 40A, 6 AWG wire has a voltage drop of 2.45V or 5.1% of the given 48V. Such wire allows for extremely efficient power transmission that is surprisingly flexible and that will suit the needs of the team this year and for many years to come.

Figure 6—Neatly coiled tether

Signals need to be transmitted from the surface to the ROV, and the ROV needs to send signals to the surface. One signal that is sent to the surface is video from the ROV's 5 cameras. This is sent over 2 shielded coaxial cables that prevent the video feed from picking up extra noise from the environment. Additionally, signals must be sent to and from the Arduino microcontroller located on the ROV and are sent over a weatherproof twisted pair Cat5E cable. Such a setup allows for tremendous amounts of analog and digital data to be transferred to and from the ROV for lag free communications.

Thrusters

Bubbles is going places, all thanks to its thrusters. The thrusters chosen have been custom made from 850W brushless motors with an average efficiency of 85%. Each motor makes use of a nylon 57mm 3 blade propeller with a 40mm pitch, and has its own electronic speed controller. Brushless motors, unlike brushed motors found in most bilge pumps, are electrically cleaner due to the lack of arcing on the brushes, more efficient due to their reduced size and design, and lighter in comparison to an equally powerful brushed motor. *Bubbles* features 5 of these motors, two for forward/ backward movement, two for vertical movement, and one for lateral movement.

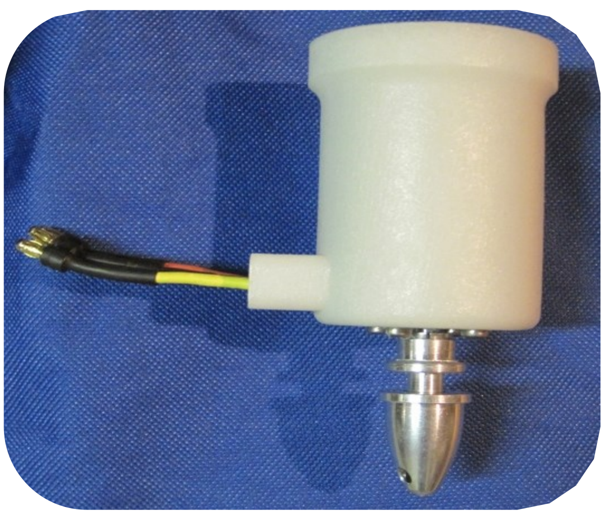


Figure 7—Custom Motor Housing

A brushless motor's speed controller needs to direct the rotor rotation, and as a result it needs to know the position of the rotor (magnets) relative to the stator coils. On sensorless brushless motors, such as those chosen, the electronics speed controller (ESC) senses the rotor's position by reading the back EMF generated as the motor spins. Based on this information, the ESC is able to produce a 3 phase AC electrical signal to spin the motor. One limitation of sensorless controllers is the need to be as close as possible to the motor in order to properly sense the changing electrical field. To accommodate this, each ESC has been potted in epoxy to waterproof them so they can be safely placed close to the motor. The ESCs chosen to accomplish this are off the shelf hobbyist motor controllers that receive a servo pulse generated from the on board microcontroller.

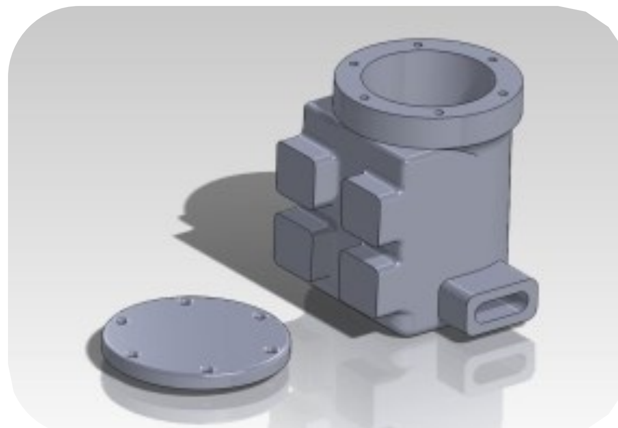
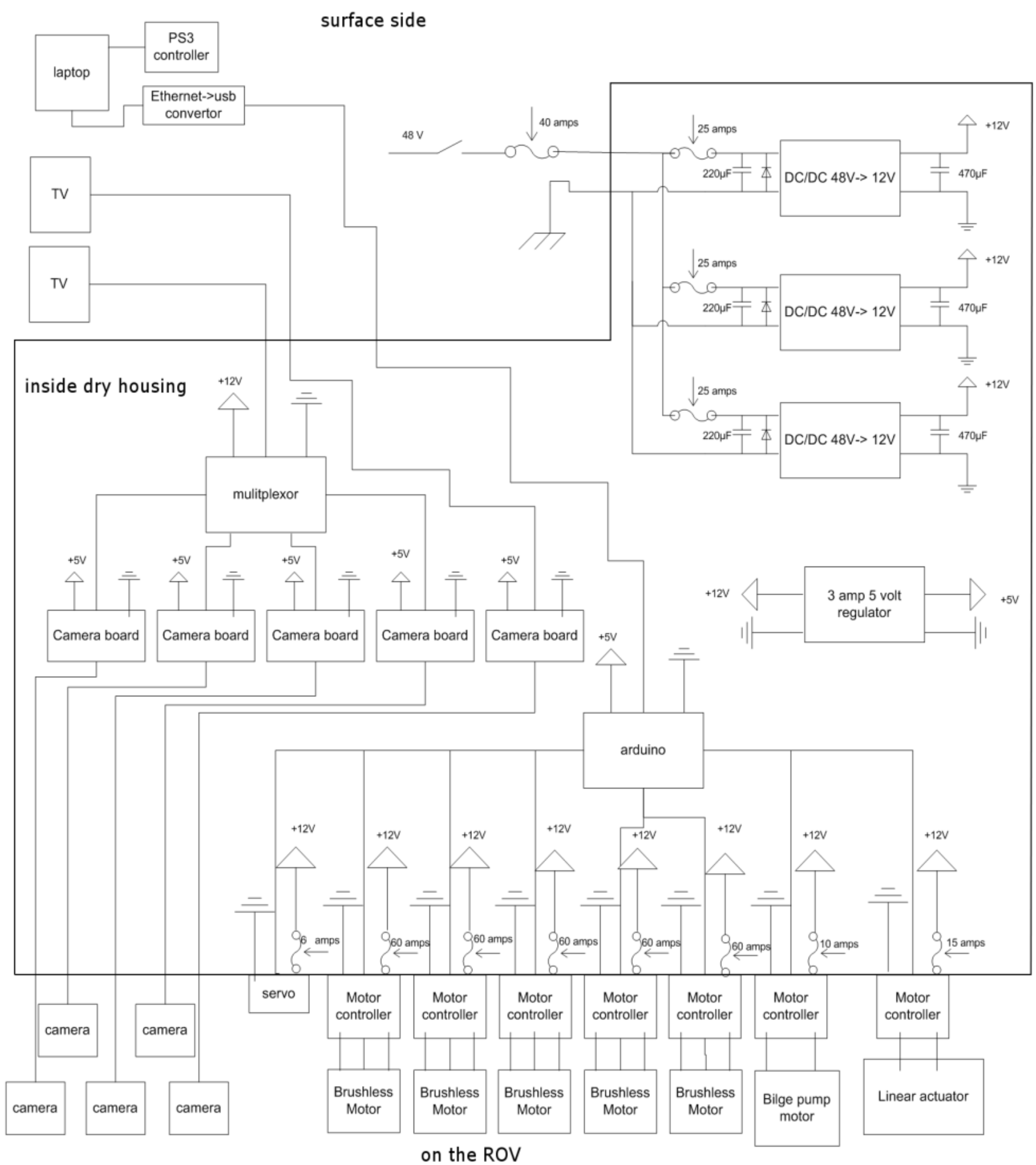


Figure 8—CAD rendering of a motor housing and lid

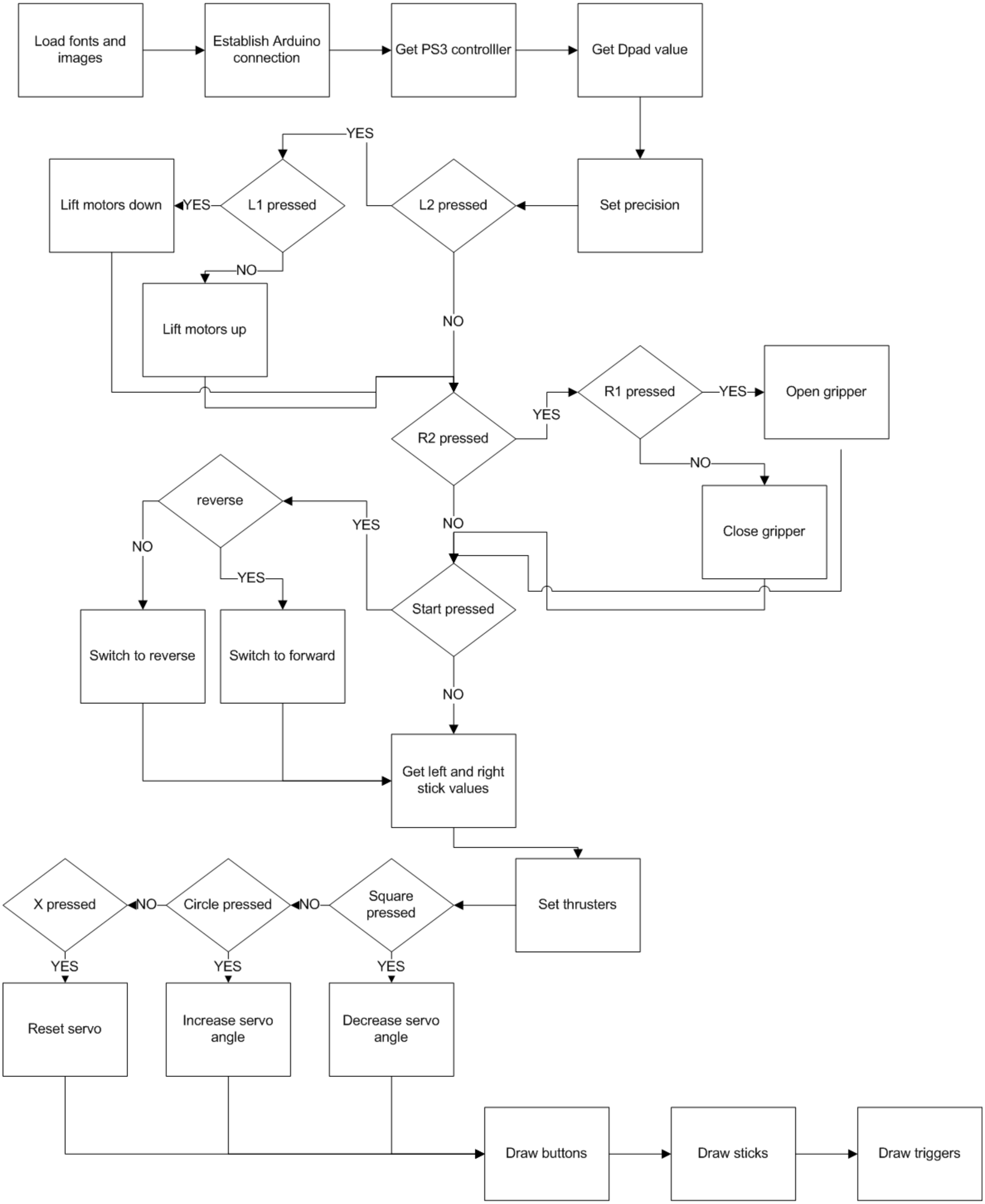
To allow the motors to last as long as possible and to protect the divers from the AC sent to the motors, each motor has its own housing. This housing was custom designed in SolidWorks by the company's Mechanical Engineering Department. The housing was designed to be as small as possible to allow for maximum water flow and to decrease the time to manufacture the housing. Each housing was manufactured using the additive Selective Laser Sintering (SLS) process. The material chosen is commercially known as DuraForm GF, which is a glass fiber filled polyamide (nylon). This material offers excellent mechanical and thermal properties that can easily handle the torque and heat generated by the motors. Additionally, the material is non-porous and does not absorb water over extended periods of time. These properties combined made Duraform GF an excellent choice for manufacturing the motor housings.

Electrical Schematic



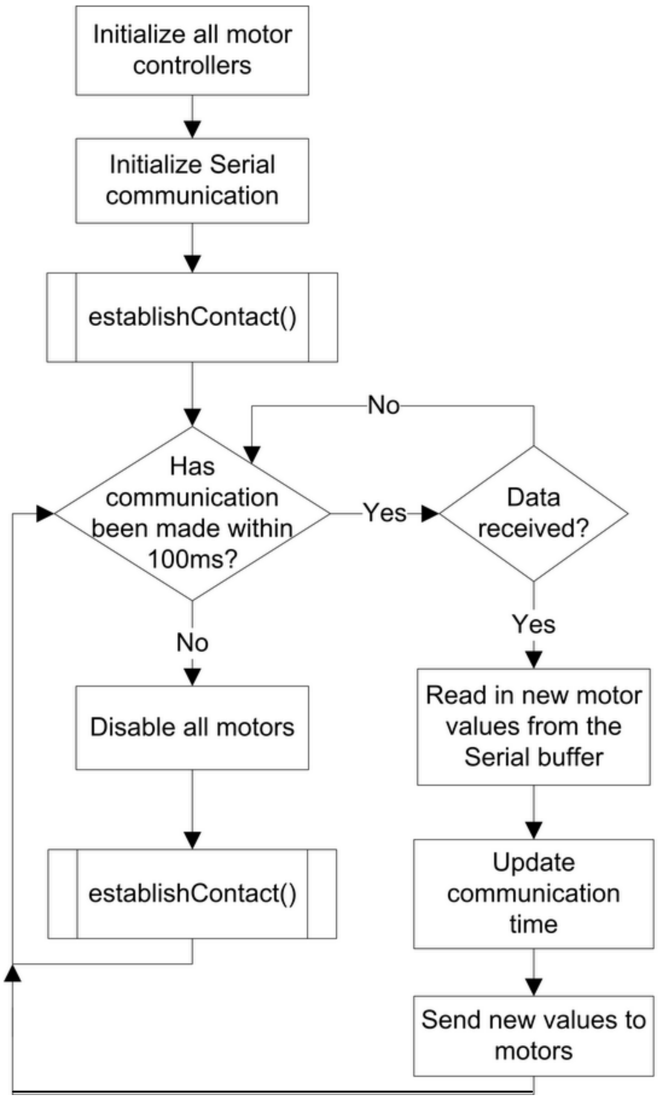
Software Flowcharts

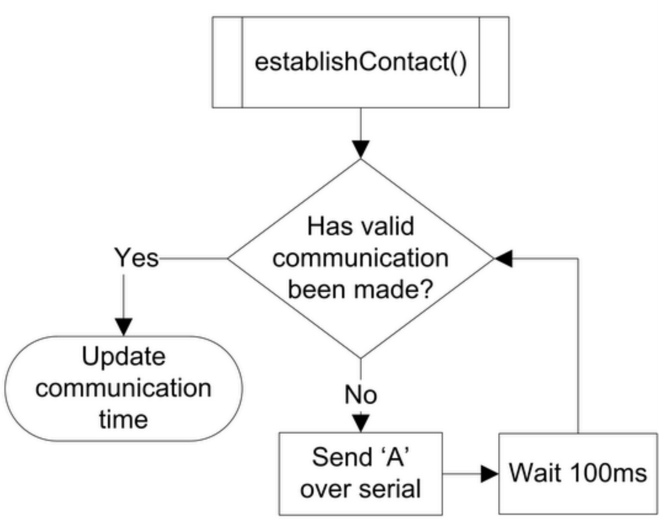
Laptop/Processing flowchart



Software Flowcharts

Arduino Uno flowchart





Control System

Each motor controller requires a TTL level servo style signal. To generate this signal, *Bubbles* uses an Arduino Uno microcontroller and makes use of the provided servo library. This library generates an electrical pulse with a period ranging from 1000 us to 2000 us, based upon a value from 0 to 180. When the motor controllers are given a 1500 us pulse, the motors do not move. With a 1000 us pulse the motors go full speed backwards and with a 2000 us pulse the motors go full speed forwards. Utilizing the analog sticks on the PS3 controller then allows for precise manipulation of the motor speed by generating pulses in between the given range.

Figure 9—Components of electrical box

Communication from the laptop to the Arduino Uno microcontroller occurs over a 23m water resistant Ethernet cable, using a USB to ethernet converter on both ends to allow for USB communication over the ethernet. The Arduino Uno’s software keeps the motors at their neutral point (1500us) until it has successfully received serial communication from the control laptop. Additionally, if the Arduino Uno goes more than 100 ms without communication, it brings all of the motors to their neutral point and waits until proper communication has been reestablished. This communication scheme allows for reliable transmission that has a failsafe to prevent the motors from running uncontrollably if communication is lost or corrupted.

Power Regulation. While it is more efficient to transmit power at higher voltages, it can often be cumbersome to work with these higher voltages. To reduce the 48V to a more common voltage of 12V, *Bubbles* utilizes three 700W DC/DC regulators that run with a 91% efficiency. These regulators were donated by TDK-Lambda, and are capable of running between 36V-76V. They produce an extremely stable and isolated output, even with a noisy input. This combined with their high efficiency made them an ideal choice for voltage regulation on *Bubbles*.

To interface with the DC/DC regulators, custom PCBs had to be designed and manufactured. Using experience from previous electrical systems, the boards were designed with extra capacitors to reduce any electrical noise the regulators do not take care of. For safety, each regulator also has its own 25A fuse and a reverse biased diode on the input. The fuse helps prevent the regulators from becoming damaged due to excess current. If the input power is plugged in backwards, the diode will conduct electricity shorting the input across the fuse. This will then blow the fuse and prevent any electronics on the ROV from becoming damaged if the power is applied backwards.

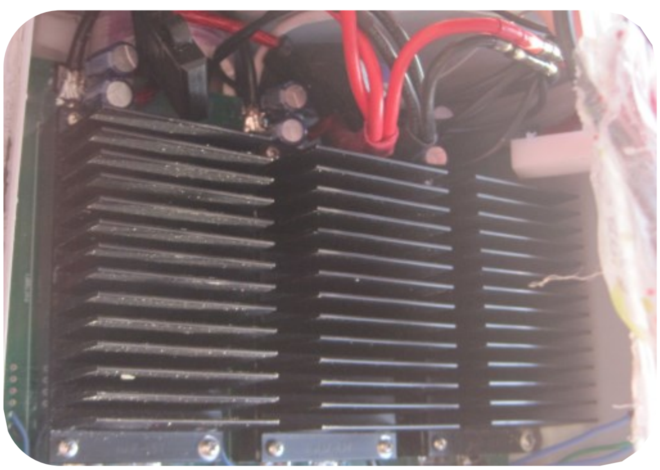


Figure 10—PCBs with regulators and heat sinks

For electrical devices that need 5V, such as the cameras and the Arduino Uno, a 5V switching DC/DC regulator is used. This repurposed cell phone charger has a 78% efficiency and is capable of running off of a 7-30V source. Using this switching regulator allows for less heat to be produced inside the main dry housing, especially when compared to a linear regulator that would have a 40% efficiency (when ran at 12V) and would need a large heat sink to accommodate the extra heat generated.

Power Distribution. To allow for a modular electrical system, everything on *Bubbles* makes use of standardized connectors and busbars. All motor controllers and motors have connections made with 3.5mm bullet style connectors. All 12V power is distributed via two aluminum busbars with screws to allow for crimped connectors to be attached to the busbar. All motors connected to the 12V busbar run through their own 60A ANL style fuse, which is mounted on the busbar HDPE body. All 5V power is distributed via 2 small screw terminals. This design allows any electrical component to be swapped with a backup at a moments notice.

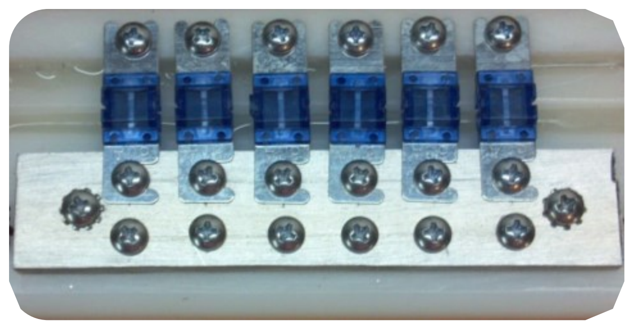


Figure 11—Team manufactured busbar, with built in fuses for power distribution

Software/Controller. A laptop running custom software is used to give the pilot instantaneous feedback on the controls. This custom software was written in a Java based language called Processing that allows for simple, yet powerful software. The software is responsible for receiving input from the PlayStation 3 controller, modifying and sending this information to the Arduino Uno on the ROV to control electrical devices, informing the pilot of communication status, and giving the pilot visual feedback of what information is being sent.

A PlayStation 3 controller was chosen as the main input device for a multitude of reasons. It has a large variety of analog and digital inputs, it is widely available, and has libraries available to interface it with a PC along with 2 joysticks on the same plane as each other to make “tank style” piloting easier. The analog triggers are used in combination with digital buttons to allow for variable speed manipulator control and variable speed lift motors. This enables the ROV pilot to have precise control of every aspect of the ROV. Therefore, many of the tasks can be completed with ease and without the controls getting in the way of the pilot. For a more detailed description of controls see page 17.

To assist the pilot with maneuvering *Bubbles* in the water different precision modes have put in place. Notably are the four precision modes which set the maximum value for each of the thrusters. Each level of precision increments the maximum allowed thrust by 25%. Each precision mode is set using one of the four D-pad buttons, and will remain at the set level until changed by the pilot. Such a system allows the pilot to quickly move the ROV large distances, carry heavy objects, or to free the ROV from props it may be stuck on while on 50% or 100% of full power. At the same time it also allows the pilot to precisely maneuver the ROV around an object that needs to be manipulated. Combined it allows for the ROV to complete the tasks at hand in the fastest manner possible.

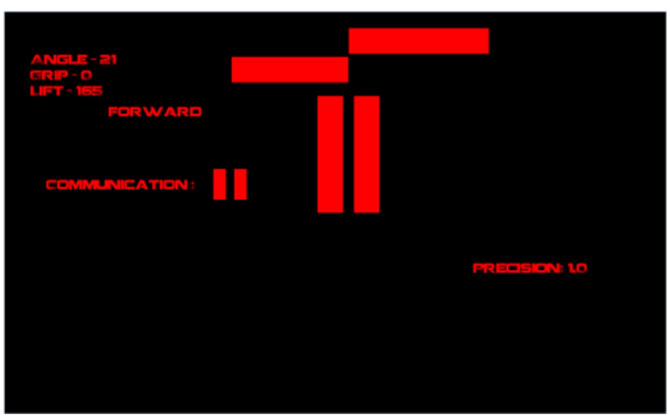


Figure 12—Processing GUI showing joystick movement

Cameras

A clear view of the surroundings is necessary to properly pilot an ROV. *Bubbles* utilizes 5 NTSC color cameras that were donated from Aqua-Vu. Each camera has a 150 degree wide angle lens that does a surprisingly good job of not distorting the image, while allowing the team pilot to see a large portion of the underwater surroundings. Since these cameras are originally intended as fishing cameras, they are already waterproof and ready to be used in deep bodies of water (up to 15m). Four cameras spread around the ROV are displayed on 1 screen at the surface via an onboard multiplexor. The remaining camera is used as the main driving camera that can see the manipulator and everything in front of the ROV.

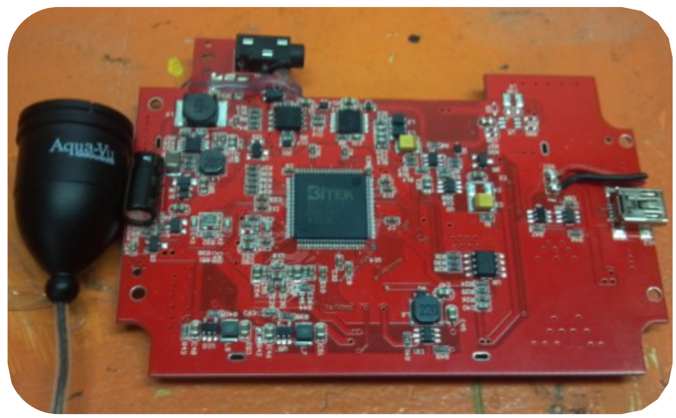


Figure 13—Aqua-Vu camera next to its processing board

Manipulator

A manipulator allows an ROV to easily accomplish tasks while it is deployed in the water. *Bubbles* makes use of a Lenco marine waterproof linear actuator capable of delivering 3.3 kN of force. The linear movement from the actuator operates a hinge giving the manipulator's claws a scissors-like movement. The claws of the manipulator are made from HDPE with rubberized tape wrapped around the ends to prevent objects from slipping as the actuator closes the claws. Such versatility allows for the manipulator to pick up bulkheads and biofouling from the seafloor with ease.

To allow for smooth operation of the manipulator custom HDPE bushing were made. One bushing is placed everywhere there is a moving joint. The HDPE allows the bolts to move smoothly while not allowing for any wiggle room. These bushing also have the benefit over bearings as they will never rust and do not need to be lubricated. This ensures that the manipulator will have a long useful lifetime for completing many of the tasks needing manipulation.

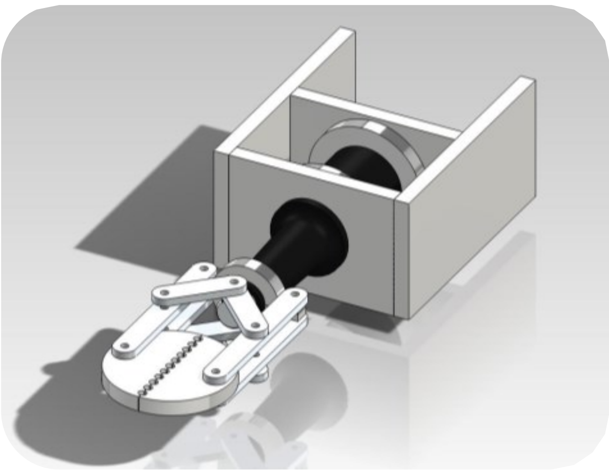


Figure 14—CAD drawing of the manipulator

Transmissometer

A transmissometer is used to measure turbidity of the water to help determine quality of and debris in the water. This is realized through the use of a an ultra low power Texas Instruments MSP430 microcontroller. The MSP430 utilizes a photoresistor and LED spaced 15 cm apart from each to take measurements through its analog to digital converter (ADC). The values measured are then sent to a laptop over a UART connection which are then graphed in a web browser through a custom HTML5 locally hosted web page.

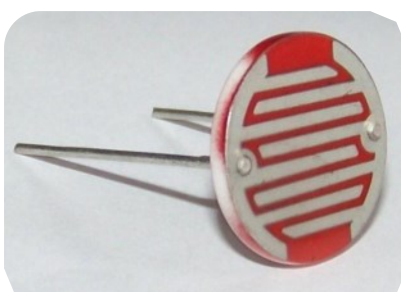


Figure 15—Photoresistor to sense changes in light brightness

Laser

When exploring places underwater, it can be quite beneficial to see how far away objects are from the ROV. Preferring a system that did not rely on mechanical devices which require valuable time in the water to setup, the team decided that a laser would be necessary. The laser chosen is a Class II laser, manufactured by Bosch Power Tools, with an output of less than 1 mw, with a wavelength of 635 nm, and an accuracy of +/- 1.5mm. To compensate for the refraction of water, measurements are taken every 10 cm for 10 m. This data was then analyzed on a computer using regression tools. It was discovered that the reported distance was off by a factor of 1.35. Dividing the reported value by 1.35 allowed the laser to be accurately used in water. This laser system has proven to work extremely well for measuring distance for the placement of the secondary node.

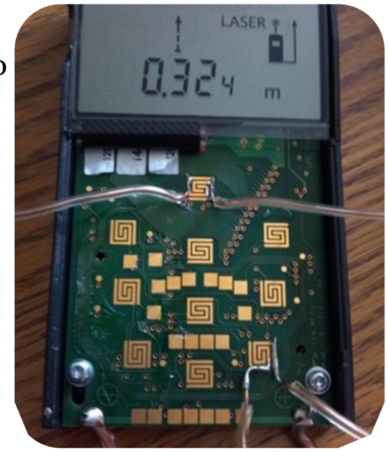


Figure 16—Disassembled laser for distance measurement

To read the distance reported by the laser, some reverse engineering is needed to be done. After looking for a serial, analog or other standardized communication protocol from the laser module with no success another approach needed to be taken. This approach was to read the data as it was sent to the LCD. Such a task involved going through the 30 pin LCD connector with a digital logic analyzer and recording the waveforms seen. Once the LCD protocol was fully understood, software was written on an AVR 328p microcontroller that then sends the “decrypted” values to the main Arduino Uno, where it can be transmitted to the laptop for the pilot to see on the Processing GUI.

Buoyancy

Figure 17—Aluminum water bottle attached to Bubbles' frame

After talking with several ROV professionals and doing research, the team had decided that in order to create an extremely stable vehicle more mass and buoyancy would be needed. Placing a large amount of buoyant objects near the top of *Bubbles* and dense weight at the bottom allows the vehicle to remain stable as the buoyant objects pull the vehicle upwards and the dense objects pull it downward. The buoyancy is produced by the four 1L aluminum water bottles and dry housing at the top of the frame producing a buoyant force equivalent to over 115kN. This buoyant force is then offset by items on board such as motors, actuators and lead weights. This system is then carefully calibrated to produce a neutrally buoyant vehicle, that has a central center of gravity.

Safety

Safety has been a main focus throughout the design and testing of *Bubbles*. The team has a philosophy of zero tolerance for unsafe practices or material. One example of safety is the wire mesh around each thruster propeller to prevent injury to fingers. Warning labels have been attached to several areas on the ROV in an effort to avoid causing any harm to those around the machine. Another area of safety is the use of separate fuses for each motor and each DC/DC regulator. Every motor has a 60 amp fuse, while every DC/DC regulator has a 25 amp fuse with a diode in reverse bias across the supplied 48V power for reverse input protection. In the event that a motor wire is severed or shorted out, one of the internal fuses will blow, stopping the current from flowing to the affected area. In addition to the internal fuses, the positive lead from the power supply is fused to limit power to 40 amps. Further, there is a switch in series to allow for safer power connection so the person connecting power does not have to worry about any electrical arching. Special design considerations were also taken into account to insure there are no sharp edges. Safety glasses were worn at all times to protect team members as they worked on the ROV. A copy of the team's safety checklist can be found on page 20.

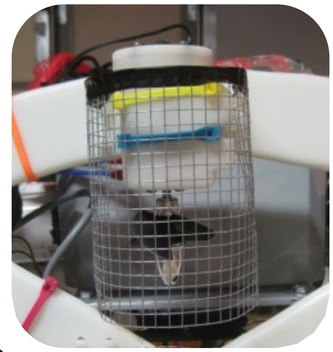


Figure 18—Thruster propeller

Challenges

Technical

When initially choosing what motors should be used, the team decided on brushless motors because, with special care, they can be used directly in the water. However, when the new safety rules came out, it was discovered that all motors would need to be physically separated from the water. After going through many revisions of shaft seals, commercial enclosures, the team was finally able to get a housing that worked well. Going through so many different revisions of motor housings was both frustrating and a great learning experience for every member involved.

Interpersonal

The team had several experienced members who could settle for nothing but the best. As a result, there was a lot to do given that they had to start everything from scratch. The combination of classes, work schedules, and the inability to get proper machine shop access at school limited times when the team could meet. As a result, large portions of work had to be done over quarter breaks and spring break. This was challenging as many team members wanted to go home during these break and there was a large physical distance between members making it difficult to find a central meeting location.

As a first year student organization at the University, the team also had a lot of paperwork to take care of to become an official student organization campus. This included learning many of the campus policies regarding material and monetary donations, student reimbursements, where companies should mail materials to, and how to register for a room for meetings. The team also struggled to find storage space on campus which resulted in most of the ROV being stored in the CEO's dorm room and at member's houses.

Trouble Shooting Techniques

With any project one has to expect difficulties and provide time for troubleshooting. This was especially true with the ROV project because of the intricate and delicate nature of the machine. In an effort to be prepared, the team created a troubleshooting plan to use when issues arose. This plan included writing down the problem, brainstorming possible solutions, discussing the pros and cons of each solution, choosing the best option, and then implementing this choice. If problems still existed after implementation, the process restarted until the perfect design was created. The goal was always to implement the best option the first time. Unfortunately, this was not always the case.

One troubleshooting experience the team worked through was finding the best motor guards to use around the thruster's propellers. The team first began with writing down the problem and potential solutions. Eventually, the decision was made to use thick but flexible sections of plastic containers. These sections were zip tied to *Bubbles* frame around the motor housings and propellers. This seemed to be the perfect solution as it prevented anyone from putting their fingers near the propellers. After attaching all of the motor guards, it was time for testing the entire ROV. Right away a difference could be seen in the velocity and acceleration of the ROV. The first thought was that the new motor guards were obstructing water flow. If only this had been the problem. It turned out the plastic was too flexible. The propellers sucked the plastic toward them and ended up chewing up the plastic sections. In the process, the propellers were also damaged. The motor guards were supposed to guard the propellers, not destroy them! This caused a new problem as the team did not have enough propellers to replace all of the damaged ones. Thus, new propellers needed to be ordered.

Figure 19—Destroyed propeller

After removing all of the plastic motor guards, the team was back to square one, which meant back to using the troubleshooting plan. The team decided it was worth it to take a little more time to find the best solution. The problem and possible solutions were written out again, but this time pros and cons for each solution were also written down. Finally, the decision was made to use wire mesh guarding. The wire was strong enough to prevent it from being sucked in by the motors, galvanized to prevent resting or corrosion from the water and as an additional bonus it allowed for better water flow! This truly was the best solution. If the troubleshooting plan had not been use, there is a possibility this solution would never have been discovered.

Future Improvement

While the team always strives to build the perfect machine, this is never truly possible. In the future, the team agrees that it would be beneficial to have higher resolution cameras to allow the pilot to see what he/she is working on better. Having HD 3D, stereoscopic cameras would be especially beneficial as it would allow for clearer view into the water while giving the pilot a better feel for how far away he/she is from items during the mission. Having digital cameras could also allow for computer assisted piloting that recognizes objects during the mission. This could then be used to help stabilize the ROV and center on an object or to autonomously do tasks requiring a lot of precision. This would help alleviate stress the pilot may feel and allow for tasks to be completed faster.

Lessons Learned

Technical

The team had a strong desire of maximizing the 2000W of power available to them. This desire lead to the team members learning about new kinds of switching regulators to convert the 48V to 12V, with extreme efficiency. Once the voltage was converted to 12V, it was sent to high efficiency brushless motors. This forced the team to learn how brushless motors functioned and how to control them using a microcontroller. This knowledge was extremely helpful in in trying to maximize the 2000W of power. Using the brushless motors not only increased the efficiency of the ROV, but also provided it with the ability to maneuver very quickly through the water.

Figure 20—High efficiency brushless motor

Interpersonal

Although the team learned a lot about engineering and robotics, some of the most important lessons of the process dealt with team dynamics. When there are more than two people working together, there is bound to be some conflict. The team members often had differing opinions when it came to design, electrical, and aesthetic choices. It was difficult to find a solution that all of the members agreed upon. It took some time, but all of the members learned to keep an open mind and consider all aspects of a suggestion. Because the members had several areas of expertise, they were able to come up with the best solutions when they were working together. One member would have an idea, and the other members could build on that to find the best possible answer or solution to the problem at hand.

Another important skill the members learned was how to effectively share their ideas with everyone on the team. A project like this requires a lot of communication and discussion. Each and every member had to participate in order to make the project a success. The members had to get used to working with people who they may have been meeting for the first time. This required them to step outside of his or her comfort zone. Being able to effectively communicate with others required the members to be outgoing. They had to be fearless when making suggestions even if they thought no one else would agree with them. Often the craziest or simplest idea was the best one.

Reflections

"Starting a new robotics team at the Milwaukee School of Engineering as a freshman has been a long, stressful, exciting and overall worthwhile experience. It has allowed me to meet and get to know new friends and faculty at school. It has also given me the opportunity to expand business contacts as we searched for materials and funds to build our ROV. After such a great first year, I can't wait to see how the MSOE Underwater Robotics team grows in the coming years. " ~ *Seth Opgenorth, CEO*

"Being a member of the MSOE Underwater Robotics team has been one of the most rewarding experiences in which I have ever participated. I have gained knowledge that will benefit me throughout my life. I learned the importance of organization, how to become a team player, and many other skills that will help me as I move forward toward a professional career. Because of this, I can confidently say all the effort, grueling hours, and sleepless nights were worth it! This experience is something that I will never forget. I know that I will be using the skills and knowledge I gained in the future.

~ *Lindsay Vogt, Accountant*

Teamwork

"Alone we can do so little; together we can do so much." ~ Helen Keller

The above quote says it all. This process would not have been possible without teamwork. Every member of the team not only had to put in many hours of work, but also contributed ideas and discussion for the technical report, poster, and engineering presentation. It was truly a team effort that brought *Bubbles* the ROV to life.

Everyone on the team was very dedicated to making this project a success. This could be seen by their willingness to take on difficult assignments and help in any way possible. Members often stayed up late to finish their tasks because they knew that others could not start on the next step until their part was completed. Each member was driven to design and build the best ROV possible. Without this enthusiasm, this project would not have been completed.

Communication was essential to working effectively as a team. To stay connected, the team used Google Drive. Google Drive allowed the team to have instant access to important documents. Every team member had the ability to modify the documents. Thus, the documents were always up to date. This was a great way to keep everyone informed as it was often difficult to get all team members together for a meeting. Between work, school, and additional extra curricular activities, schedules almost never lined up.

The Google Drive contained a document that listed all of the tasks needed to be completed along with deadlines for each of them. Team members were assigned tasks based on their expertise. As the project advanced, new tasks were added to the document. There was always something else that needed to be completed. Every time a member would look at the document five new tasks seemed to be added Because of the magnitude of work required, this practice proved to be truly useful to the team. Everyone knew what needed to be accomplished and when. As the members completed their task, they marked on the document that it was done. Everyone could see how far along the project was and where it was going.

The members never gave up and pushed forward even when challenges arose. The support of everyone was needed to accomplish this complex project. It is truly amazing to see what teamwork can accomplish.

Figure 21—Nick and Lindsay working on Bubbles

Table of controls for PS3 controller

Button	Function
Left Joy Stick*	Left thrusters
Right Joy Stick*	Right thrusters
L2*	Lift Motors (upward)
L2*+L1	Lift Motors (downward)
R2*	Gripper open
R2*+R1	Gripper close
L3	Lateral thruster (left)
R3	Lateral thruster (right)
D-pad up	100% thrust
D-pad right	75% thrust
D-pad left	50% thrust
D-pad down	25% thrust
Start	Reverse thrusters

**analog input device*

Figure 22—Credit: Sony Corporation

Budget/Expense Sheet

Material Expenses

Item	Quantity	Cost per Unit	Total Donation	Total Purchase
100ft Coaxial Cable	1	$15.00		$15.00
Actuator	1	$230.00	$230.00	
Actuator Speed Controller	1	$50.00		$50.00
Aqua-Vu Cameras	5	$400.00	$2,000.00	
Arduino Microcontroller	1	$25.00		$25.00
Assorted Materials	1	$108.00		$108.00
Batteries	4	$100.00	$400.00	
Brushless Motors	5	$22.00		$110.00
Connectors	1	$30.00		$30.00
DC/DC Heat Sinks	3	$16.00		$48.00
DC/DC Regulators	3	$360.00	$1,080.00	
HDPE	1	$160.00	$160.00	
Laser	1	$100.00		$100.00
Main Dry Housing	1	$140.00	$140.00	
Motor Controllers	5	$26.00		$130.00
Motor Housings	5	$411.00	$2,055.00	
Multiplexor	1	$60.00		$60.00
Outdoor Ethernet Cable	1	$25.00		$25.00
Package of Propellers	1	$10.00		$10.00
Printed Circuit Board (PCB)	1	$60.00		$60.00
Prop Adaptors	5	$2.00		$10.00
PS3 Controller	1	$50.00		$50.00
PVC Connections	1	$35.00		$35.00
Servo	1	$50.00		$50.00
Tether Wire	1	$300.00	$300.00	
USB to Ethernet Converter	1	$10.00		$10.00
Wire/Heat Shrink	1	$80.00		$80.00
Note: All components/systems were new this year.		**Total**	**$6,365.00**	**$1,006.00**
		Grand Total (Fair Market Value of Bubbles)		**$7,371.00**

Travel Expenses

Item	Description	Quantity		Price per Unit	Total
Train Ticket	44 hours, round trip	2	tickets	$442.00	$884.00
Hotel at Competition	1 room	5	nights	$130.00	$650.00
Meals	4 members, 4 meals each	16	meals	$8.00	$128.00
		Grand Total			**$1,662.00**

Monetary Contributions/Fundraising

Description	Amount
Supply One	$500.00
Midwest ROV, LLC	$1,000.00
CITO	$1,000.00
Candy Bar Fundraiser	$200.00
Grand Total	**$2,700.00**

Summary

Total Material Donations	$6,365.00
Total Cash Revenues	$2,700.00
Total Material Expenditures	($1,006.00)
Total Travel Expenditures	($1,662.00)
Ending Cash Balance	**$32.00**

Acknowledgements

Aqua-Vu Video—Donation of 5 color cameras

CITO—Monetary donation

Concourse BMW—Batteries for practice

Integra Enclosures—Donation of 2 IP68 dry housings/enclosures

Kohler Company—Donation of HDPE

MATE—Hosting a terrific competition and for being a great resource

Midwest ROV, LLC—Technical support and monetary donation

MSOE—For covering registration and providing excellent faculty

MSOE RPC—Donation of 5 printed motor housings

SupplyOne—Monetary donation

TDK-Lambda—Donation of 3 DC/DC regulators

UWM Freshwater Science—For technical support and use of facilities

Vogt Family—Providing a pool for practicing

Thank you to our Faculty Advisor, Dr. Darrin Rothe, for guiding and supporting us throughout this project. Last but certainly not least, we would like to thank our families for providing us with moral support and for their willingness to help us in any way!

Safety Checklist

	Required Action
	Put on safety glasses
	Make sure the dry housing cover is secure and sealed
	Ensure all wires, motors, propellers, and material are securely fastened
	Check that there are no exposed sharp edges
	Ensure that motor guards are in place and are guarding the propellers
	Make sure that bare wires are not exposed
	Uncoil tether
	Check that 40 amp fuse is in place
	Double check the point of attachment to power source
	Double check the point of attachment to ROV

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