ZO_3 Robotics, Inc.

Ozaukee High School,
Fredonia,Wisconsin

Oostburg High School,
Oostburg, Wisconsin

MATE

Thunder Bay
National Marine
Sanctuary
Proposal

2014

Employee Directory

Evan Lallensack, CEO

Joseph Ceranski, Assistant Programmer
Ben Conine, Web Design
Zac Dulmes, Mechanical Engineer
Ian Ecclestone, Mechanical Engineer
Erin Hoffmann, Business
Alex Huibregtse, Mechanical Engineer
Jackie Janik, Technical Writing
Roman Katzer III, Tooling Engineer
Jason Kuntsmann, Accounting

Jacob Dulmes, COO

Bryan Lammers, Mechanical Engineer
Justin Mentink, Mechanical Engineer
Zenyse Miller, Technical Writing
Becca Paulus, Business
Matthew Stokdyk, Technical Writing
Josh Vogt, Assistant Programmer
Zach Vogt, Electrical Engineer
Jake Wagner, Course Engineer
Liz Weidert, Business

Mentors

Mr. Brad Doro, Mathematics
Mr. Chris Hartzell, Business
Mr. Terry Hendrikse, Science
Mr. Dustin Richter, Technical Writing
Ms. Leah VanMinsel, Mechanics
Mr. Randy Vogt, Electronics

May 28th, 2014, International Revision

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ABSTRACT

Returning for a fifth year, ZO_3 Robotics Inc. has again set out to construct a specialized remotely operated vehicle for the MATE International Robotics Competition. This craft, affectionately known as Black Widow, has been built specifically to explore shipwrecks of the Great Lakes. Widow is able to test for liquid conductivity found within wrecks, sample nutrient-rich agar from the depths of the lake, and retrieve artifacts from a ship's remains. To accomplish these tasks, ZO_3 has custom built a hydrodynamic high-density polyethylene frame designed specifically for the instruments needed to be successful in the mission. Essential instruments include a dexterous and fully-functional gripper system, used to retrieve artifacts from the wreck; a conductivity sensor, used to test liquid salinity through conductivity; and a 3D-printed auger, used to harvest biological samples from beneath the lake. Powered by twelve motors and equipped with eight full-color cameras, Widow is able to navigate underwater environments with difficult to match agility and precision. ZO_3 has programmed Widow entirely with student-written coding and has thoroughly embraced its underwater success. The ROV is managed entirely through its onboard microcontroller, receiving commands from the topside pilot who utilizes both a PlayStation DualShock 2 controller and a computer keyboard. ZO_3 has found repeated success due in large part to its strong business orientation; taking on a corporate structure that is perfectly suited to our needs has helped us immensely. Created for speed, safety, and love of exploration, Black Widow is the pinnacle of ZO_3's enthusiasm and hard work.

COMPETITION MISSION

The Great Lakes serve as a beneficial resource to the economy as well as the environment, and conserving the lakes is no small effort. The marine environment of the Great Lakes boasts astonishing diversity as a fresh water habitat, containing a number of micro-ecosystems that require careful conservation. One such area is Thunder Bay in western Lake Huron, aptly nicknamed "Shipwreck Alley" because of consistent shipping tragedies in and around its waters. Shipwrecks reveal valuable information about the local ecosystem as well as the Great Lakes system as a whole. In an act of protection and long-term preservation, the Thunder Bay National Marine Sanctuary (TBNMS) has begun researching how these artifacts are being changed chemically, biologically, and physically over time.

Figure 1: A shipwreck of Thunder Bay

To aid in this research process, the TBNMS has commissioned a high-quality Remotely Operated Vehicle to survey the sites. ZO_3's Black Widow has been built specifically with these tasks in mind. While scouting a recently discovered shipwreck, the ROV is able to measure the ship, conduct a sonar scan, determine the ship's cargo, and return artifacts containing dates and historical significance from within the ship to the surface. Using all of this information, the ship's name, along with its home port, can be determined by ZO_3's topside team. To measure the health of the surrounding environment, Widow is able to sample groundwater for conductivity, sample a microbial mat, and estimate the local zebra mussel population. To establish permanent health for the local environment, Black Widow has been equipped with tools that enable it to replace a sensor to monitor local underwater activity. To help maintain environmental purity, Widow can remove litter and other debris from the wreck site with ease.

CORPORATE PROFILE

As ZO_3 is split between two schools, a coherent and well-functioning business approach had to be achieved quickly. Striving for efficiency, ZO_3 has developed a structured and individualized approach to business management. The company is split into two primary branches: Business and Engineering. Ozaukee student Evan Lallensack, Chief Executive Officer and team member of three years, is leader of the Business Department. Oostburg student Jacob Dulmes, Chief Operating Officer and team member of two years, heads the Engineering Department. Sharing executive power between the two branches has streamlined decision making while also encouraging communication between the different sects of each branch. This approach has given each school an equal voice in Widow's construction while also playing on the specific talents of each half of the team.

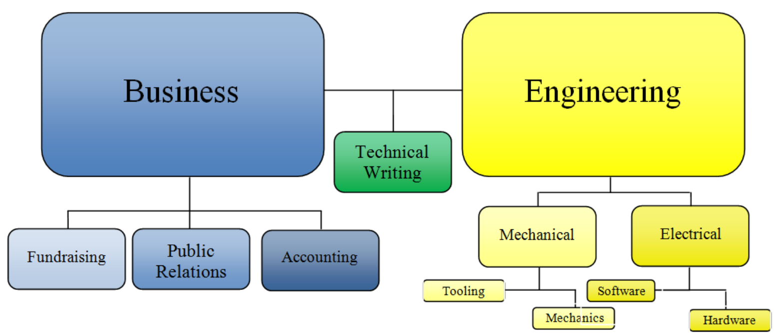


Figure 2: ZO_3's corporate Structure

The Business Department is in charge of all financing and public relations. Sub-departments include Fundraising, Public Relations, and Accounting. Fundraising, headed by Erin Hoffmann, is responsible for seeking donations and operating money-making ventures. Those active in Public Relations operate the company website and are chiefly responsible for making the poster. Accounting, done solely by Jason Kuntsmann, tracks all business expenditures accrued by the other departments.

The Engineering department is split into two sub-departments: Electrical and Mechanical. Electrical Engineering, directed by pilot Zachary Vogt, is in charge of all software and electronic wiring and is stationed primarily in Ozaukee. The Mechanical department, staged in Oostburg, is in charge of the physical structure and working components of the ROV, including frame and tool specifications.

Within both departments exists a distinctive sub-department, Technical Writing. Lead by Matthew Stokdyk, the responsibilities of the team's technical writers include composing the technical report, supplying information for the poster and website, writing press releases, and offering support for the business department when penning official documents.

ZO_3 firmly believes that the best ideas surface when more talented individuals are involved in the creation process. By creating a complex and specific business structure, ZO_3 has been able to achieve high quality results for many years. Through this system, each individual is able to achieve great things, in turn allowing the company to achieve as well.

DESIGN RATIONALE

Due to the tooling diversity required for full shipwreck exploration, ZO_3 was determined to add a new level of complexity to the design of the ROV. A focus on versatility and efficiency was heavily emphasized. The company constructed the craft with the mission in mind, manufacturing multiple tools specifically for mission tasks. Aesthetically, inspired by the "fangs" of the conductivity sensor on the front of the ROV, the team named the machine Black Widow. Following that theme, the ROV maintained a black and red color scheme while subtly incorporating the iconic Black Widow hourglass wherever appropriate.

Frame

The first component of Widow addressed was the frame. Serious consideration was given to reusing the frame from last year's craft, Nemo. Ultimately, the team decided to forgo the possible structural risk involved with modifying the existing frame. Moreover, ZO_3 was motivated by a wish to fabricate a new, superior frame.

Several designs were proposed to reinvent the ROV, including an "H-shaped" model that featured a hard, polyurethane and aluminum body. When the mission details were announced, the company was given greater insight into what the frame had to accomplish and the instruments it had to carry. The design that was finally settled upon utilized many ideas from Nemo's frame while still taking in some of the concepts brought forth by the "H" design. The H design helped break the team away from the cubical design set forth by Nemo, lending a longer, rectangular body and a custom cut-out of the Black Widow hourglass to the frame design.

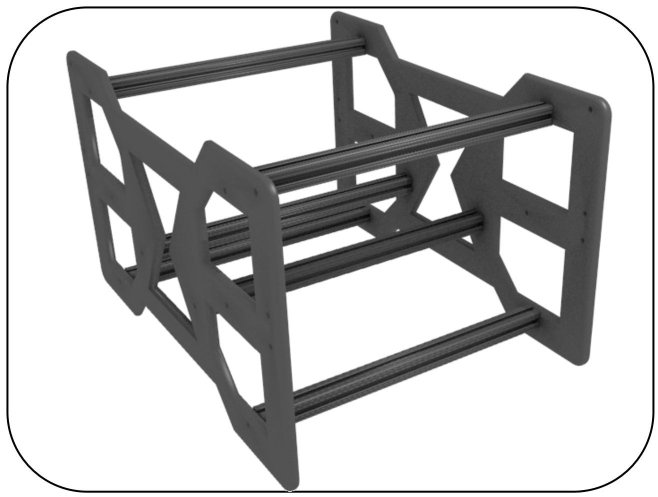


Figure 3: A render of Black Widow's frame

Because of its reliability in the past, the team chose to construct the frame from High-Density Polyethylene. HDPE creates a strong yet functional frame due to its high tensile strength and density near that of water, allowing for a sturdy frame with little impact on the craft's buoyancy. The black coloration of the frame, as well as the patterns cut into its side, add to the aesthetic of the craft by keeping with the "black widow" theme.

The HDPE that composes the sides of the frame is 1.25 cm thick. Both sides of the frame are identical sheets cut to a length of 60 cm and a height of 35 cm. The sheets are joined by bars of 80/20 aluminum, giving the whole frame a width of 40 cm. The inclusion of 80/20 cross members helps to stabilize the sides of the frame while also providing versatile tool mounts.

Dry Housing

The dry housing, Black Widow's "brain," is an IP68 rated Integra Enclosure donated by Integra in 2013. It efficiently stores all vital electrical components of the ROV, specifically its microcontrollers and motor boards, and was chosen for its reliability in preventing water intrusion. The only connections in and out of the enclosure are the SubConn bulkhead connectors, which are completely sealed against the water outside of the housing with gasket sealer and epoxy. The lid of the housing is fastened securely with screws and reinforced with silicone sealant normally used for waterproofing boat engine components. ZO_3 takes extra care to ensure a completely waterproof seal, double checking it before each pool run.

The dry housing not only guarantees the safety and functionality of Widow's electrical components but also a calculated buoyancy that keeps the ROV neutral while underwater. The largest dry housing to date, the Integra enclosure measures in at 25.4 x 20.3 x 15.4 centimeters for a total volume of 7.866 liters. This large volume helps to offset the weight of the tools and frame, allowing for a nearly neutrally buoyant ROV. The dry housing is fitted at the top of the craft to allow easy access to the tether. This placement also lends additional stability to the craft. By focusing the positive buoyancy of the dry housing at the top and keeping the heavier elements mounted on the bottom, Widow's center of gravity is kept low while in the water, keeping Widow stable during all movements.

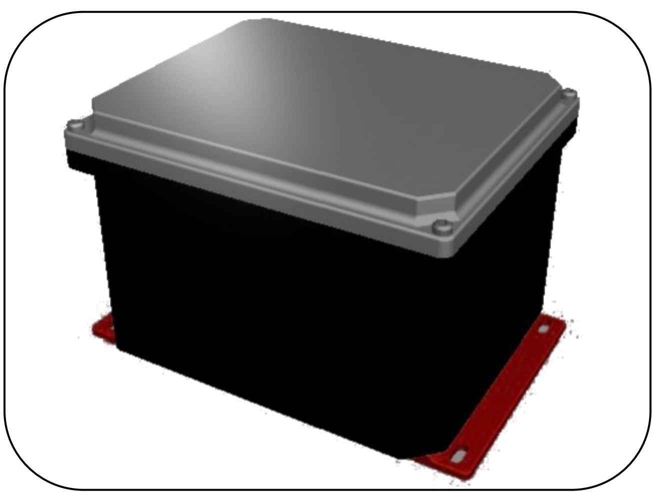


Figure 4: A CAD drawing of the dry housing

Bulkhead Connectors

Black Widow's dry housing features six SubConn bulkhead connectors, donated by SubConn in 2010 and 2011. The bulkheads provide a secure, waterproof connection from the tether to the dry housing, allowing information and power to be relayed without damaging the electrical components of the craft. Each connector is secured with Blue RTV Silicone gasket sealer and 3M Scotchcast 2130 epoxy to ensure a flexible yet reliable seal.

Figure 5: Black Widow's bulkhead connectors

Widow receives its electricity from the largest of the connectors, a two-pin bulkhead rated for 25 amps of continuous current. The craft's onboard microcontroller communicates with the surface through a CAT5 Ethernet cable fastened to an eight-pin connector. Additional data, chiefly signals sent to the motors and information incoming from the outside sensors, are sent through Widow's four 16-pin, 18 AWG connectors.

The bulkheads also provide the ability to quickly and easily disconnect the dry housing and its components, which proves useful every year as the craft is torn down and reconstructed to suit new missions, preventing possible damage to the components within the dry housing.

Tether

The tether, Widow's only lifeline, is an essential part of the ROV. Fitted at the top of the craft to avoid entanglement and increase maneuverability, the tether binds cables that reach every onboard system. The tether was sized at eighteen meters in length to allow Widow to travel 3.5 meters under the surface of the water or to a maximum of 4.42 meters from the control table. The tether is wrapped in a protective plastic shroud and fitted with buoyant foam every 40 centimeters, ensuring positive buoyancy to further prevent entanglement. Binding the cables with a shroud prevents messy wiring while also allowing them to slide during operation.

Figure 6: Black Widow's tether, neatly coiled

The main power for the dry housing flows through an 8 AWG marine grade cable, which reaches from the topside power supply to the bulkheads, after which the dry housing distributes power accordingly. The video signals from the cameras are sent to the surface through the tether along their stock 28 AWG and 100 Newton sheer-tested cables. The shielding of the camera wires prevents excess energy generated by auxiliary forces from interfering with the analog video signals. Primary communication with Widow is facilitated through the SubConn CAT5 Ethernet cable that runs through the tether. The tether features only two non-electrical components. These components, matching 2.5 mm diameter plastic tubes, are responsible for sending air below the waves. One is attached to the depth sensor, giving it the ability to compare underwater pressure with surface air pressure. The other exists in case of emergency, in the event an air-lift bag would need to be inflated to raise the ROV.

Propulsion

Maneuverability and movement were key concepts addressed when determining the design of the ROV. To maximize movement, twelve Tsunami 1200 bilge pumps have been converted into thrusters using prop shaft adapters and Octura 1250 and 1250r propellers. This combination of adaptations provides the most efficient operation in terms of the power produced to power input ratio. Each motor efficiently produces 7 Newtons of force while consuming only 4.2 amps of current. All motors are mounted inside the frame to prevent entanglement during the mission and transportation.

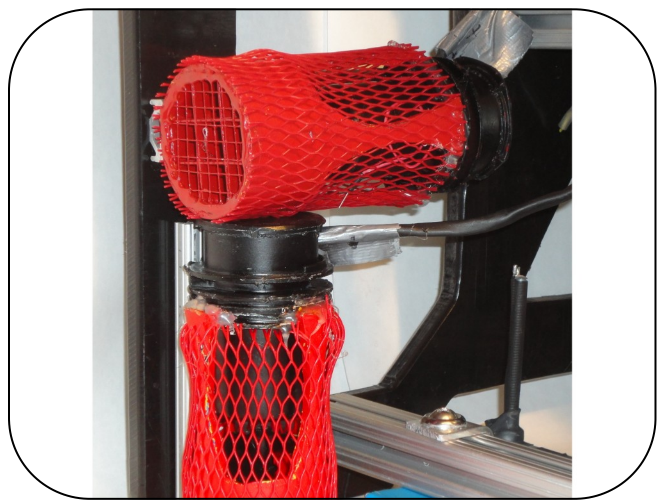


Figure 7: Two of Black Widow's Tsunami motors

To maximize stability and speed, four motors are assigned to each type of directional movement (up/down, left/right, forward/backward). All are mounted symmetrically, with the exception of "left/right" motors. These two motors, near the front of the ROV, are placed higher to accommodate additional tools, simultaneously focusing weight in the rear-bottom of Widow for buoyancy focusing. All motors counter-rotate with their symmetrical partners. All motors are mounted in-series, with the exception of the left/right motors, which are mounted in parallel to aid with strafing.

Each motor uses approximately 50 watts of power with 4.2 amps of current at 12 volts. When all forward/backward motors are fired, they use approximately 16.8 amps of current. As 25 amps are allotted, the thrusters fall well short of the required limit, even considering the current used by the electronic components of the craft. With this limited power, the motors can generate up to 28 Newtons of force. According to Newton's 2nd Law, the ROV can accelerate at 1.544 m/sec^2 in all directions.

As a safety precaution, each motor is enclosed in a motor guard within the frame of the ROV. These guards, comprised of eggcrate mesh, PVC tubing, and plastic shrouding, prevent objects and appendages from becoming trapped within the spinning propeller. The guards are filed down to reduce friction and aid in fluid dynamics.

Control System

Hardware

Focusing on precision and accuracy is essential for any capable ROV. Having found success in the past with Arduino microcontrollers and Pololu motor controllers, ZO_3 continued their use for the 2014 mission.

Widow's seven Pololu 15V18 motor controllers are responsible for moderated power to all thrusters, servos, and actuators. These controllers allow the pilot to manually adjust the settings of each element. Manual adjustment allows the power and polarity of each motor to be adjusted independently. Each controller can provide a maximum of fifteen amps, at up to eighteen volts, and comes with a 150 µf capacitor built-in to filter excess electrical noise.

The motor controllers fall under the control of Widow's Arduino MEGA Microcontroller. The microcontroller manipulates the motor controllers by releasing Pulse-Width Modulated (PWM) signals. The Arduino adjusts the duty cycle (the ratio between the "on" and "off" time of each pulse) of these signals to the change the power sent to the motor boards, allowing for precise control of each element. Featuring 54 input/output pins, sixteen analog pins, 128KB of flash memory, and a 16MHz

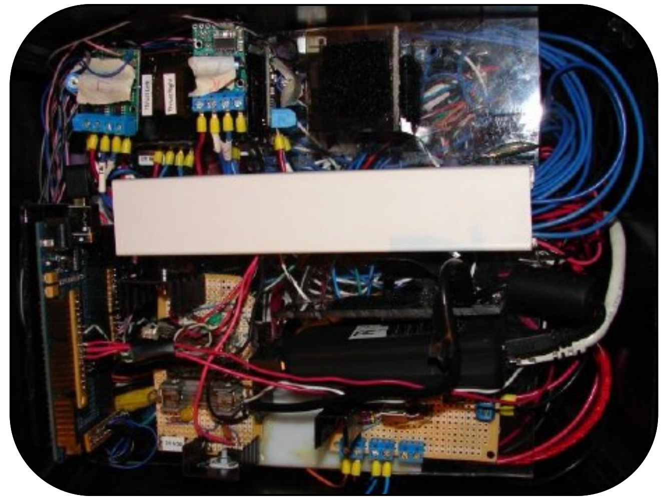


Figure 8: An interior view of Black Widow's dry housing

Atmel processor, the controller boasts massive yet efficient power. Of the 54 digital pins, fourteen are used to send PWM signals, which control the thrusters and servos. Half of the sixteen analog pins are used to interact with sensors and probes, specifically the electrical sensor, depth sensor, and conductivity sensor. The Atmel processor and 128KB of flash memory enable Widow to process software commands without hesitation. In compliance with MATE specifications, the microcontroller is powered through an onboard 12V DC to 5V DC converter.

The ROV is manipulated with a laptop keyboard and PlayStation 2 DualShock 2 controller. The joysticks of the controller are used to drive the primary motion of the craft while the keyboard toggles Widow's modes.

Figure 9: A DualShock 2 controller

Software

ZO_3's custom software serves two crucial functions: to control the microcontroller and to translate data from the tools. The microcontroller software, written in C, is stored within Widow's 128 kilobytes of on-board flash memory. The code allows the microcontroller to communicate with the motor controllers, which are responsible for the craft's propellers and grippers.

The software collects analog signals from the depth sensor, current sensor, and Arduino's accelerometer. The signals are then converted to a digital signal on the topside laptop's graphical user interface (GUI). These readings from the laptop's software communicate with the microcontroller and aid the pilot in determining position, orientation, and stability. Multiple aspects of data are displayed simultaneously by overlaying them on the laptop. This enables the pilot to monitor both position and data. Prominent components of data displayed are thrust generated by each motor, current consumption, status of the instruments, craft depth, and forward orientation. The laptop then interprets, commands, and toggles accordingly when it receives input from the DualShock 2 controller or keyboard.

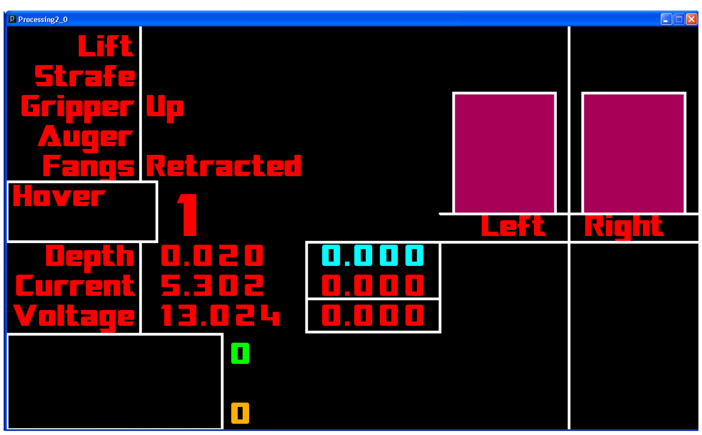


Figure 10: Student designed GUI displaying multiple vital signs as well as thruster power

Modes

To be properly equipped in all mission situations, ZO_3 has given Widow multiple modes of operation that alter the basic functions of the craft to enhance certain maneuvers. For example, "hover" mode suspends Widow in the water, much like a spider hanging steadily on a web. Hover mode is enabled primarily by the depth sensor. Once activated by the "H" key on the keyboard, the craft is suspended at its current depth. This constant positioning is produced by the thrusters, which exert force in amounts parallel to the amount of change in depth to prevent movement and stabilize the ROV.

Activated by the "G" key, "ground" mode fires all thrust motors downward at 50% to settle the ROV at the bottom of the pool so movement can be restricted to lateral directions. "Precision" mode, activated by pressing the "P" key, reduces all thruster values to half of their original voltage. This allows the pilot to make fine movements while using the full range of the joysticks on the controller. A new background mode, "voltage," uses the electrical sensor to detect when voltage is approaching over-loading levels, at which point certain functions are cut to reduce voltage.

Finally, our programming has allowed the creation of a unique orientation selection feature, named "direction" mode. Activating a key assigned to direction mode allows the pilot to designate any side of the craft as "front." The variables within Widow's code instantly adapt so that the microcontroller reassigns input to a different side of the craft as "front." Though dominance often falls to the short sides of the craft because of the rectangular frame design, all sides are equipped with this function. Specific sides are easily determined by the background color of the GUI, which changes based upon the selection. This feature increases task efficiency and completion time because the pilot does not need to concern himself with turning the craft around or navigating sideways or backwards.

Video System

Through five years of trial, ZO_3 has discovered that maximizing vision during missions is a top priority. To accomplish this, Black Widow is fitted with eight full-color cameras that can see all sides of the craft as well as every essential tool used during the mission tasks.

Widow's cameras, donated over multiple years by AquaVu, were manufactured for ice fishing. Each camera broadcasts in an analog signal that transmits a desirably wide, 150 degree field of vision and displays in 480p definition. They were chosen specifically for their IP68 rating, their functioning depth of up to twenty meters, and their minimal and lightweight design.

The images gathered by the cameras travel through the tether to the topside, linking directly to the video -processing center. The center, a customized case, condenses the signals from the eight camera boards into three multiplexors, which are responsible for segregating video feeds for display purposes. The footage travels, via HDMI cables, to three, 81 cm (diagonal) Vizio video monitors. Arranged to surround the pilot, the leftmost monitor features four cameras focused on specific tools which aid in specific mission tasks. The rightmost monitor shows the displays from the cameras mounted on the cardinal sides of the craft. The center monitor, which can be toggled to suit current needs, displays only one feed, of the side of the craft currently specified as “forward” by the copilot.

Figure 11: One of Black Widow’s eight cameras

Grippers

Drawing inspiration from the gripper system developed for the 2013 mission, ZO_3 decided early in the design process to divide gripper functionality amongst multiple tools as opposed to a single, multi-use gripper. Widow features three grippers, each suited specifically for different tasks.

The strongest of the grippers is mounted vertically at the aft of the ROV. Powered by a linear actuator, the gripper weighs a massive 1290 grams, helping to focus the weight on the bottom rear of the craft. The strength provided by the size of the actuator allows the gripper to move cumbersome props such as the anchor line with ease while its weight and placement help define Widow’s buoyancy.

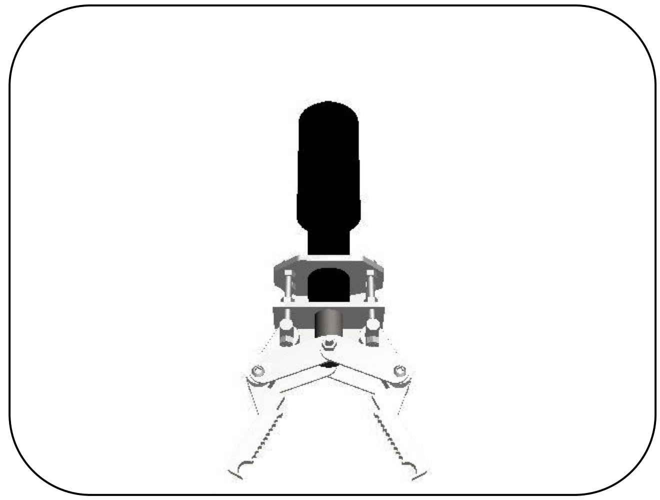


Figure 12: A CAD drawing of the linear actuator gripper

The most dexterous of the grippers is mounted opposite the linear actuator to help distribute functionality and mass. Much like a mandible, this gripper gives Widow an extra degree of motion in addition to the ability to clamp onto objects. Mounted horizontally, the gripper allows props to be retrieved quickly and precisely, including those that are subsurface to the craft. The mandible is controlled by two Savox servos that are IP67 and are able to generate 28.322 Newton-centimeters of force. The gripper action is moderated by a servo

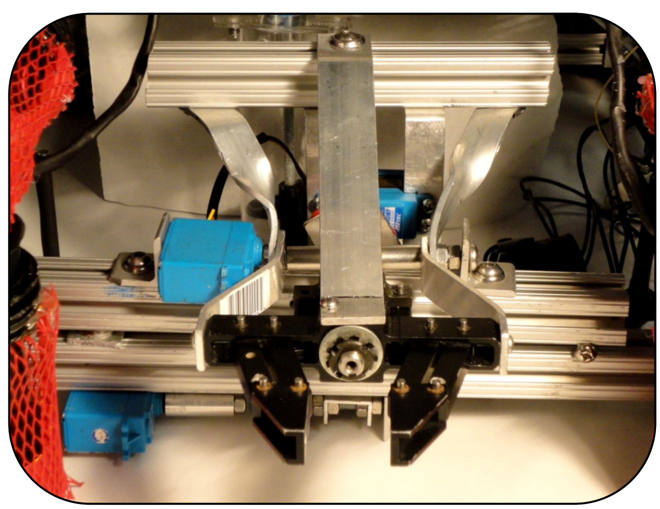


Figure 13: Black Widow’s “mandible” gripper

mounted at its base, rotating a drive that clamps the claw shut. Its ability to reach subsurface is granted by a servo mounted near its attachment to the craft that shifts the entire gripper downward via 80/20 aluminum bars.

The final and most simplistic gripper is mounted on the underside of the craft. Nothing more than a hook and latch operated by a servo, this gripper is another innovation carried over and modified from last year's Nemo. Its only function is to carry the basket, a device used to lift collected props to the surface. Bringing the basket down on the hook gripper allows the stronger and more dexterous tools to remain free for more specialized tasks.

Figure 14: The hook-and-latch gripper

Agar Extractor

ZO_3 decided early on that its approach to agar extraction would be simple. Plans were made in the early design phases for an auger, much like one that burrows through the ice on a lake while ice-fishing. Finding that a metal auger would be too heavy, easily rusted, and requiring modification, our engineers decided to model and 3D print a custom auger instead. After multiple attempts, a short size was settled upon to minimize weight and expedite construction.

Made from acrylonitrile butadiene styrene (ABS), the auger itself measures approximately 3.81 cm in

Figure 15: The agar extractor

length. The helix is protected by a Plexiglas tube approximately 15.24 cm in length, allowing space to store agar that is brought from the mat. The bottom of the auger's helix is flush with the edge of the tube, with a point protruding beneath the edge. The auger is spun by a Savox servo that is mounted atop the pipe on a sheet of Plexiglas. When Widow is above the sample, the entire craft lowers and enters "hover" mode as the auger is inserted into the microbial mat. After it has returned to the surface, the servo runs in reverse to empty the contents of its casing, a maximum of 235 mL.

Figure 16: A render of the servo and the aluminum adapter (grey) developed to connect the servo to the auger

Measuring Rule

Multiple devices were suggested while brainstorming methods to measure the length of the ship. Laser measurement was a popular idea but was ultimately replaced by a simplistic solution: a tape measure. With neodymium magnets and a plastic ring fitted to its end hook, the 4.88 meter tape measure easily attaches to the screws that hold the shipwreck together, remaining attached even when Widow moves directly backward. The markings on the tape are clear enough in water to guarantee an accurate reading for the copilot. To remove the magnetic clasp, the pilot simply has to adjust Widow's angle to lessen the grip the neodymium has on the screws, lifting to remove the ring. Because of the spring loading within, the tape measure collects itself. The magnets then loosely bind to the casing of the measure, holding it shut.

Basket

When the team learned that a large number of objects would have to be retrieved and returned to the surface, it became clear that making repeated trips up to deliver the artifacts would waste precious mission time. To rectify this, it was decided that Widow would carry a basket to the pool bottom, where it would place all props for easy transport to the surface. The design of the basket draws inspiration from the Acoustic Doppler Current Profiler prop from the 2013 mission, as it features a milk crate with top handle that attaches to the bottom of the craft using a hook and latch gripper.

Sensors

Depth Sensor

One of Widow's most useful functions is its "hover" mode, which allows it to dynamically suspend itself in the water. In order to accomplish the calculations responsible for this, we employ a Keller submersible level hydrostatic depth sensor. The sensor emits data in an analog signal, which ranges from zero to five volts in up to six meters of water. A Wheatstone Bridge within the sensor gauges water pressure, relaying data to the dry housing. Within the housing, the onboard Arduino microcontroller calculates the data, displaying it in real time on the topside GUI. The readings are accurate to within two hundredths of a centimeter. The microcontroller is unable to detect the full sensitivity of the device, however, as it is only able to read analog values between zero and five volts (approximately .0049 volts per its 1024 units). Despite this, the microcontroller and sensor retain accuracy to within two centimeters, which is sufficient for maintaining stability. The accuracy and reliability of this system, proven through dozens of pool runs, has reaffirmed its value to the ROV.

The depth sensor serves another, mission-focused purpose this year. Because of the difficulties in measuring the horizontal length of the ship, ZO_3 engineers knew a measuring rule would be inappropriate for measuring the vertical height of the wreck. To remedy this, the depth sensor is utilized to measure the vertical distance through Widow's descent. By beginning at the top of the wreck and moving to the pool floor, the pilots are able to calculate the height of the ship to an accuracy of a few centimeters.

Figure 17: The depth sensor

Electrical Sensor

To avoid the risk of blowing the main 25 amp fuse, the team employed an electrical sensor to monitor the ROV's current intake. Capable of continuously measuring 30 amps and 50 amps for up to one second, the electrical sensor works in conjunction with the Arduino microcontroller. The microcontroller reads the analog values output by the sensor and displays the current values on the laptop screen. The Arduino's code stops sending current to the thrusters and the linear actuators when it reads 23 amps or greater to avoid blowing the fuse.

To prevent the microcontroller from being overloaded, the electrical sensor is equipped with a voltage divider. This divider features two resisters of 66,300 ohms and 27,400 ohms to reduce the incoming voltage to a range of 3.5 to 4.0 volts, as the microcontroller accepts a maximum of five volts.

Conductivity Sensor

The environment that exists in and around a shipwreck can be determined by a number of factors, including the conductivity of the water venting within it. To measure the conductivity within the samples of water present in the mission, Widow has been equipped with a two probe conductivity sensor. Veritable fangs, the sensor is made from two electrical contacts that each contain an anode and a cathode, which lead back to the microcontroller for processing. The probes are mounted thirty centimeters apart on an aluminum bar that is affixed to a Savox servo. When given a command from the surface, the servo can lower or raise the instrument. When raised, the entire sensor is taken inside the frame of the craft, preventing exposed portions from being damaged.

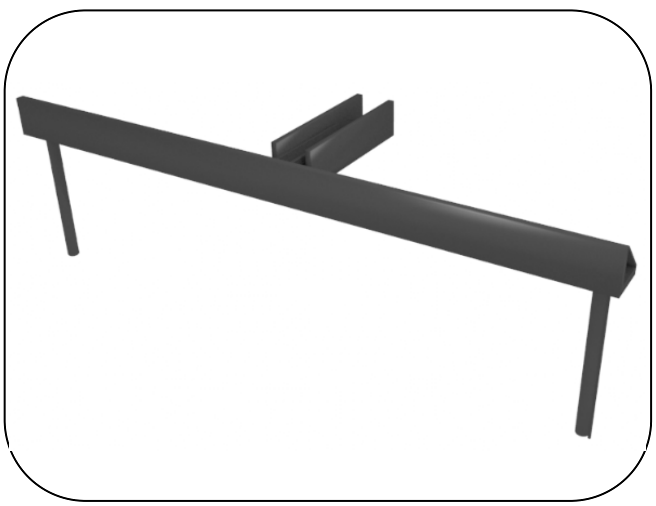


Figure 18: A render of the conductivity sensor

After being securely lowered, Widow descends over the two samples of water, puncturing the filaments that contain them. A minute electrical signal is sent through the anode in each of the prongs, which travels through the solution to the cathode. On the topside, a graph on the GUI displays the conductivity of two samples. Because the more saline solution offers less resistance in the current's travel, the graph uses Ohm's Law to compare the two samples, showing a clear difference between the saline and non-saline samples.

Design Theme

One of the first mission-specific tools designed was the conductivity sensor. When sketches were being drawn up of what the sensor might look like when mounted aboard the craft, several members of the team noticed a fang-like resemblance. Comparisons soon likened the craft to a spider, and the name Black Widow quickly emerged from the frenzy of ideas. The company, unanimously agreeing that an inclusive Black Widow theme would be unique and fun, decided early-on to pursue the theme.

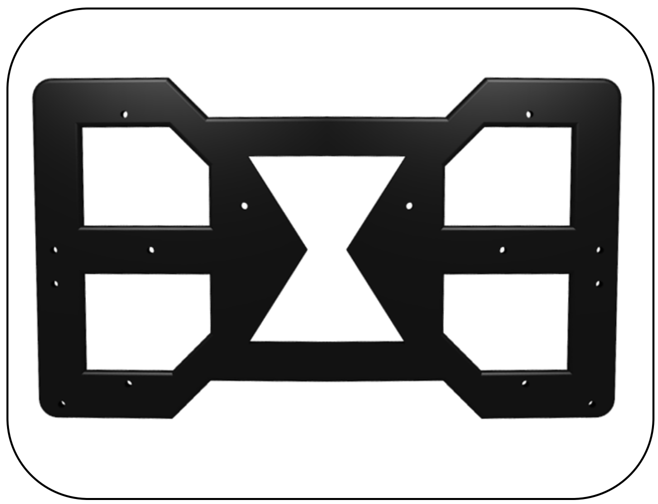


Figure 19: The hourglass shape is featured prominently in the frame design.

The black and red colors of the spider are perhaps the greatest quality borrowed for the construction of our ROV. ZO_3 selected black HDPE for the frame, the body of the spider. The distinctive hourglass shape iconic to the species is cut into the sides of the frame. The motor shrouds were painted red to match the tether and further the Black Widow coloration. On the topside, the GUI was recolored to a red on black interface. The team's colors became red and black, invading the shirt and poster. The company's logo was designed to feature the spider prominently. For the first time in team history, all elements of the company have been consolidated with a single unifying theme. The team takes great pride in the encompassing Black Widow motif, and believes it has given a sense of identity, camaraderie, and unity throughout the design process.

CHALLENGES FACED

Technical

ZO_3 experienced a number of failures involving 3D printing this year. Our initial attempts to create an agar extractor involved printing a 10 cm auger. The only printer available to the team was Oostburg High School's, a single extruder device. The tool was initially successfully printed, though the plastic scaffolding on which the printer built the device soon became an issue. Because of the helical nature of the auger and the thickness of the supporting latticework, clearing the space where the agar would have to slide became impossible, ultimately snapping the tool in half. A smaller version was later printed, proving ultimately more useful than a larger tool.

Learning from this experience, the team decided to begin printing the parts for a gripper, which would require less latticework. The strain became too much for the printer, however, breaking it. The team recovered quickly, resurrecting the main pieces of last year's main gripper and repairing the printer with purchased parts.

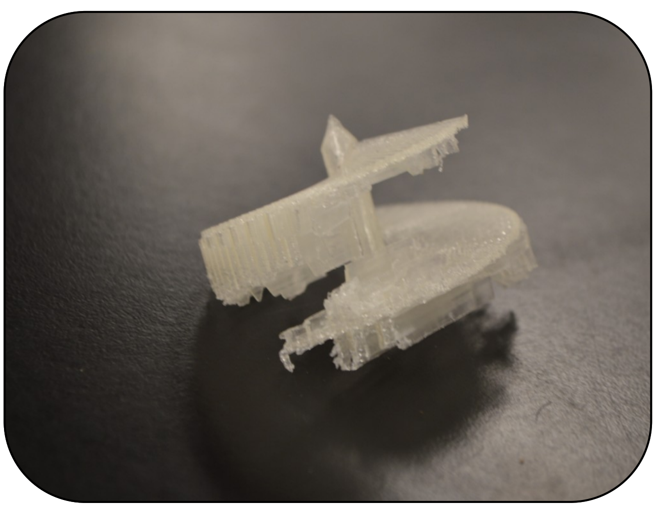


Figure 20: The broken, lattice-filled auger prototype

Interpersonal

Perhaps the greatest challenge faced by the team was distance. ZO_3 is split between two high schools that are 28 kilometers apart, making transfer of ideas and materials difficult. The corporate structure is perhaps the greatest example of how the teams were able to overcome this challenge. Executive power is split between both schools, as are company focuses. Ozaukee primarily addresses business endeavors, whereas Oostburg is responsible for a bulk of the engineering. Some students do overlap in these areas, so weekly meetings that alternated location between the schools were devised. Eager to embrace technology to expedite the construction and management process, ZO_3 relied heavily on digital communication through email, video conferences, and Google Documents.

TROUBLESHOOTING

ZO_3's troubleshooting method is one that is persistent and explores all avenues of resolution. When a problem arises, the company quickly assembles employees and works to collectively identify the problem. After identifying the issue, the team discusses possible solutions or alternative routes to achieve the goal. The solution that is most effective is then applied. If a measure fails, the process restarts.

Perhaps the clearest example of troubleshooting this season was the case of Widow's auger. Originally, the tooling engineers planned to use Oostburg's 3D printer to print the auger. After printing the first prototype, the designers realized that the single extruder of the printer was an issue, as the lattice that ran up the helix of the tool could not be removed without breaking it. Before a different design could be explored, the printer broke. In an attempt to create public outreach while also obtaining a functioning auger, we contacted a 3D printing and extrusion company, submitting our design for printing. Weeks after taking in the design, however, the company backed out. We identified that the broken printer was an obstacle that needed to be overcome, ordering the parts to repair it. After it was corrected, the modelers created a new design for printing, one that was shorter and required minimal latticing during printing. This new design is currently featured on the ROV and works exceedingly well for the difficult circumstances surrounding its creation.

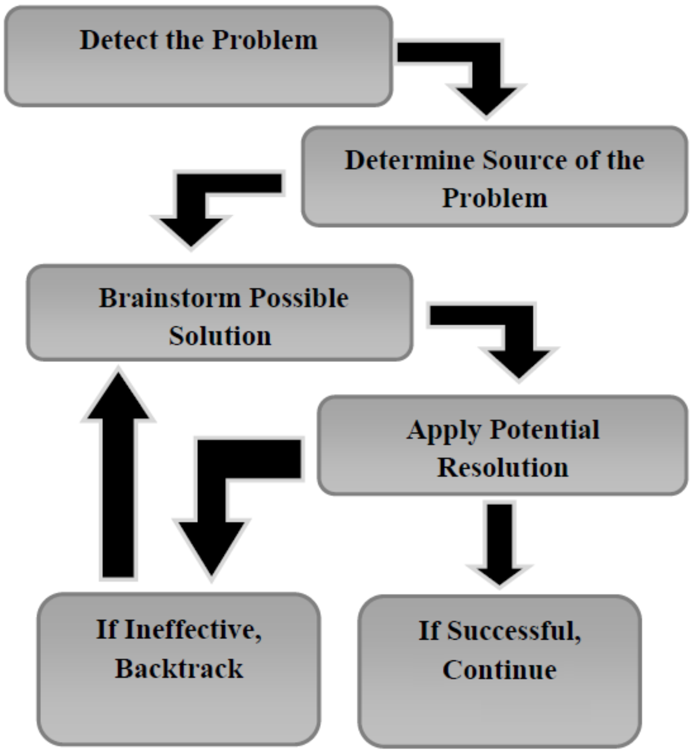


Figure 21: ZO_3's troubleshooting process

SAFETY

Though lethal venom isn't an issue with our Black Widow, it still has its fair share of hazards which must be accounted for. In order to guarantee the safety of the craft and its personnel, ZO_3 has taken a number of precautions to prevent both electrical and mechanical dangers.

The most important safety feature lies topside, at the very end of the ROV's tether. Thirty cm from its point of attachment, the tether ends in a 25 amp, single inline fuse. When securely attached to the power supply, the fuse monitors a steady, constant flow of current to the dry housing. In the event the fuse blows, damage to Widow will be minimal, as all the positive leads on the craft's components have been fused to prevent energy backlash. To manage the heat generated by the dry housing's electronic components, devices that draw high amounts of power were wired in parallel through the bulkhead connectors, dividing the current load through multiple cables. All possible leaking areas were thoroughly sealed.

Safety features exist for those working around the craft as well. All sharp frame edges have been rounded or marked as sharp and padded. Exposed electrical areas have been marked. The propellers are shrouded with modified PVC cylinders, rubber mesh, and Eggcrate wire light diffusers to prevent entanglement and skin contact, and are marked as moving parts. All team members are required to wear safety glasses and closed-toed shoes when operating or modifying Widow. Before each run, all safety components, from the fuse to our goggles, are checked to ensure universal safety.

	Pre-mission Safety Checklist
	All items attached to ROV are secure
	Hazardous items are identified and protection provided
	Sharp edges that have not been smoothed are marked
	Single inline 25 amp fuse is in place
	No exposed copper or bare wire
	No exposed propellers
	All wiring securely fastened
	Tether is properly secured at surface control point and at ROV
	All wiring and devices for surface controls are secured
	All control elements are mounted inside an enclosure
	On-deck team is wearing safety glasses and closed toe shoes

Figure 22: ZO_3's safety checklist

LESSONS LEARNED

Technical

This year has taught ZO_3 that the first idea isn't always the best solution. When designing the frame, many members of the team supported a design for an H-shaped body and polyurethane top. The idea gained steam very quickly, though multiple technical considerations, such as weight and buoyancy, were ignored in pursuit of an appealing design. When calculations were made, coupled with newly released mission details, ZO_3 was forced to reconsider its design and confront the plan's technical flaws. Drawing from this, however, the team was able to create a versatile and usable design.

Later in the process, during the creation of the auger, the engineers discovered that the initial, ten cm design of the tool was highly inefficient and difficult to produce. The team learned that investing time and resources into an idea that was not thoroughly thought-out, such as a heavy frame or a long tool, was ultimately impractical.

Interpersonal

No other time in company history has seen executive power split between two individuals, let alone two individuals from different schools. Because both candidates were equally capable of leading the company, a decision was made to split power and streamline decision making. This experiment has given ZO_3 a sharp increase in efficiency, a very valuable lesson to be applied to the future. Allowing both sides of the company, business and engineering, to function simultaneously in separate capacities has produced expediency in nearly every action.

FUTURE IMPROVEMENT

The team's greatest wish throughout this process has been to have more dexterous grippers. Though the gripper system improves in strength and range each year, the team is still met with limitations created by the hardware. Grippers that are more similar to arms, with many degrees of movement, are one of areas set for improvement in the future. Our current grippers are relatively simplistic, much like hands or claws instead of arms due primarily to lack of strength in servos. Stronger hardware will enable better grippers in the coming years. Our team is also consistently making advances with 3D printing quality, which will allow superior customization in future robotic appendages.

REFLECTIONS

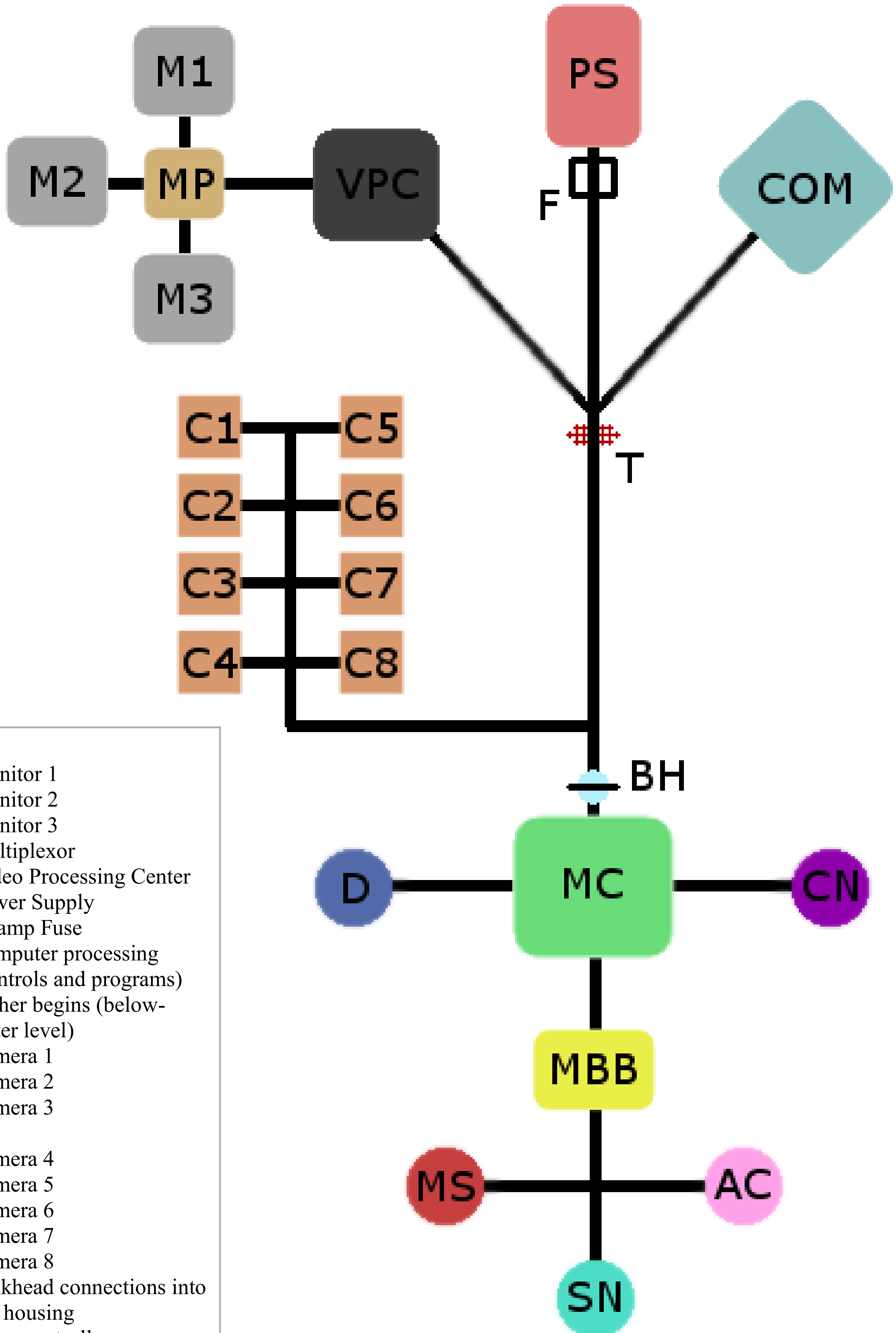
"Coming into my second year being on the ROV team, I knew it would bring about new experiences, but I didn't realize it would bring about an entirely new role on the team. This year I am the COO of the team and in charge of the tasks needed to be done by the Oostburg side. This leadership role taught me many skills including communication and being efficient. Communication was huge as our team is split between Ozaukee and Oostburg, so I had to communicate clearly with the CEO in Ozaukee on what needed to be done. Efficiency was also very important because I had to make sure everybody from Oostburg had a job and we were getting everything done as quickly as possible. This experience on the team has also been very influential to my future career path of becoming a mechanical engineer because we are constantly solving problems and creating new designs. This has all made the MATE ROV Competition one of my most influential activities throughout high school."

—Jacob Dulmes, COO

"Finding myself in charge of the technical report this year was quite the surprise. I had not expected a sudden increase in my responsibilities as a technical writer, nor was I prepared to lead the report's composition. Despite how uneasy I felt about it initially, inheriting this position has proven to be a tremendous learning opportunity. My talents have always been outside of the mechanical realm, so my membership on the ROV team often seems strange to the casual observer. Writing for the team, however, has given me an enormous amount of experience. It has honed a multitude of specific writing skills and taught me how to intensively revise my work. My interest in science waned in my early high school years, but it has been thoroughly renewed by this ROV program, greatly broadening the possibilities for my future."

—Matthew Stokdyk, Lead Technical Writer

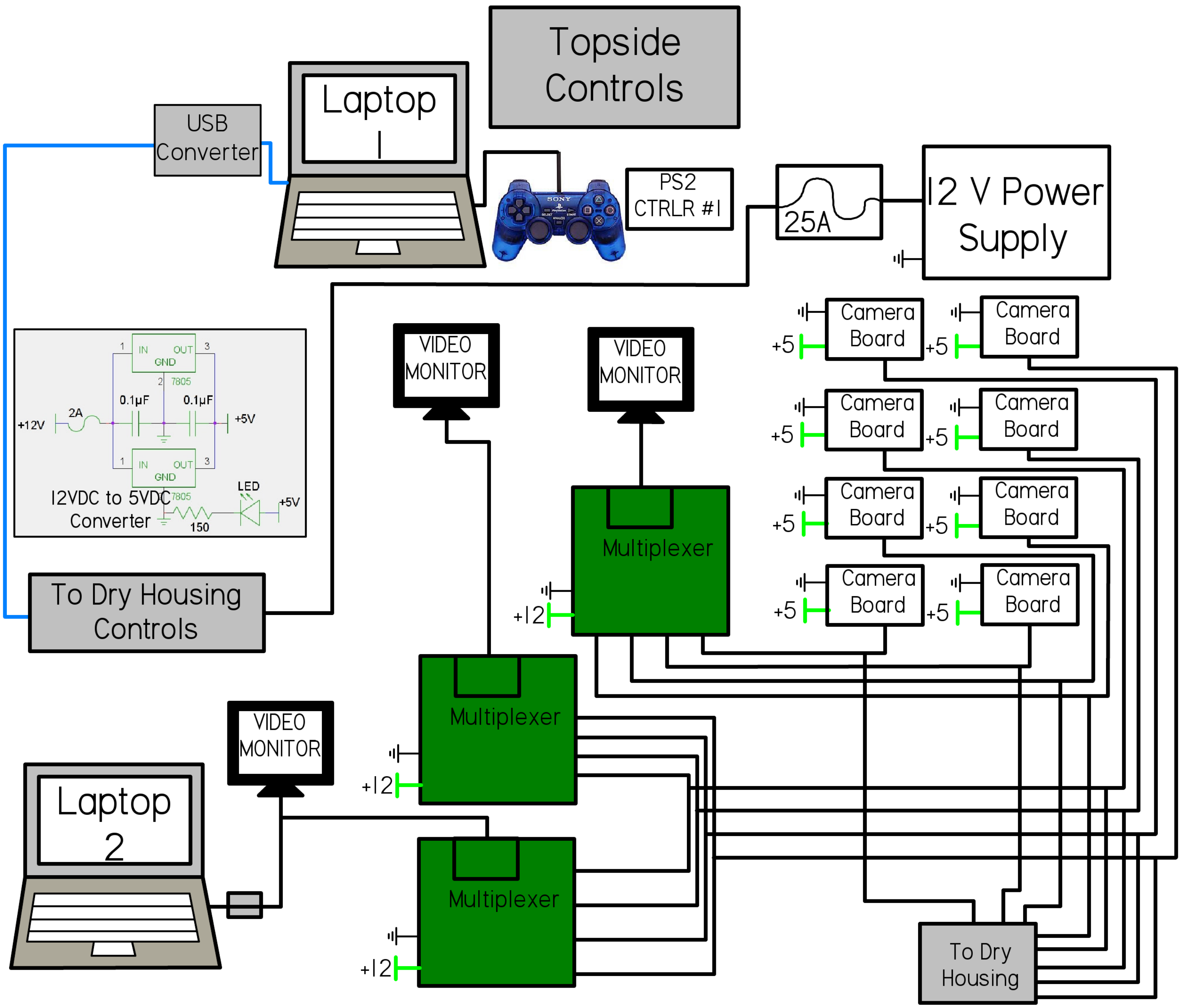
System Interconnection Diagram

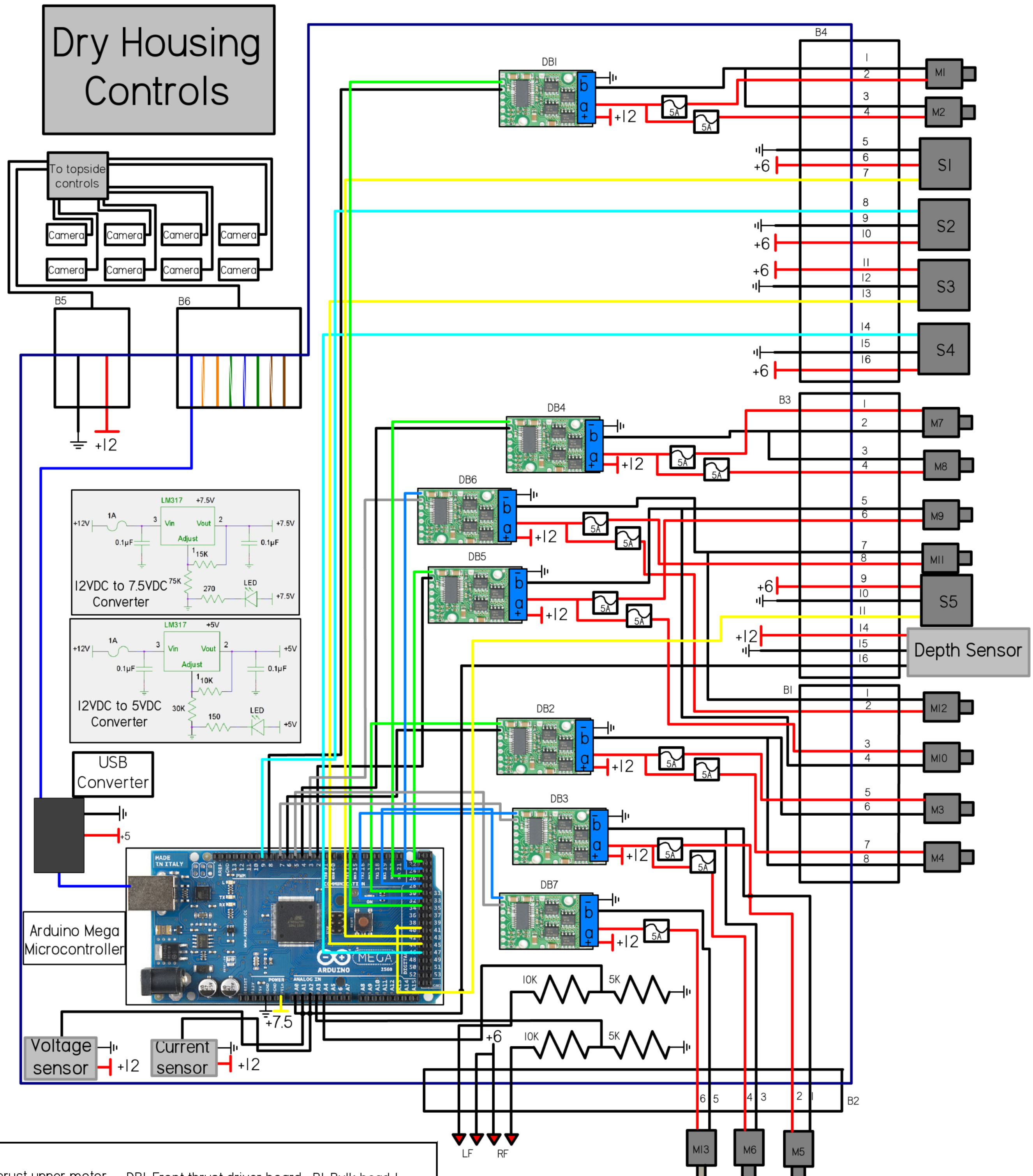


Legend

M1:	Monitor 1
M2:	Monitor 2
M3:	Monitor 3
MP:	Multiplexor
VPC:	Video Processing Center
PS:	Power Supply
F:	25 amp Fuse
COM:	Computer processing (controls and programs)
T:	Tether begins (below-water level)
C1:	Camera 1
C2:	Camera 2
C3:	Camera 3
C4:	Camera 4
C5:	Camera 5
C6:	Camera 6
C7:	Camera 7
C8:	Camera 8
BH:	Bulkhead connections into dry housing
MC:	Microcontroller
D:	Depth sensor
CN:	Conductivity sensor
MBB:	Motor board bank
MS:	Motors (12)
SN:	Servos
AC:	Actuators

Topside Electrical Schematic





Legend

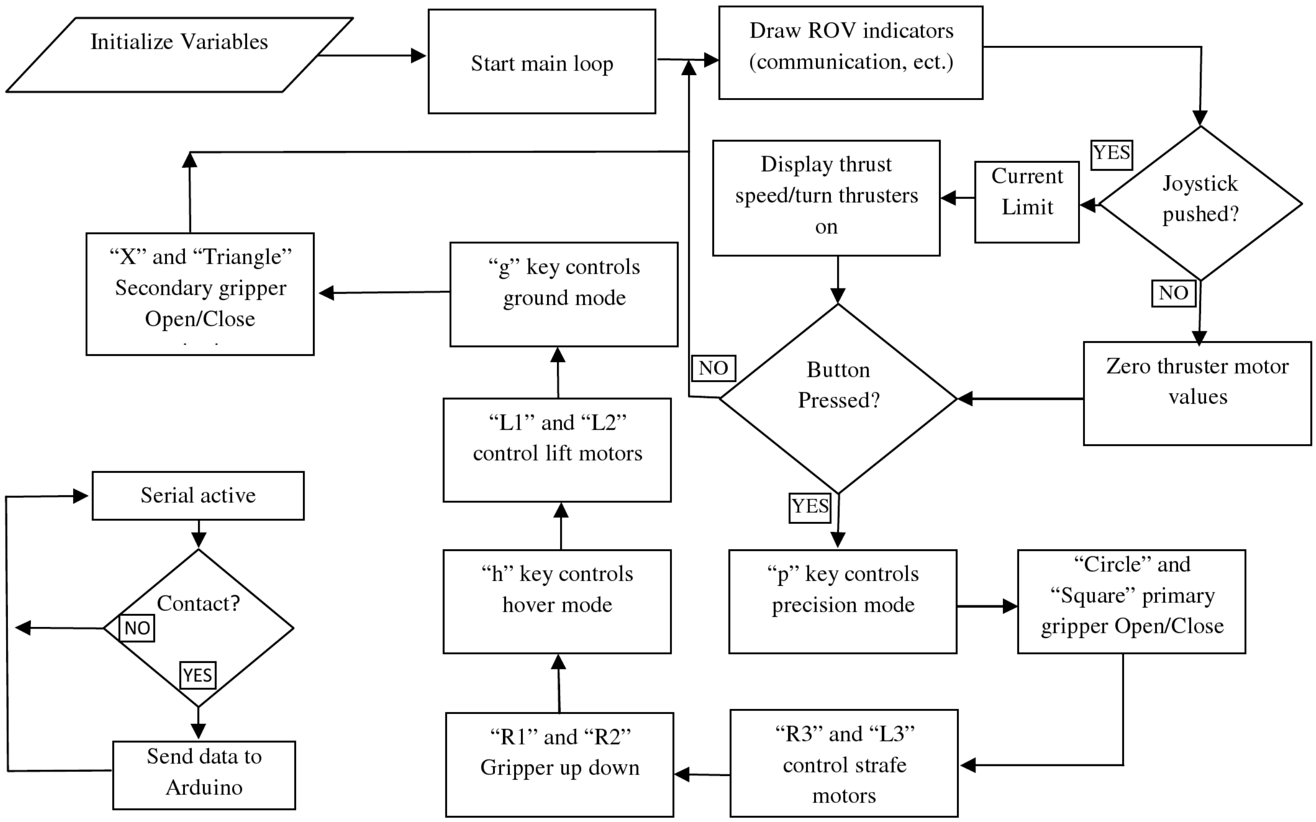
- M1: Front thrust upper motor
- M2: Front thrust lower motor
- M3: Right thrust upper motor
- M4: Right thrust lower motor
- M5: Back thrust upper motor
- M6: Back thrust lower motor
- M7: Left thrust upper motor
- M8:Left thrust lower motor
- M9: Front lift left motor
- M10: Front lift right motor
- M11: Back lift left motor
- M12: Back lift right motor
- M13: Gripper open close motor

- DB1: Front thrust driver board
- DB2: Right thrust driver board
- DB3: Back thrust driver board
- DB4: Left thrust driver board
- DB5: Front lift driver board
- DB6: Back lift driver board
- DB7: Gripper open/close
- S1: Gripper Up/Down servo
- S2: Auger servo
- S3: Gripper Open/Close servo
- S4: Hook servo
- S5: Fang servo

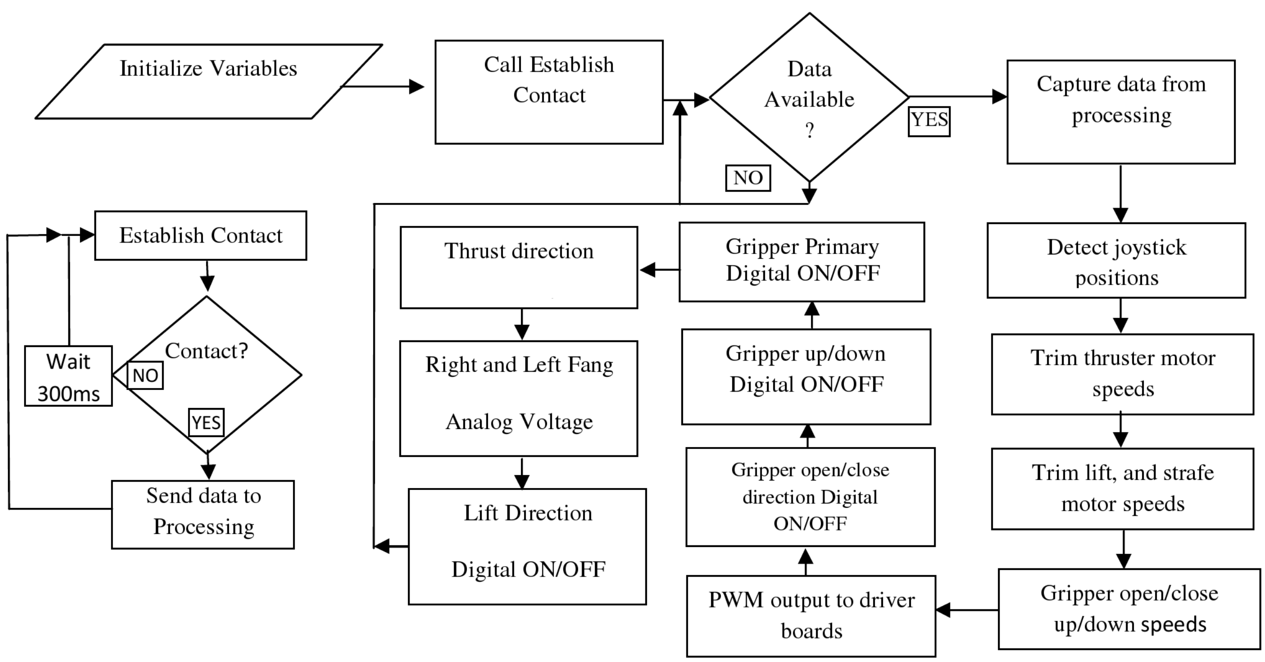
- B1: Bulk head 1
- B2: Bulk head 2
- B3: Bulk head 3
- B4: Bulk head 4
- B5: Bulk head 5
- B6: Bulk head 6
- MC: Microcontroller
- LR: Left Fang
- RF: Right Fang

Software Flowcharts

Processing Computer Code



Arduino Microcontroller Code



Black Widow Controls

Black Widow PS2 Controls

Rightstick	Right Thrust
Leftstick	Left Thrust
R1	Gripper Up
R2	Gripper Down
L1	Lift Upwards
L2	Lift Downwards
Triangle Button	Gripper 2 Open
X Button	Gripper 2 Close
Circle Button	Gripper Open
Square Button	Gripper Close
D pad up	Half Lift Upwards
D pad down	Half Lift Downwards

Black Widow Keyboard Controls

P Key	Precision Mode
H Key	Hover Mode
G Key	Ground Mode
The Four Directional Arrows	The Four Directional Modes
F Key	Extend and Retract Fangs
A Key	Take Sample and Deposit Sample
M Key	Opens and Closes Hook

Reused Parts Purchased or Donated in Previous Years

Year	Transaction	Description	Amount	Total
2009	Expense	Purchase of power supply	$ 78.68	$ 78.68
2009	Expense	Purchase of Arduino MEGA	69.99	148.67
2010	Expense	Purchase of USB hub and extender	91.83	240.50
2010	Material Don.	Attwood Marine donation of bilge pumps	138.00	378.50
2010	Material Don.	Lenco Marine donation of linear actuators	792.50	1,171.00
2011	Expense	Purchase of multiplexor	52.00	1,223.00
2011	Material Don.	Donation of propellers	43.47	1,266.47
2011	Expense	Purchase of depth sensor	263.00	1,529.47
2011	Expense	Purchase of motor drivers	170.00	1,699.47
2011	Material Don.	SubConn donation of bulkheads	500.00	2,199.47
2011	Expense	Purchase of additional bulkheads	372.15	2,571.62
2011	Material Don.	SubConn donation of bulkheads	500.00	3,071.62
2011	Material Don.	AquaVu donation of cameras	1,549.45	4,621.07
2012	Material Don.	Integra donation of dry housing	131.00	4,752.07
2013	Expense	Miscellaneous hardware	250.00	5,002.07
2013	Material Don.	Attwood Marine donation of bilge pumps	159.96	5,162.03
2013	Expense	Purchase of HiTec servos	210.46	5,372.49
2013	Material Don.	AquaVu donation of cameras	1,599.96	6,972.45
2013	Expense	Purchase of TV monitors	627.00	7,599.45

2013/2014 Budget

Date	Transaction	Description	Amount	Balance
		Initial Balance	$	$ 847.09
18/12/2013	Expense	Hardware purchase	39.76	807.33
18/12/2013	Material Don.	PVC piping donation from Stephan's Heating and Plumbing	22.04	807.33
23/12/2013	Material Don.	Black HDPE sheet from the Kohler Model Shop	89.70	807.33
31/12/2013	Monetary Don.	Fredonia Mobil donation	500.00	1,307.33
08/01/2014	Expense	Team t-shirt purchase	340.80	966.53
15/01/2014	Expense	Savox servo purchase	307.93	658.60
19/01/2014	Expense	Business cards	17.63	640.97
21/01/2014	Monetary Don.	Donation from Mr. Watry	100.00	740.97
22/01/2014	Expense	Metal auger	31.76	709.21
22/01/2014	Material Don.	80-20 aluminum from Neff Engineering	110.00	709.21
29/01/2014	Material Don.	Heat shrink wrap	24.45	709.21
02/02/2014	Expense	Hardware purchase	24.06	685.15
19/02/2014	Deposit	Candy bar fundraiser profit	564.00	1,249.15
21/02/2014	Expense	Assorted supplies	21.89	1,227.26
24/02/2014	Monetary Don.	Cargill C.A.R.E.S. donation	100.00	1,327.26
25/02/2014	Expense	Snacks	18.62	1,308.64
20/03/2014	Expense	Team t-shirt purchase	650.00	658.64
27/03/2014	Deposit	T-shirt reimbursement	650.00	1,308.64
05/05/2014	Monetary Don.	Monetary donation from Bemis	300.00	1,608.64
24/05/2014	Deposit	Brat fry profits	1,400.00	3,008.64

2014 Totals				
Reused	Expenses	Donations	Profits	Final Balance
$7,599.45	$1,452.45	$1,246.19	$2,614.00	**$3,008.64**

ZO_3 ROBOTICS MEMBERS

Figure 23: The Ozaukee members of ZO_3

Back row *(left to right): Joseph Ceranski, Zach Vogt, Jason Kunstmann, Ben Conine, Jacob Wagner, Evan Lallensack*
Front row *(left to right): Zenyse Miller, Jackie Janik, Becca Paulus, Josh Vogt, Liz Weidert*

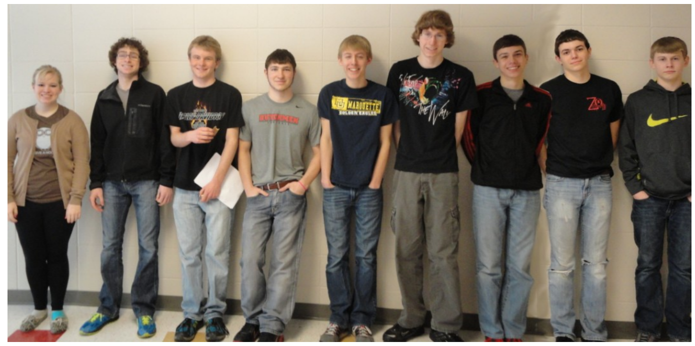


Figure 24: The Oostburg members of ZO_3

(left to right) Erin Hoffmann, Roman Katzer III, Ian Ecclestone, Bryan Lammers, Jacob Dulmes, Matthew Stokdyk, Justin Mentink, Alex Huibregtse, Zac Dulmes

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Figure 25 (left): ZO_3 rehearsing a pool run. The complete control setup can be seen.

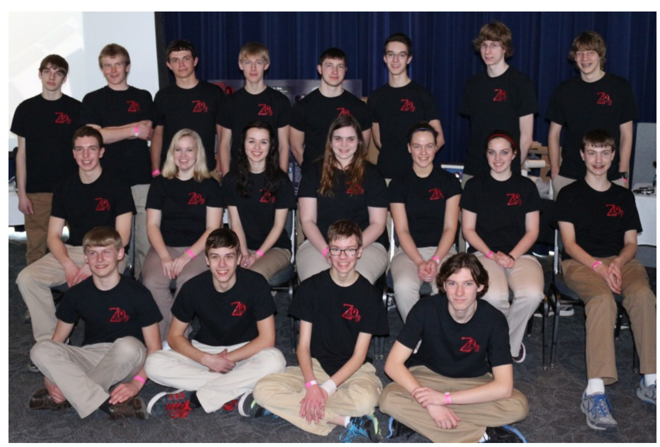

Figure 26 (right): ZO_3 after winning the regional competition, wearing matching team attire

Figure 27 (left): An early planning meeting, before Black Widow was constructed

Employee Roster

Employee	Position	Grade Level	Years on Team	School	Intended Major
Joseph Ceranski	Assistant Programmer	Freshman	1	Ozaukee	Undecided
Ben Conine	Web Design	Junior	2	Ozaukee	Chemistry
Jacob Dulmes	COO	Senior	2	Oostburg	Mechanical Engineering
Zac Dulmes	Mechanical Engineer	Sophomore	1	Oostburg	Undecided
Ian Ecclestone	Mechanical Engineer	Senior	2	Oostburg	Mechanical Engineering
Erin Hoffmann	Business	Junior	1	Oostburg	Music Education
Alex Huibregtse	Mechanical Engineer	Senior	1	Oostburg	Mechanical Engineering
Jackie Janik	Technical Writer	Junior	1	Ozaukee	Graphic Design
Roman Katzer III	Tooling Engineer	Senior	2	Oostburg	Paper Science Engineering
Jason Kunstmann	Accountant	Junior	2	Ozaukee	Chemical Engineering
Evan Lallensack	CEO, Co-Pilot	Junior	3	Ozaukee	Mechanical/Chemical Engineering
Bryan Lammers	Mechanical Engineer	Senior	2	Oostburg	Technical Education
Justin Mentink	Mechanical Engineer	Sophomore	1	Oostburg	Mechanical Engineering
Zenyse Miller	Technical Writer	Junior	1	Ozaukee	English
Becca Paulus	Business	Senior	2	Ozaukee	Finance
Matthew Stokdyk	Technical Writer	Senior	2	Oostburg	English
Josh Vogt	Assistant Programmer	Freshman	1	Ozaukee	Software Engineering
Zach Vogt	Electrical Engineer, Pilot	Junior	3	Ozaukee	Undecided
Jake Wagner	Course Engineer	Junior	2	Ozaukee	Mechanical Engineering
Liz Weidert	Business and Poster	Senior	2	Ozaukee	Design

Black Widow

Dimensions: 60 cm length x 40 cm width x 35 cm height
Dry Weight: 32 Kg
Approximate total cost (materials): $8,500

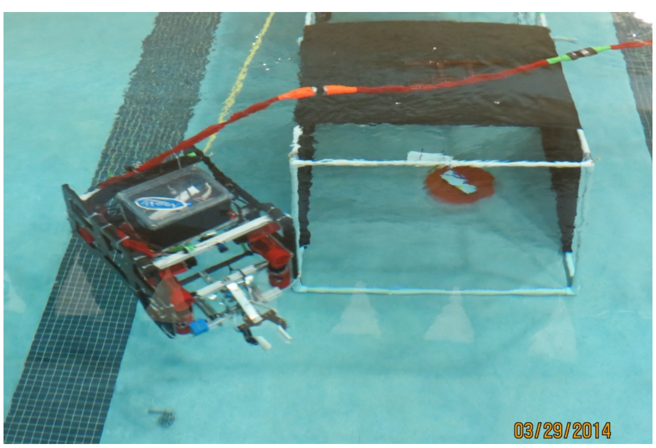

Figure 28: Black Widow in the pool

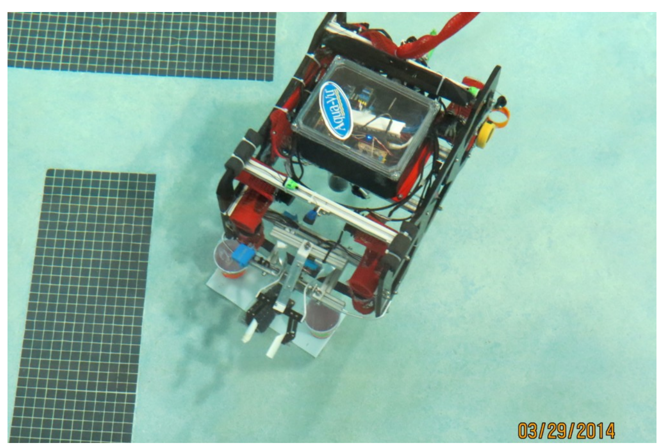

Figure 29: Black Widow interacting with the "venting" water

ACKNOWLEDGEMENTS

ZO_3 Robotics would like to thank all those involved in aiding the completion of our ROV through their donations of supplies, time, and insight.

AquaVu Video—Donation of cameras

Attwood Marine—Donation of Tsunami motors

Integra Enclosures—Donation of dry housing unit

Kohler Model Shop—Donation of HDPE

Lenco Marine—Donation of linear actuators

Neff Engineering—Donation of 80/20 Aluminum

Stephen's Heating and Plumbing—PVC piping and adapter donations

SubConn—Donation of bulkhead connectors

HiTec RCD USA, Inc.—Discounted price of servos

Polulu—Discounted price of motor boards

Bemis—Flat monetary donation

Cargill—Flat monetary donation

Fredonia Mobil—Flat monetary donation

Watry's Maintenance Service—Flat monetary donation

Janik Family—Providing a practice pool

Miller Family—Providing a practice pool

The Hartnett Family—Use of printer for poster

Families of Team Members—For support

Oostburg High School—Providing facilities and support

Ozaukee High School—Providing facilities and support

MATE, specifically Ms. Liz Sutton—For hosting this competition

In addition to the groups and entities listed above, ZO_3 would like to express its sincerest gratitude towards multiple individuals. We would like to extend our thanks to our instructors, Terry Hendrikse, Randy Vogt, Brad Doro, and Leah VanMinsel, for their dedication to helping our company succeed. We would also like to thank Chris Hartzell for his business guidance throughout this process. Finally, our team is thankful for the help of Dustin Richter, Kaelyn Griffin, and Seth Opgenorth who have given invaluable advice to the team from years of ROV experience.

PHOTOGRAPH ACCREDITATION

Matthew Stokdyk — Logo[1], ROV Cover Photo, Figures 2, 3[2], 4[3], 6, 7, 11, 12[4], 13, 14, 15, 16[2], 17, 18[2], 19[2], 24

Jeff Lallensack — Figures 25, 26, 28, 29

Andy Richter — Figures 5, 8, 21, 22

Liz Weidert — Figures 20, 23, 27

Zach Vogt — SID, Electrical Schematics, Software Flowchart

WikiMedia Foundation — Figures 1, 9

Josh Vogt — Figure 10

[1]Original Logo Designed by Zach Vogt

[2]Models created by Jacob Dulmes, rendered by Matthew Stokdyk

[3]Model and render created by Evan Lallensack, edited by Matthew Stokdyk

[4]Model and render created by Eric Hartnett, edited by Matthew Stokdyk

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