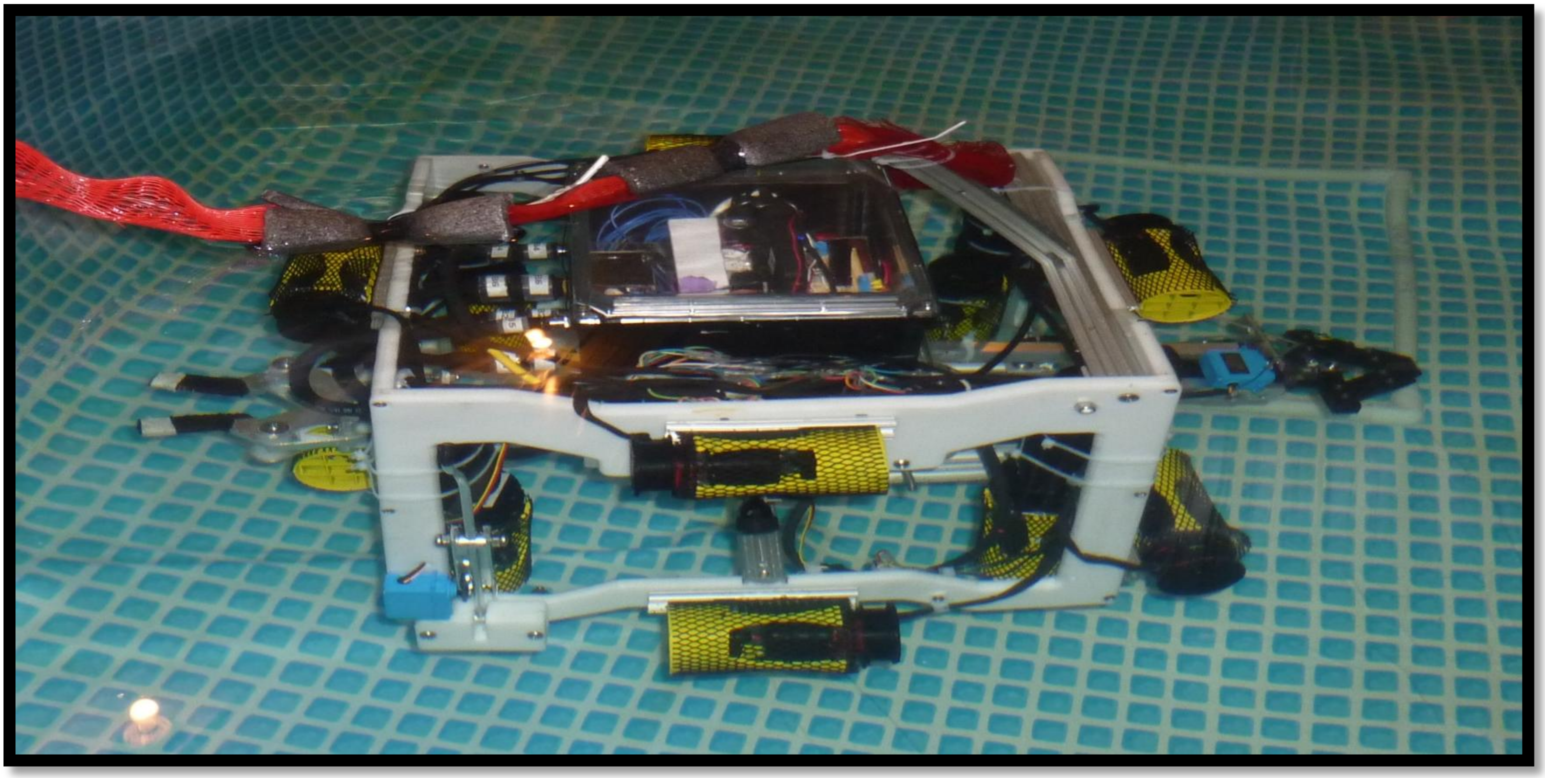
ZO$_3$ Robotics, Inc.

Ozaukee High School- Fredonia, WI
Oostburg High School- Oostburg, WI



NEMO

Ocean
Observatories
Initiative
Proposal

2013

Employee Directory

- Kaelyn Griffin- CEO
- Ben Conine- Accounting
- Jacob Dulmes- Mechanical Engineer
- Ian Ecclestone- Mechanical Engineer
- Lexi Green- Mechanical Engineer
- Roman Katzer- Tooling Engineer
- Jason Kunstmann- Course Engineer
- Evan Lallensack- 3D Modeler
- Bryan Lammers- Mechanical Engineer
- Becca Paulus- Business
- Andy Richter- Technical Writer
- Mark Shininger- Web Designer
- Matthew Stokdyk- Technical Writer
- Zach Vogt- Electrical Engineer
- Jacob Wagner- Course Engineer
- Liz Weidert- Fundraising

Mentors

- Mr. Terry Browne
- Mr. Terry Hendrikse
- Mr. Dustin Richter
- Mr. Randy Vogt

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ABSTRACT

ZO$_3$ Robotics astutely adopted the philosophies of a traditional corporate structure to obtain maximum efficiency in all facets of the mission while creating our ROV, Nemo. The business oriented approach involved assigning specific titles and tasks to each employee member, under the administration and leadership of our CEO, Kaelyn Griffin. Thorough delegation of tasks and division of labor allowed for well-engineered individual components and flawless integration of parts into a dynamic underwater robot. Creating an ROV capable of performing tasks analogous to those faced by industrial robots used to adjust and update underwater marine observatory systems was considered at all stages of the design process. Our company's custom-built systems allow the ROV to install a scientific instrument on the seafloor, record and collect temperature data, in addition to replacing underwater scientific equipment such as the Acoustic Doppler Current Profiler. Utilizing a low mass high density polyethylene (HDPE) frame allows several key systems to be featured on our ROV. These systems include multi-functional grippers, a temperature sensor, and a video system featuring eight multiplexed analog cameras. In addition, a student coded digital control system permits simple, yet powerful control over the ROV through CAT5 Ethernet communication, an onboard Arduino microcontroller, a manifold of Pololu motor drivers, and 12 counter rotating Tsunami thrusters. Combining the elements of principle application and objective consideration has resulted in the creation of an unparalleled ROV capable of safely and effectively performing tasks in the developing realm of marine data collection.

COMPETITION MISSION

The ocean provides unheralded amounts of aesthetic, economic, and ecological value. The recognition of the immense oceanic value by conscious individuals across the globe has led to the development of the Ocean Observatories Initiative (OOI) project, which has been funded with the intention of ushering a revolutionary era in marine data collection. A group of esteemed professionals at the University of Washington have begun creating the Regional Scaling Nodes (RSN) system, the OOI's first cabled marine observatory. Imperative to proper functioning of the RSN are seven terminal points referred to as primary nodes, which are responsible for the distribution of power and bandwidth throughout the system. Each primary node is connected to a sensor network containing a diverse set of data obtaining devices. In the case of the Axial Seamount, devices have been installed to: compare volcanic expansion and contraction during eruption, measure seismic activity, view organism interactions, etc. ZO_3 Robotics engineered Nemo to effectively and reliably complete typical challenges confronted by ROV's while mending and improving the Axial Seamount Hydrothermal Emissions Study (ASHES). First, our ROV must insert the Science Interface Assembly (SIA) component of the primary node into the Backbone Interface Assembly (BIA) of the primary node. Next, an ocean bottom seismometer (OBS) is stationed at the ASHES site, where it is linked to the nearby primary nodes SIA. Then, the monitoring of temperature at a hydrothermal vent is achieved through the installation of a temperature sensor. In order to obtain accurate water current measurements at the Axial Seamount, the ROV must dexterously remove and replace an Acoustic Doppler Current Profiler (ADCP) positioned on a mooring stand. In many cases, the ROV's underwater journey is concluded with discharging any biofouling which has accumulated on devices at the ASHES site. In this manner, ROV's have proved to be essential in these underwater operations, and will remain fundamental to the continuous functioning of RSN in an ever changing and improving field of marine science.

Figure 1: A primary node of the RSN system

CORPORATE PROFILE

Our Corporation quickly realized the goal of manufacturing an ROV fit for oceanic surveying maintenance to be no simple task. Difficulties arose from the complexity of the mission, as well as our company being based out of two separate high schools. Therefore, implementing a traditional corporate structure consisting of strategic focus, leadership, and employee task allocation was pivotal in engineering and fabricating an ROV to the standards of ZO_3 Robotics.

The first vital component of our corporate structure was a strategic focus. In essence, ZO_3 Robotics tactically considered methods and materials to create the most effective ROV in regards to the task at hand. The second cardinal feature in our corporate approach was relying on experienced guidance and leadership from team CEO, Kaelyn Griffin. As one of the few returning members with previous ROV experience, she has developed resourcefulness, personal insight, and the aptitude to effectively mandate tasks for completion in her skill set. The final corporate element applied to reach our goal was proper employee task allocation. Each team member was assigned a role within a department based on his or her strengths and weaknesses. The various departments include: business and accounting, electrical engineering, frame engineering, technical writing, and tool engineering. Maximum team efficiency relied upon unconditional unification of every department.

In addition, communication between the two schools was essential to successful completion of the ROV. During weekly meetings, the two schools were able to collaborate and plan weekly assignments, as well as track the past week's progress. Furthermore, electronic communication via email and Google Drive assisted in proficient integration of ideas and efficient delegation of tasks. Without question, embracing a corporate structure revolving around the concepts of prudent planning, leadership, and individual accountability has rendered the completion of the company goal.

Figure 2: Company CEO Kaelyn Griffin

DESIGN RATIONALE

Establishing a definite strategic direction in constructing our ROV was an obstacle encountered early in the design process. Due to the diverse complexity of the mission and substantial quantity of tasks to be completed in the restricted time frame, ZO_3 Robotics concentrated on manufacturing a versatile and efficient ROV. Our heightened emphasis on versatility and efficiency are particularly reflected through our decisions regarding frame, dry housing, tether, tooling, and thrusters.

Frame

Selecting a frame material was one of the early tasks for the company, and after several meetings and significant research, the engineers narrowed the field down to two options: High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE). ZO_3 ultimately decided upon 1.25 cm thick HDPE, though serious consideration was given to Low Density Polyethylene (LDPE) because of its lower density (.92 g/cm^3 vs .97 g/cm^3). Despite the difference in density, our mechanical engineers decided to forgo the minimal addition in mass (estimated at roughly 190 grams) in exchange for its superior physical and molecular properties. These properties include strong intermolecular forces and tensile strength, which result from minimal polymer branching and allow for increased frame strength. This increase in strength creates a more stable material, providing a more functional foundation for tool and thruster attachment.

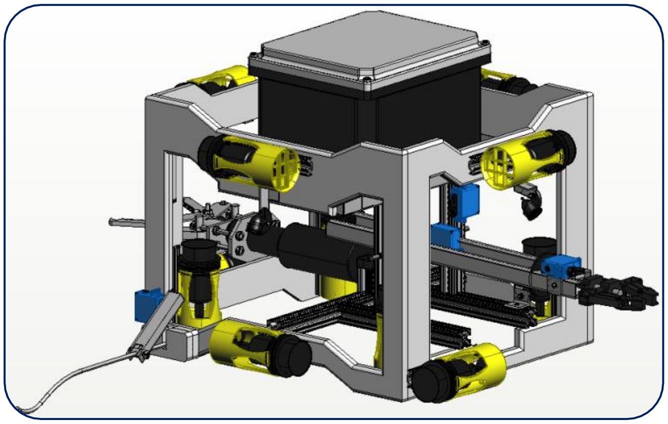

Figure 3: A complete student CAD drawing of Nemo

In addition to material, design was another crucial aspect of our frame. Faced with the prospect of challenging tasks featuring a number of steps, the frame engineers knew they would have to create a versatile, yet functional craft able to adequately accommodate the dry housing and multiple grippers, while still insuring consistent motor placement. This design had to be both substantial enough to maintain stability during missions and aid in neutral buoyancy, while remaining minimal enough to promote speed and agility.

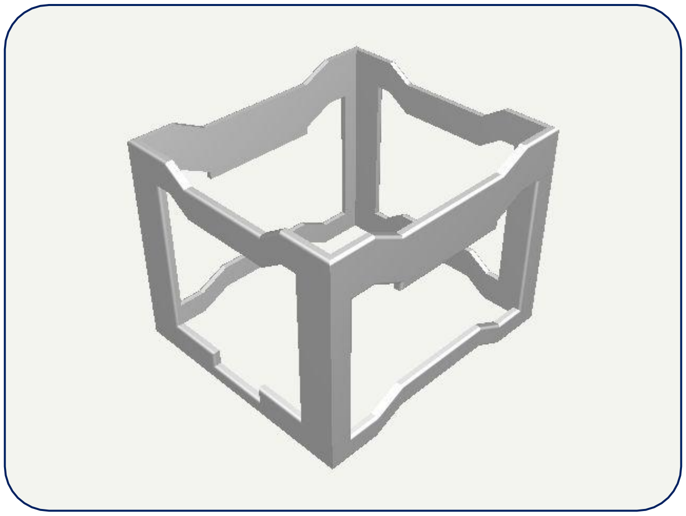

Figure 4: A student CAD drawing of Nemo's HDPE frame

In order to achieve optimum performance, the frame was given four identical faces with a width of 45.7 cm, a height of 38.1 cm, and a depth of 35.6 cm. This cube shaped design ensures maximum functionality and efficiency. Each side is perforated with a large hole to minimize material usage and maximize tool functionality, which both aids in the fluid dynamics of the ROV and in the operation of the grippers and sensors required for mission tasks.

Each side of the craft holds two motors. When fired in various software configurations, the craft can travel in any of its four directions with parallel functionality. In addition, Nemo has four additional lift motors for travelling vertically. This regularity also aids in gripper related tasks, of which there are many. Each side is mounted with a unique gripper, which can each be used to interact with the props of missions, often simultaneously. By creating a frame with identical faces, ZO_3 has alleviated many of the predicted technical difficulties involved with the 2013 competition, optimizing the craft and utilizing every available surface to complete missions.

Dry Housing

ZO_3 Robotics sought to determine which dry housing option would contribute to optimal protection of Nemo's electrical software components. Selection of a dry housing unit was not taken lightly for two reasons: because the dry housing accommodates and waterproofs all onboard electronics and it is a major factor affecting buoyancy. Upon further research, ZO_3 Robotics came to the conclusion an Integra electrical enclosure would be utilized to promote easy access to electronics, provide the correct buoyancy, and ensure the electrical components and coding that power the ROV remain safe from water intrusion. ZO_3 Robotics has taken advantage of an Integra enclosure with an Ingress Protection (IP) rating of 68. IP rating refers to the degree of defense to the infringement of solid materials. In its use as a dry housing unit aboard an underwater bot, this translates to protection from water infiltration. With our Integra enclosure boasting the highest possible IP rating of 68, the electrical components held within are kept void of any water seepage. An industrial silicone sealant, normally used in waterproofing boat engines, was applied to the outer seal of the Integra enclosure for additional waterproofing insurance. Also, screws were employed as additional means of electrical protection.

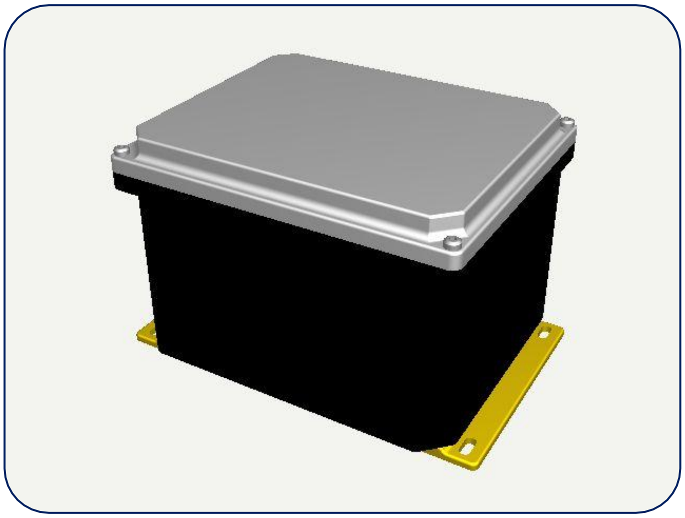

Figure 5: A student CAD drawing of our Integra enclosure dry housing unit

The Integra enclosure varies from dry housing units in past years mainly in its volume, which determines amount of space for electrical components and aides in providing proper buoyancy. The previous use of an enclosure of 25.4x20.3x10.1 centimeters, with a total volume of

5,244 cm^3 required the addition of four soda bottles providing 2200 cm^3 of floatation to aid in achieving neutral buoyancy. However, this year's Integra enclosure measures 25.4x20.3x15.4 centimeters for a total volume of 7,866 cm^3. Due to this 50% increase in volume, the need for additional floatation was unnecessary; rather, a small amount of ballast weight (250 grams) was added to achieve neutral buoyancy. In addition, the larger volume provided a more spacious compartment to organize and house the ROV's intricate electrical systems.

Bulkhead Connectors

The bulkhead connectors are vital components guaranteeing communication and power reach the ROV, while also preventing the leaching of any water. Donated by SubConn in 2010 and 2011, the six bulkheads are connected to the Integra enclosure with Blue RTV Silicone gasket sealer and 3M Scotchcast 2130 epoxy. The main power supplying bulkhead connector is constructed with two main pins rated for 50 amp maximum spike and 25 amps of continuous power. In addition, an eight pin bulkhead connector and plug is used for Cat5 Ethernet communication, which enables our dynamic control systems. Lastly, four 16 pin, 18 AWG bulkhead connectors are used for motors, sensors, and other components running connections out of the dry housing unit and into the onboard Arduino Mega. Thus, the bulkhead connectors allow power and communication to reach the ROV unmarred by the intrusion of water. Also, the ease at which the bulkhead connectors can be unplugged allows the removal of the dry housing from the ROV frame. Simple dry housing extraction also permits quick modifications or adjustments of the dry housing components in a time and labor efficient manner.

Figure 6: The SubConn bulkhead connectors drilled into the dry housing

Tether

Being the only way to communicate with and power Nemo, the tether is an essential aspect of the ROV design. It was fitted by the engineers at the top of the craft to avoid entanglement and increase maneuverability. The tether houses cables that reach every system, and was sized at eighteen meters in length in order to reach all mission props at a depth of up to 3.5 meters and a length of 14.5 meters from the control table. In order to ensure positive buoyancy, which prevents entanglement with the mission props, the tether is wrapped in pipe insulation foam every forty centimeters. The power, communication, and video cables are all bound together in a braided sleeve, which prevents them from tangling and allows them to slide during operations.

To provide the dry housing with efficient and easily conserved power, 8 AWG marine grade cable is used. Passed through the tether from the topside, the cable transfers energy to the dry housing exclusively, where it is then distributed to the many subcomponents of the ROV. The video signal from the eight cameras is sent through their stock, 28 AWG and 100 Newton sheer- tested cables to the control table, where they are integrated into three multiplexers. The shielding of the wires prevents electromagnetic energy generated by outside forces from interfering with the analog video signals. The tether houses one other non-electrical cable, which is a SubConn CAT5 ethernet cable that allows for communication between the microcontroller and the software.

Propulsion

The maneuverability and movement of Nemo are essential to its design and functionality. Because of its rectangular design, the team decided that thrusters would be placed on all sides of the craft for the purpose of stability and versatility during gripper based tasks, which comprise a bulk of mission assignments. The number of motors totals to twelve and are orientated to counter rotate with each other, reducing torque and stabilizing craft movement. To the outer sides of the craft are attached two Tsunami 1200 bilge pumps, which have been converted into thrusters using prop shaft adaptors and Octura 1250 and 1250r propellers. The Tsunami 1200/Octura 1250 propeller setup was chosen by our research and development team for its ability to provide the most efficient operation in terms of power produced to power taken in. Testing revealed that these motors produce 7 Newtons of force while consuming 4.2 amps of current. Within the bottom inside corners of the ROV are placed an additional four of these thrusters to allow vertical movement and provide the ability to hover. In place of the strafing motors used in previous years, the engineers this year decided to capitalize on the increased motor count on the craft. By using all four thrust motors available in any direction, Nemo can now "strafe" using full power. Learning from the substantial pool currents present at the 2012 international competition, the company discovered that a single strafing motor, producing five Newtons of thrust, was not enough to crawl in the powerful currents. This year, however, the strafing motion is equipped with four thrust motors, providing twenty-eight Newtons of force. The parallel motor array improves the craft's ability to maintain its position while working on mission tasks.

Figure 7: A side view of the Tsunami 1200/ Octura 1250 propeller setup

Each motor runs at approximately 50 watts of power, utilizing 4.2 amps of current at 12 volts. All four thrust motors required to move Nemo forward use roughly 16.8 amperes of power, which falls well within the 25 allotted amps in combination with the power used by the electronic components of the craft. Using this power, the motors are able to generate up to 28 Newtons of force which can, according to Newton's 2nd Law, accelerate the ROV at 1.544 meters per second squared. This force is equal in all directions.

Each motor is enclosed in a motor guard designed for safety and to prevent objects from becoming trapped within the spinning propeller. The guards were filed down and made as smooth as possible to reduce friction with water flowing around the ROV, maximizing its flow through the enclosure to increase efficiency.

Control System

Hardware

Because of the immense upgrades made to Nemo in preparation for gripper related tasks, precision and accuracy in controlling the craft were paramount concerns. To facilitate this precision, the team built upon the success of previous years and installed an Arduino Mega microcontroller and multiple Pololu motor controllers.

In order to precisely manipulate the motors during operations, Nemo's pilot, Zach Vogt, must be able to manually adjust the voltage provided to the thrusters. To accomplish this, the team implemented a full H-Bridge: a motor controller that allows the power and polarity of each motor to be adjusted independently. This H-Bridge is incorporated into the ROV's Pololu 15V18 motor controllers. These controllers can provide a maximum of fifteen amperes, at up to eighteen volts, and each comes with a 150 μf capacitor built in to filter excess electrical noise. The power output of the H- Bridge is modified by the controller when it receives a

Pulse-Width Modulation (PWM) signal from the Arduino Microcontroller. This pulse turns on and off with a varying rate at high frequency, manipulating the power sent to the motors with great precision.

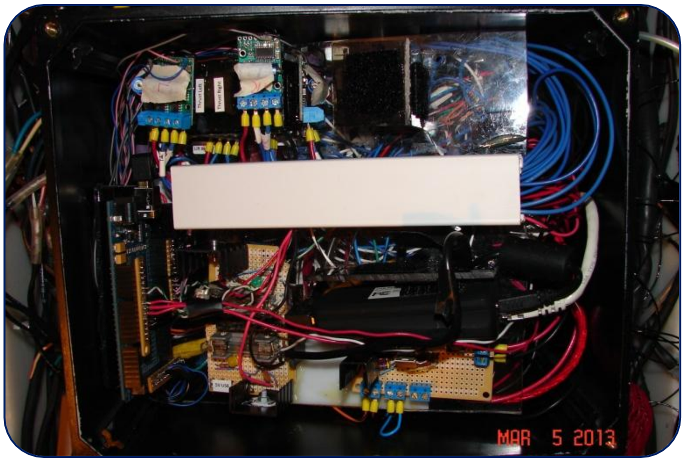
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Figure 8: An interior view of our dry housing unit's electrical hardware components

The microcontroller, an Arduino Mega, is one of the most advanced and powerful Arduinos available. Featuring 54 input/output pins, sixteen analog pins, 128KB of flash memory, and a 16MHz Atmel processor, the controller boasts massive, yet efficient power. Of the 54 digital pins, fourteen are used to send PWM signals, which regulate the thrusters and actuators. The sixteen analog pins are used to interact with sensors and probes, specifically the current sensor and depth sensor. The Atmel processor and 128KB of flash memory enable Nemo to process software commands without lag or hesitation. In compliance with MATE specifications, the microcontroller is powered through an onboard 12V DC to 5V DC converter, which is fed electricity from the provided topside 12V power supply.

While the actions of Nemo inevitably fall to the pilot, his commands must be relayed through a control mechanism. The team utilizes both the keyboard of the laptop and a PlayStation 2 DualShock 2 controller. The twin analog joysticks are used to manipulate the control of the craft, directing all of the thrusters through the software interface.

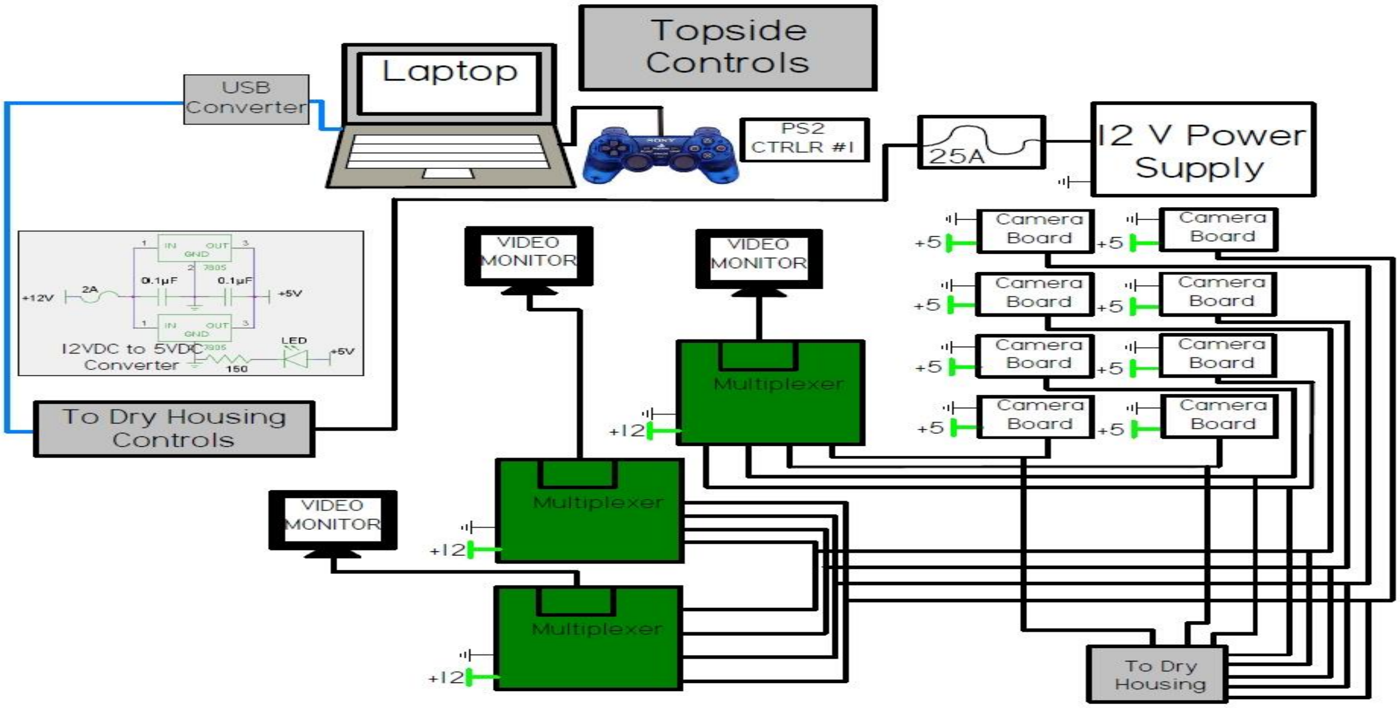
Figure 9: A PlayStation 2 Dual Shock controller used to operate Nemo

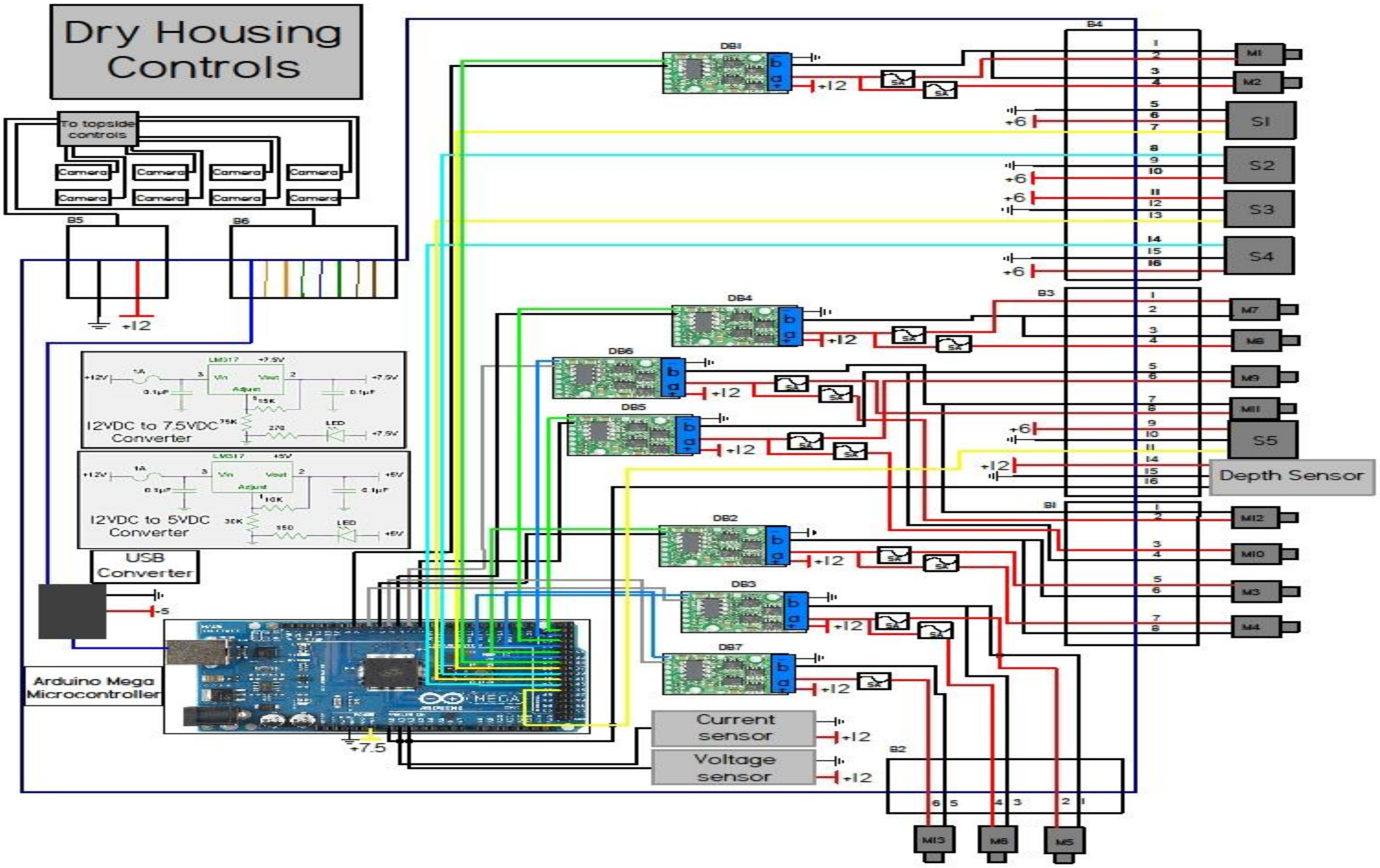
Software

After several years of using and modifying the same code, this year's software engineers resolved to completely restructure the software. By reducing redundancies, replacing simple and process intensive loops with more straightforward methods, and reinventing older functions, Nemo gained a newfound usability, and is now more stable than ever. The software was rebuilt in the fashion of two distinct programs: one which controls the microcontroller, and one which translates the data from the tools and cameras and displays it on the controller's laptops.

The microcontroller's software is written in C, with added object oriented libraries, and was developed in the Arduino's integrated development environment. This code is stored within the 128K of on-board flash memory, which was uploaded from a host computer via a serial connection. This code enables the microcontroller to send Pulse-Width Modulated signals to the motor controllers, which drive the craft and operate the grippers. The software also collects the analog signals from the depth sensor, current sensor, and accelerometer, and subsequently translates them into readable numbers, which are displayed on the laptop's graphical user interface (GUI). These readings are vital in determining the position, orientation, and stability of the craft, especially during delicate, gripper related tasks.

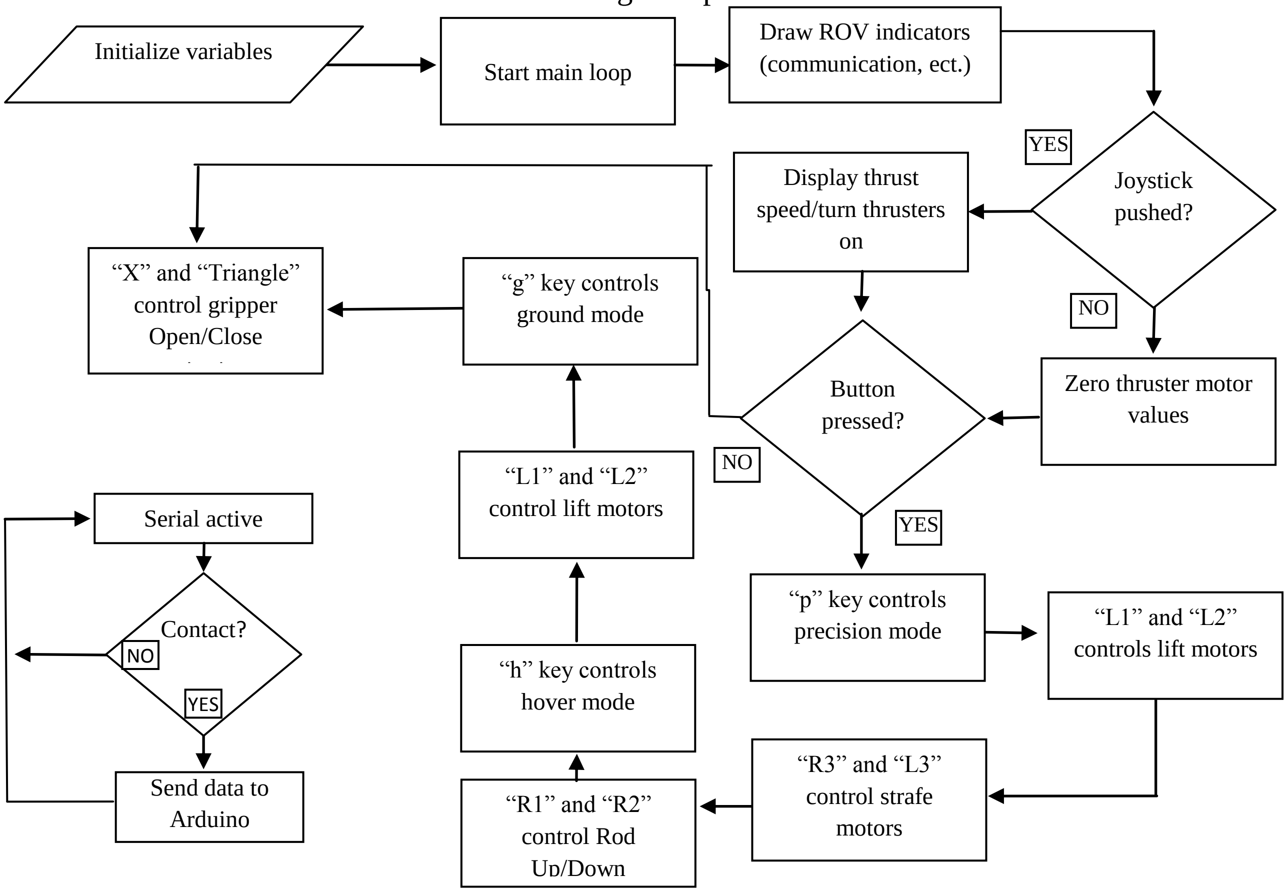
Electrical Schematic



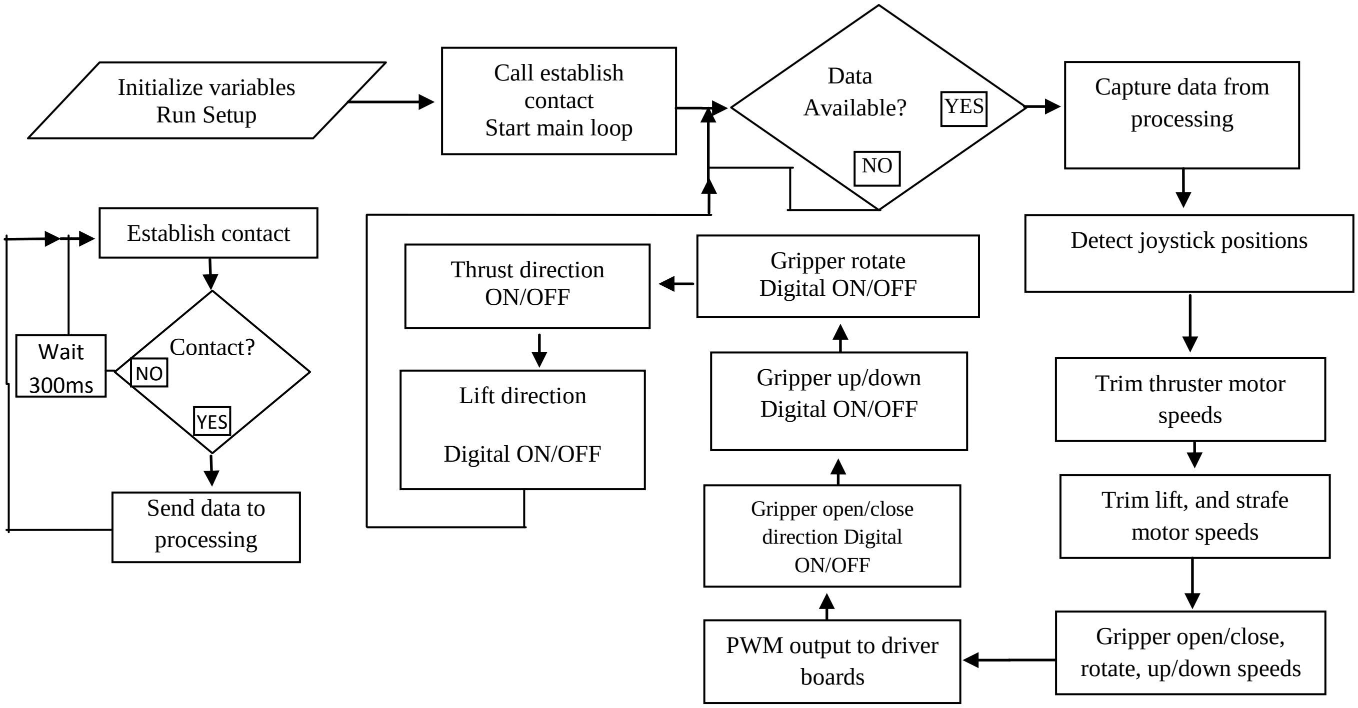


Software Flowchart

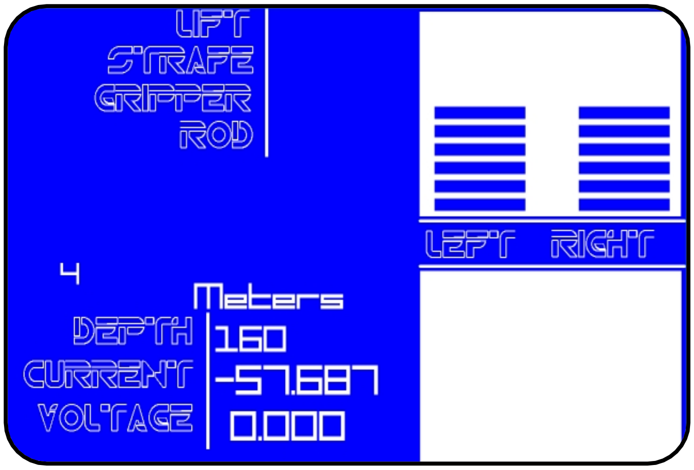
Processing Computer Code



Arduino Microcontroller Code



The laptop executes software that works in conjunction with the microcontroller, and is responsible for sending instructions and receiving data, as well as displaying them for the pilot. The software simultaneously displays the data gathered by the various tools and sensors of Nemo by overlaying them upon the main video signal of the laptop, so the pilot can both monitor his position and data. The most prominent figures displayed are the thrust generated by each of the motors, the current being drawn, the status of the instruments, craft depth, and forward orientation. The laptop interprets, commands, and toggles accordingly when it receives inputs from the keyboard or the DualShock 2 controller.



DEPTH 160
CURRENT -57.687
VOLTAGE 0.000

Figure 10: Java based graphical user interface, GUI, written by our software engineer, Zach Vogt

Modes and Applications

One of the key assignments the software engineers were tasked with was properly equipping Nemo with multiple modes of operation. Each mode, when engaged, changes the basic functions of the craft so it is better suited for a specific task. For instance, the "ground" mode, which fires all thrust motors downward at 50%, stabilizes the craft at the bottom of the pool while underwater. This stability is imperative when pulling the pin connecting the OBS to the elevator and inserting the CTA into the bulkhead connector.

Another important mode is "precision" mode, which reduces the voltage supplied to the thrusters to half, allowing the pilot of the craft to maneuver with fine movements, utilizing the full range of the joysticks on the controller. This increased precision, in combination with the stability added by the "ground" mode, is essential in the installation of Cable Termination Assemblies (CTAs), as very subtle movements are required to properly insert the prongs of the CTA into the bulkhead connector. "Precision" mode is also essential in the insertion of the Scientific Interface Assembly into the Backbone Interface Assembly.

The final mode, "direction" mode, was created to compliment the design and navigation of the ROV itself. As all faces of the craft are equally dominant, direction mode allows the pilot to toggle between each face. Pressing "S" on the keyboard enables the pilot to change from the view and forward software orientation of the current "forward" camera, to a view and forward software orientation of an adjacent side. In this case a new forward is determined and all navigation in this direction will intuitively be perceived as forward by the pilot. Another toggle will allow the pilot to view the "back" view camera while providing forward software orientation in this direction. Two more toggles will bring the camera view and forward software orientation back to the original position. Beyond all modes and hardware upgrades, this change has proven significant in increasing task efficiency and completion as Nemo's operator, Zach, need not concern himself with navigating backward, sideways, or even turning the craft.

Video System

In order to clearly view every component of the tasks presented, ZO$_3$ Robotics decided the best course of action would be to place cameras, like many other features of the ROV, on all sides. In the 2012 competition, a combination of both four monochromatic cameras and four full color microcameras were utilized. This year, in order to increase the senses of the ROV pilot, the company decided all of the cameras would be full color. The cameras, donated by AquaVu and commonly used for ice fishing, are full color, broadcast in 480p, and feature a wide 150 degree field of vision. The cameras were chosen for their liquid ingress protection rating of 68, functioning depth of up to twenty meters, and compact, lightweight design. Cameras were mounted on the four ordinal all sides of the ROV, with additional cameras being placed above the craft's grippers. The craft sports a total of eight cameras, which all transmit in analog.

Figure 11: One of Nemo's eight, color, wide view cameras donated by AquaVu

The video signals gathered by the cameras are sent to a quad input multiplexer within a topside video case. The multiplexer emits video signals in PAL output, which are subsequently converted to NTSC before being sent, via HDMI cables, to three, 81 cm (diagonally) Vizio video monitors. The cameras focused on the tools are relayed to a monitor split into four quadrants, each featuring a different tool view. The other four cameras used for navigation are displayed simultaneously on a second monitor. This monitor displays all four operating sides of the craft in real-time. The third monitor displays only one of the four navigation views, which is the current side of the craft being used to move forward.

Gripper System

Due to the immense amount of gripper related tasks in this year's competition, the company decided it would be wise to invest in upgrading and expanding Nemo's arsenal of grippers. The craft houses four of these tools, each fully functional and task oriented. Two of the grippers act as clamps to grip and carry objects, while a third gripper functions as a simple, yet vital latch. The fourth gripper acts as a rod, used exclusively to remove and safely secure the ADCP from the mooring platform.

The team's initial attempt at the creation of a gripper was to purchase and modify an existing robotic arm. When the modification began, however, it was apparent that the arm was not strong enough and could not complete the tasks required with sufficient dexterity. After multiple modifications to the tool, it became clear that a pre-purchased gripper could not match the ingenuity of the company's engineers. Utilizing a set of servos originally purchased to strengthen the arm, the team created three specialized grippers, replacing the arm entirely.

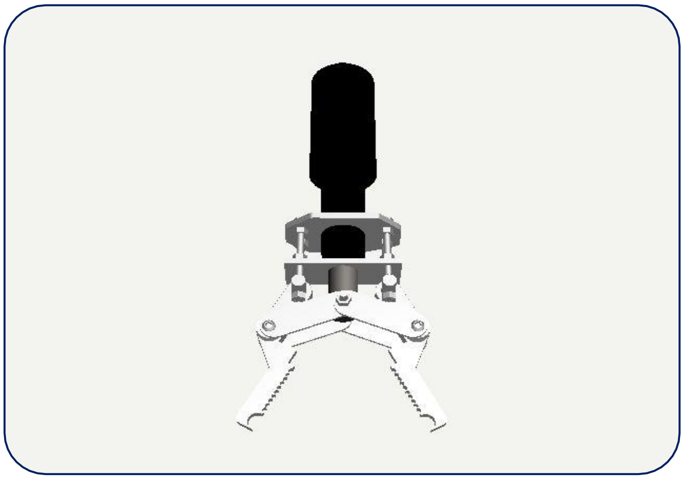


Figure 12: A student CAD of the rear facing linear actuator gripper

The first gripper added to the craft was previously featured on the 2012 ROV (Figure 12). It functions from a linear actuator, and is able to clamp and hold heavy objects with ease—a feature especially useful in lifting props such as the OBS. The actuator of the gripper, however, weighs a massive 1290 grams. The second gripper (Figure 13), which had yet to be constructed, could most certainly not weigh this much.

The fabrication of this new gripper took many phases of design. The engineers began with a scissor hinge, opened and rotated by independent, digital servos. These servos, produced by HiTec, with an IP rating of 67, produce a maximum torque of 1.99 kilograms per centimeter. This clamping hinge was attached to an aluminum arm, mounted to the ROV. Still needing a gripper that could perform delicate tasks, the engineers decided to add an additional degree of motion. The gripper was given the ability to move vertically from a height 2 cm subsurface to 30 cm above the pool surface. Because Nemo is able to complete these tasks while remaining stable on the pool floor using ground mode, this motion is beneficial in efficient task completion such as removing the pin from the elevator and picking up the OBS cable and bulkhead connector. The three servos used to power this gripper weigh a mere 183 grams (dry weight), an enormous reduction in mass in comparison to the actuator. The gentle yet broad movements of this gripper are key to the success of the installation of delicate instruments such as the temperature sensor and the easy removal of biofouling from instruments within the observatory, while the ability to rotate greatly reduces the time needed to insert CTA's into bulkheads.

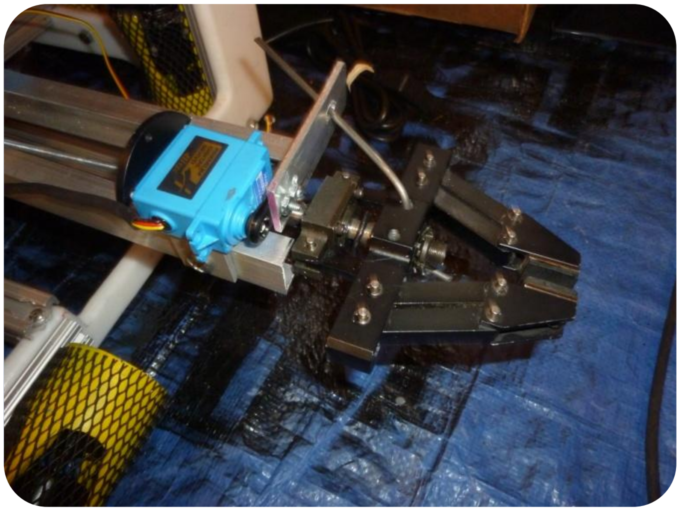


Figure 13: Nemo's clamp gripper with the ability to move up and down, as well as rotate 100 degrees

During the engineering of the second gripper, it became evident that including a third clamping device would greatly reduce mission time. This gripper, also featuring a HiTec servo, uses the servo arm to close against a hook attached to the bottom of the craft, giving Nemo the ability to carry and pick up objects. This functionality was included specifically to carry the Science Interface Assembly (SIA) into the water, allowing the other, more dexterous grippers to remain usable. Though simple, the latch gripper aids greatly in the movement of heavy objects, allowing the full thrust of the craft to be utilized while lifting a prop.

Figure 14: The aluminum rod gripper used to extract the ADCP from the mooring platform

Upon the completion of the third gripper, it was noted by an engineer that the ADCP (Acoustic Doppler Current Profiler), a prop which must be carried by a gripper after its removal from the platform, was difficult to remove because of its recessed position in the mooring platform and would occupy one of the more dexterous grippers throughout the remainder of the mission. To address this, a fourth "gripper" was created (Figure 14). Operated by a servo, the tool is a simple aluminum rod, 0.625 cm in diameter. The shaft of this rod is threaded into an aluminum cylinder. When the rod is piloted into the hook of the ADCP, the servo rotates the cylinder, bringing the rod and prop up to the side of the craft, where they remain until the ROV resurfaces. This simple feature greatly improves mission times, as the clamping grippers can remain usable throughout the remainder of the mission.

The grippers lend one more quality to the ROV: its name. Early in the design process, when only two grippers were being considered for the craft, the company had still not named the ROV. As the design at the time called for one, fully functional gripper and a secondary, simple clamp, it was suggested by Matthew Stokdyk, a technical writer, that the craft be named “Nemo,” after the fictional fish from the Pixar movie *Finding Nemo*. One of the defining traits of the character Nemo was that, because of a birth defect, he had only one fully functional pectoral fin, with the other limited in use. Associating a parallel between the character and the plans for the craft, the company agreed upon the name “Nemo.”

SENSORS

Depth Sensor

Figure 15: Our submersible Keller depth sensor securely attached to Nemo

The depth sensor aboard the ROV is essential in enabling it to hover while completing tasks. The instrument, a Keller submersible level hydrostatic depth sensor, emits data in the form of an analog signal, which ranges from zero to five volts of electricity in a maximum of six meters of water. This data is generated using a Wheatstone Bridge that gauges pressure, and is calculated in a linear fashion by the onboard Arduino microcontroller. This information is displayed in real time by the software’s GUI, and the readings are accurate to within two hundredths of a centimeter. The microcontroller, however, cannot detect the full sensitivity of the device, for it is only able to read 1024 analog values between zero and five volts (approximately .0049 volts per unit). Be that as it may, the microcontroller and probe retain accuracy within two centimeters, which is more than sufficient for the ROV to maintain stability during tasks.

Electrical Sensor

ZO_3 Robotics utilizes a current sensor to detect if our ROV approaches its current limit, in which case the 25 amp fuse would be blown. Capable of measuring 30 RMS amps continuously and 50 amp peaks for nearly a second, Nemo’s current sensor boasts supreme electrical precaution. The current sensor works in symphony with the Arduino microcontroller, which reads analog values from the sensor, and proceeds to transmit a constant stream of the current measurements to the surface computer. A necessary safety measure to prevent blowing our fuse lies in the Arduino’s code enabled capability to limit the electricity powering the thrusters and linear actuators from exceeding 23 amps.

Also, a voltage divider with two resistors of 66.3K ohms and 27.4K ohms has been installed to confine Nemo’s voltage to 3.5-4.0V. This analog value is relayed from the Arduino to our laptop, allowing the ROV operator to reduce motor output if the maximum current draw is approached.

Temperature Sensor

Engineering and constructing a temperature sensor, separate of our ROV and capable of making prompt and accurate readings required members of the ZO_3 Robotics engineering staff to apply logical ingenuity. It was decided to make use of a simple waterproof aquarium thermometer. The thermometer uses simple analog resistor technology and had initially been equipped with a 26 AWG, 3.2 meter cord, which was replaced with a durable 16 AWG, 15.24 m cord. Next, a 3 cm diameter piece of galvanized metal tubing was modified to 10.5 cm in length upon which a hole was drilled 2.5 cm from the top of the tubing. The thermometer’s probe was then soundly installed in this hole.

Figure 16: A simple temperature sensor constructed of a 15 cm piece of galvanized pipe

Once deployed onto the mouth of the hydrothermal vent, the temperature sensor is able to measure the temperature of the water within 2 degrees Celsius of the actual temperature in less than 60 seconds. In addition, when our sensor is positioned in the vent, a live stream of its temperature readings will be transmitted to our surface monitor through a cable attaching the sensor with the topside digital display where the data can be recorded and plotted. Without question, the logical approach geared towards originality was pivotal in creating a cogent temperature sensor.

CHALLENGES FACED

Technical

Properly programming our clamp hinge, servo controlled, gripper provided an exceptionally trifling technical hardship while assembling the ROV. Upon first operating the gripper, we discovered it assumed one of two positions: either open at its maximum level of 160 degrees, or completely closed. This gripper had been programmed with the intention of opening one degree at time under the command of Nemo's pilot. Due to the Arduino's expeditious processing behavior, an adjustment of a few degrees from our topside computer caused the Arduino to cycle through the entire gripper code, thus causing the gripper to either open or close all the way. This issue was resolved once our electrical engineer, Zach, altered the gripper's code and allowed the computer to process gripper commands at the computers maximum rate. As a result, our topside computer and Arduino processor are now able to operate cooperatively, providing our clamp hinge gripper the ability to open and close with great precision.

Interpersonal

Initially, the 28 km distance separating Ozaukee and Oostburg High Schools threatened the ability of ZO_3 Robotics to fluidly function as a singular enterprise. To resolve this complication, methods were utilized analogous to those employed by large scale corporations consisting of separately located branches. Foremost, ZO_3 Robotics took advantage of an array of technologically efficient communication devices including: texting, emailing, conference calls, and group brainstorming sessions via online messaging systems. In addition, a Google Document titled "ZO3 Robotics 2013" was shared with all team members. This document contains a multitude of tabs, allowing each team member to remain informed of progression in every facet of our corporation. The final measure taken to overcome the distance barrier between the two schools was weekly team meetings at Oostburg High School. These meetings ensured continual developmental progression of our ROV, and led to the proliferation of exceptional team camaraderie.

SAFETY

The main aspects of safety consideration include hazards posed by electrical shocks via the 25 amp power supply, spinning motor propellers, and sharp edges. The fusing of all positive leads to Nemo's motors, actuators and pumps greatly reduces damage in the case of a blown fuse or motor overload. If this happens, only the damaged component will no longer be able to properly function. Our 25 amp single inline fuse is aptly located within 30cm of its attachment point. Furthermore, we have securely attached a durable tether to our surface controls and our ROV to maintain a safe, uninterrupted flow of electricity. Another electrical precaution taken was the application of 18 gauge wire to necessary elements. To manage electrical heat, components relying on ample amounts of electricity are wired in parallel through the bulkhead connectors, dividing the current load through multiple cables. One of the most crucial facets of our electrical safety features is the precise sealing and binding of all onboard electrical wires.

In addition to electrical prudence, measures were administered to guarantee the safety of those involved in the construction, inspection, and use of Nemo. Our ROV has been sturdily manufactured, preventing the possibility of accidental deployment of any loose objects. Also, all potentially threatening sharp edges and electrical aspects have been marked with visible hazard decals. At every phase of the competition, employees are required to utilize safety goggles while engineering, and operating the ROV. We have securely mounted our propellers within custom built motor guards (Figure 16) made of PVC cylinders, mesh, and Eggcrate wire light diffusers. This eliminates the threat of our propellers becoming tangled with MATE props. Finally, our ROV design is bereft of sharp edges, as exhibited by major components such as the frame, two grippers, and dry housing unit.

	Safety Checklist
	All items attached to ROV are secure
	Hazardous items identified and protection provided
	No sharp edges or elements of ROV design
	Single attachment point to power source
	Single Inline 25 amp fuse
	No exposed copper or bare wire
	No exposed motors
	All wiring securely fastened and properly sealed
	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

TROUBLESHOOTING

Creating a precise troubleshooting process was crucial to providing an organized direction of attack in correcting any faults in the operation of our ROV. In the event an obstacle was encountered with the functionality of the vehicle as a whole, we immediately attempted to determine the source of the problem. Upon verifying the cause of the problem, our corporation jointly brainstormed possible solutions. We would then apply this resolution to Nemo. If the applied method solved the complication, ZO$_3$ Robotics continued to progress in completing their mission. Under the circumstances the solution failed, we backtracked in the troubleshooting process to the brainstorming phase.

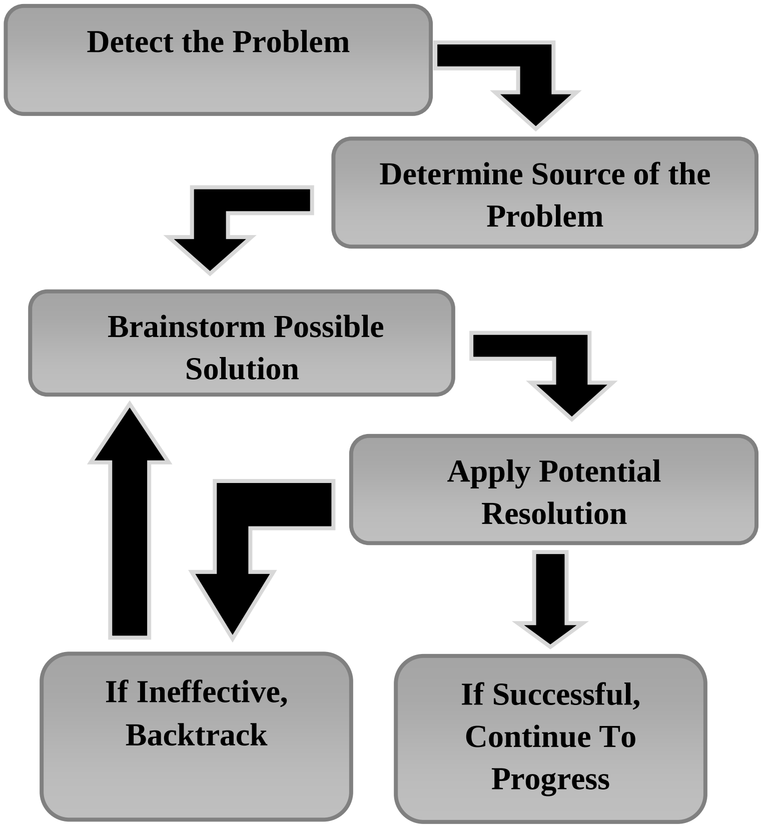


Figure 18: ZO$_3$ Robotics' troubleshooting process

At one point during either the design or testing phase, our corporation applied our troubleshooting process to each component at least once. Specifically, our gripper system caused for the application of our troubleshooting process in numerous instances. When it became evident the functionality of the gripper system had become impaired, our operators searched for the root of the encumbrance in the form of a software malfunction, a blown electrical fuse, or the inadequacy of specific component of the gripper. Once the source of the problem was pinpointed, a solution could be acted upon to remedy the hindrance. In essence, our troubleshooting actions immensely reduced the tensions experienced while mending a deterrent during the production of Nemo.

LESSONS LEARNED

Technical

Of the multitude of technical lessons discerned by ZO_3 Robotics, the most notable came in the field of electronic organization. Initially, Nemo's electrical components were assembled in a functioning manner and hastily placed in the dry housing unit. As stated by electrical engineer, Zach Vogt, the interior of the Integra enclosure was a "complete rats-nest." In the event of a disruption in the electrical current which would hinder the performance of the ROV, locating and repairing the source of the problem was a painstaking process. As a result, ZO_3 Robotics adjusted the electronics within the Integra enclosure in a tidy configuration. This included separating all wires with wire dividers, as well as making all points of connection visible. Therefore, when an electrical complication arises, detecting and mending a loose or corroded connection can be completed without difficulty. In essence, ZO_3 has been enlightened to the fact proper electrical organization is essential in possessing an elite electrical system.

Interpersonal

The interpersonal difficulties faced throughout the duration of this competition taught each company member applicable lessons in responsibility, cooperation, and trust in others. First, it became evident early in the competition that every ZO_3 employee would have to embrace his or her responsibility on a daily basis in order for our corporation to function fluidly. Idleness by one individual caused the entire team to fall behind schedule: an unacceptable flaw in any successful corporation. A specific instance in which division of labor was aptly applied can be seen through the work of the practice course coordinators. Had the practice course not been fully assembled upon the completion of the ROV, improvement in any operational component of Nemo would have been futile, and the advancement of the organization as a whole would have been hindered.

Figure 19: Course engineers Jason (left) and Jacob (right) installing the practice course in our practice pool

Also, imperative to ZO_3's continual progression was each employee promptly learning to cooperate with and respect the ideas of others. In the event of a discrepancy over a decision in the design and engineering process, a compromise was swiftly determined and acted upon. Finally, placing trust in individuals to complete their tasks in an exceptional manner was a key trait all members of ZO_3 Robotics learned. Each member was assigned his or her task for a specific reason, and the efficient operation of the company was reliant on the completion of each of these individual tasks. These lessons will prove to be invaluable to all members of the team as responsibility, cooperation, and trust are crucial traits one must possess to be a prosperous individual in a contemporary workplace and society.

FUTURE IMPROVEMENT

It has become evident that one central and intriguing adjustment could be exercised to improve the performance of our ROV. Currently, Nemo has one pilot in charge of operating and maneuvering all components in every task. In the future, our corporation hopes to revise our software in a manner which will allow the regulation of our ROV from two separate PlayStation 2 controllers. Utilizing two controllers would allow one pilot to maneuver the ROV from location to location, while a second pilot would then operate the specific components of the ROV necessary to complete the task. In essence, exploiting a dual operator system would result in astute specialization of tasks: a required approach in achieving maximum efficiency. This strategy has proven competent as real-world ROV's are controlled from two separate pilots. Although ZO$_3$ Robotics simply ran out of time, we will continue to pursue this possibility in the quest to create the optimal operating system.

REFLECTIONS

"Being part of ZO$_3$ Robotics the past two years has taught me a variety of skills. I have learned the importance of meeting deadlines and staying organized. It has been a challenge attempting to balance my school work, extracurricular activities, and ROV work, which has helped me learn how to better manage my time. This competition has also opened my eyes to true engineering. At last year's competition, I witnessed how different groups can come up with various solutions for the same problem. My time spent working on our ROV has greatly influenced my chosen career path, and I know I will apply the skills I have developed during this competition for the rest of my life. I would like to thank both MATE and all of my mentors over the past two years for giving me such an impactful experience. Their dedication, as well as the dedication of my fellow team members, has made this experience the best of my high school career."

-Kaelyn Griffin: CEO, Ozaukee High School

"Earlier this year I was asked if I wanted to be a part of the ZO$_3$ Robotics team and boy am I glad I did. It has taught me many lessons that I will use in the future. It has taught me that being part of a team carries great responsibility. Your team relies on you to get your job done on time to the best of your ability. I have also learned all the steps to the engineering process. I have been a part of everything from designing the robot, to making fine tune adjustments while testing and evaluating it. This experience has influenced me to want to become an engineer and has given me insight in regards to what it means to be one. This has been one of the main highlights of my high school career and it would not have been possible without my mentors and teammates."

-Jacob Dulmes: Mechanical Engineer, Oostburg High School

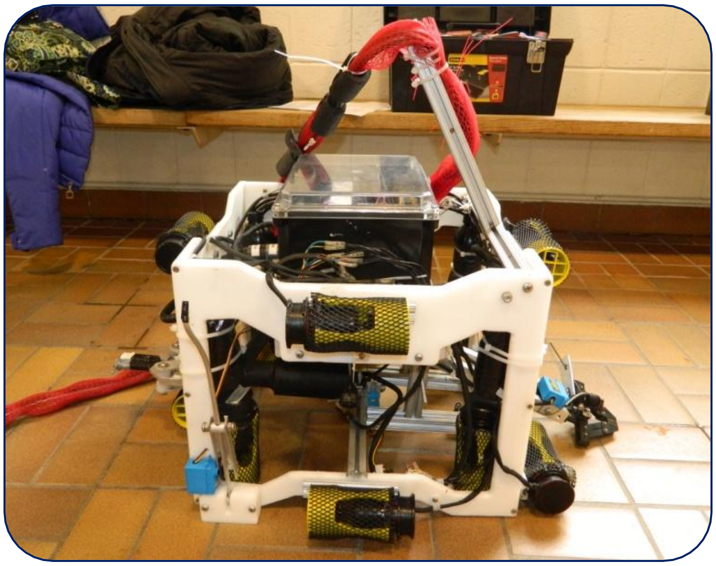


Figure 20: ZO$_3$ Robotics' completed ROV, Nemo

Figure 21: The members of ZO$_3$ Robotics

ACKNOWLEDGMENTS

ZO3 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 Company- Donation of frame material

Stephen's Heating and Plumbing- PVC piped and adapter donations

The Hartnett Family- Use of printer for poster

Hitec RCD USA, Inc. - Reduced price of servos

NOSD PTR- Flat monetary donation

Oostburg Community Education Foundation- Flat monetary donation

Port Washington State Bank- Flat monetary donation

Culvers of Port Washington- Hosting company fundraisers

Watry's Maintenance Service - Flat monetary donation

Sharon-Cutwell Company - Flat monetary donation

Exxon Mobil - Flat monetary donation

Oldenburg Metal Tech - Flat monetary donation

Cargill - Flat monetary donation

Vogt Family – Providing a practice pool

Paulus family- Providing a practice pool

Thomas Jefferson Middle School- Providing a practice pool

Ozaukee High School- Providing facilities and support

Oostburg High School- Providing facilities and support

MATE- For hosting this phenomenal competition

Furthermore, our corporation would like to express our sincerest gratitude towards certain individuals for their continued assistance throughout the competition. First, our instructors, Terry Hendrikse and Randy Vogt, have had a profound influence on the completion of our company's goal. In addition, Terry Browne has been extremely valuable to our corporation in offering his knowledge in all business related matters. Finally, our team is exceedingly thankful to Dustin Richter, as he and his ROV experience have proven invaluable during all phases of creating our technical report.

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Budget/Expense Report

School: Ozaukee and Oostburg High Schools
Instructor: Mr. Terry Hendrikse and Mr. Randy Vogt

Date	Transaction Type	Description	Material Donation	Amount	Balance
12/3/2012	Deposit	2012 International 1st Place Prize		$600.00	$600.00
12/13/2012	Donation	4x4 HDPE Sheet	95.70		600.00
12/15/2012	Expense	Octura Propellers		(15.59)	584.41
12/15/2012	Expense	Prop Shaft Adapters		(4.78)	579.63
12/18/2012	Donation	Integra Enclosures	131.00		579.63
12/18/2012	Expense	OWI Robotic Arm		(52.84)	526.79
1/4/2013	Expense	Stainless Steel Hardware		(250.00)	276.79
12/29/2012	Deposit	Funds from Oostburg		1,500.00	1,776.79
1/11/2013	Donation	T1200 Tsunami Bilge Pump	159.96		1,776.79
1/14/2013	Expense	HS-5646WP Servos		(210.46)	1,566.33
1/14/2013	Donation	AV Micro Plus Aqua Vu Cameras	1,599.96		1,566.33
1/18/2013	Deposit	Ozaukee PTR Money		750.00	2,316.33
1/21/2013	Donation	PVC Pieces	22.04		2,316.33
1/23/2013	Deposit	Visa Gift Cards		200.00	2,516.33
1/26/2013	Expense	Assorted Parts		(115.22)	2,401.11
2/3/2013	Expense	Plexiglass		(5.65)	2,395.46
2/3/2013	Expense	Nuts and PVC		(4.35)	2,391.11
2/6/2013	Deposit	PWSB Donation		200.00	2,591.11
2/11/2013	Expense	Plexiglass		(5.28)	2,585.83
2/12/2013	Expense	TV Monitors		(627.00)	1,958.83
2/18/2013	Expense	RCA Cables and Food		(39.31)	1,919.52
2/21/2013	Expense	5-Volt regulators [2]		(4.18)	1,915.34
2/26/2013	Expense	Waterproof heat shrink		(82.79)	1,832.55
3/3/2013	Expense	Radio Shack Receipt		(6.31)	1,826.24
3/4/2013	Expense	Radio Shack Receipt		(7.33)	1,818.91
3/12/2013	Expense	ROV Shirts		(733.25)	1,085.66
3/12/2013	Expense	ROV Shirts		700.25	1,785.91
4/4/2013	Donation	Ozaukee Flight Deposit		2,100.00	3,885.91
4/4/2013	Expense	Ozaukee Flight Reimbursement		(2,100.00)	1,785.91
4/4/2013	Donation	Exxon Mobile Donatino		500.00	2,285.91
4/9/2013	Donation	Donation from Mr. Watry		100.00	2,385.91
4/15/2013	Donation	Sharon-Cutwell Donation		250.00	2,635.91
4/16/2013	Donation	Oostburg Flight Deposit		1,200.00	3,835.91
4/16/2013	Expense	Oostburg Flight Reimbursement		(1,200)	$2,635.91

Final Summary:

Total Material Donations	$2,008.66
Total Cost of ROV (Cash Expenditures)	$5,464.34
Total Cash Revenues	$8,100.25
Ending Cash Balance	$2,635.91

APPENDIX I

Nemo’s Controls

Rightstick	Right Thrust
Leftstick	Left Thrust
R1	Rod Down
R2	Rod Up
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
D pad right	Gripper Up
D pad left	Gripper Down
Select	Gripper Rotate Left
Start	Gripper Rotate Right