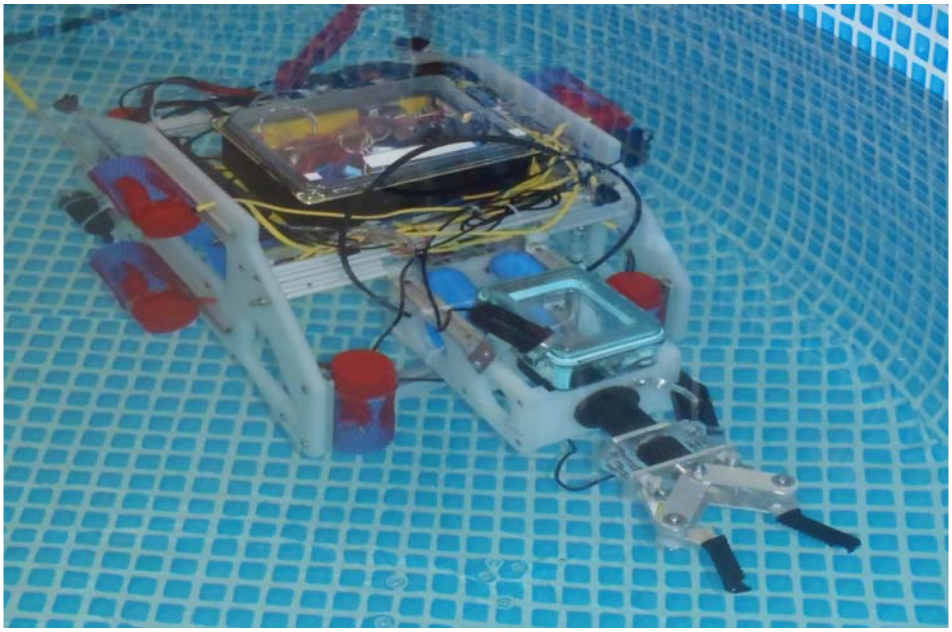
ZO_3 Robotics, Inc.

Ozaukee High School – Fredonia, WI
Oostburg High School – Oostburg, WI



GEN4

ZO_3 Robotics, Inc. Members

Eric Hartnett – CEO, Technical Engineer, CAD Design

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Seth Opgenorth – Electrical Engineer, Technical Writer

Alex Wynveen – Director of Communications

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Evan Lallensack – Technical Engineer

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Brooke Dieringer – Fundraising Coordinator

Zach Vogt – Electrical Engineer

Amanda Nordby – Public Relations

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Eric Meinnert – Faculty Mentor

Dustin Richter – Mentor

Randy Vogt – Mentor

Terry Browne – Business Mentor

Abstract

ZO3 Robotics is dedicated to engineering innovation, interpersonal connection, and individual leadership. Our corporate structure resulted in each member having both individual deadlines and collective group goals, for maximum efficiency. In addition, the collaborative effort between two schools required a heightened emphasis on effective communication to allow for seamless integration and compatibility of components, along with completion of all tasks in accordance with a strict schedule. Always aiming for excellence, our remotely operated vehicle (ROV) utilizes numerous superior features. These include innovative Tsunami bilge pump motor thrusters, a compact and low mass LDPE frame, a multi-functional gripper, and a proboscis allowing for oil extraction. The ROV also incorporates multiple digital systems, such as electrical mapping technology and an advanced student -coded digital control system. The precise control and high degree of maneuverability of GEN4 can be attributed to the digital control system, which allows for effective and reliable completion of the mission tasks. Our design rationale has led to an ROV more than capable of solving problems engineers commonly encounter with underwater shipwrecks such as the *SS Gardner*. The ROV is proficient in surveying a shipwreck site, identifying its current location and orientation, and safely extracting oil from the sunken ship. The business-oriented infrastructure of the company has allowed the corporation to not only overcome technical and interpersonal challenges, but engineer an unparalleled vehicle and component systems serviceable to all clients.

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Competition Mission

World War Two was the first oil-based war, as the remnant shipwrecks lurking across the ocean seafloor attest. These dangerous time-bombs are laden with fuel, and threaten ecological systems, wildlife, and humanity. One example of the danger inherent in these wrecks presented itself in 2001; a State of Emergency was declared in Yap, a Federated State of Micronesia, when oil was found to be leaking from the sunken *USS Mississinewa*. An estimated 24,000 gallons of oil spilled into the lagoon over two months, and 5,000,000 gallons remained on-board the *Mississinewa*. Due to the oil spills, fishing halted for four months. Untold amounts of wrecks like the *Mississinewa* lie beneath the surface today, waiting for a tropical storm to activate their hazardous potential. If engineers cannot find solutions to safely and efficiently map these ships' locations and determine the potentially hazardous on-board contents, the shipwrecks will remain where they are, slowly poisoning the environment while presenting environmental and economic threats.

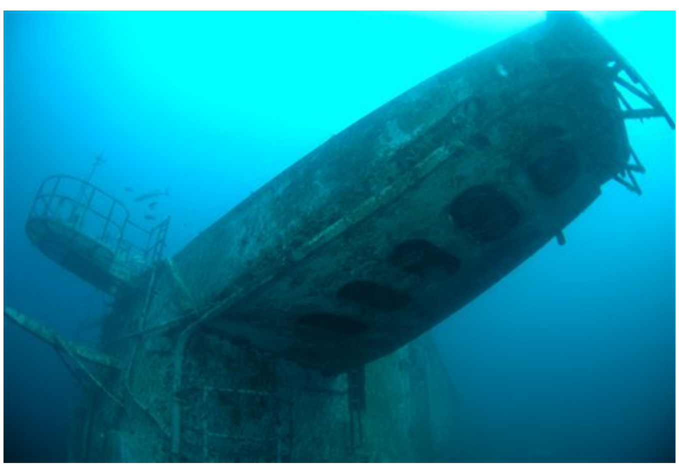


Figure 1. *Underwater shipwrecks from World War II pose many dangers of various kinds*

The tasks set by the MATE ROV competition simulate the actual tasks a company would face in exploring a potentially dangerous underwater shipwreck. Specifically, the competition focuses on assessing the fictional *SS Gardner*, an oil tanker sunk on Dec. 25, 1942. The *SS Gardner* is representative of typical shipwreck hazards engineers would encounter because of its chaotic state of wreckage, including debris in the surrounding area and its fallen mast. If left unattended, the Gardner could cause damage worth billions of dollars to the economy and incalculable to the environment. ROVs tasked with preventing future damage need to map the shipwreck site, measure length, note orientation, and identify nearby debris, before they are able to retrieve other relevant information for above-water scientists to examine. Finally, the ROV must be able to safely extract any remaining oil, preventing eminent future danger. ROVs and their engineers must be environmentally conscious as well, as shown in the competition task designed to simulate the rescue of endangered species.

Corporate Profile

To engineer an effective and reliable ROV, Oostburg and Ozaukee High Schools combined forces in a corporate-based, effective team set-up. The collective effort between two schools meant communication and delegation of tasks were of the utmost importance. Several key new positions were enacted this year, including the Director of Communications and Testing Coordinator, ensuring GEN4 was well-equipped to complete all mission tasks. CEO Eric Hartnett delegated specific tasks among the members, and worked to ensure they were completed by set deadlines. To maximize efficiency, labor was divided into departments including public relations, testing and practice coordination, accounting, and technical writing, as well as tooling, electrical, hydrodynamic, and frame engineering. Specialization and division of labor were key reasons for the success of GEN4. Due to the small size of ZO_3 Robotics, many members took multiple positions on their shoulders.

Communication between schools was a central concern this year, one that ZO_3 Robotics anticipated and met with technological reliance. With several kilometers physically separating students in two different schools, Google Docs, webcam meetings, and in-person meetings were utilized in order to work as a unified team. With a relatively new incoming team, much reliance was also placed on the only returning member and CEO Eric Hartnett, a veteran ROV engineer and source of steady leadership for the corporation. Eric used strict schedules and deadlines to connect the two schools and stay firmly on track, as well as ensure compatibility and integration of components Daily writing assignments for two technical writers in different locations, and engineering assignments for members working with different components of the ROV, were vital to ZO_3 Robotics. Google Docs' real-time editing was particularly effective, and allowed students to work collectively at any given time or location. Regular check-ups and meetings ensured the ROV continually progressed, and "GEN4 continued to Move 4ward."

Design Rationale

Each component of GEN4 has been carefully and individually engineered with past MATE experiences in mind, as well as foresight into the specific 2012 mission tasks. ZO_3 Robotics Inc. has discovered from previous experiences that mobility and maneuverability are critical aspects of any ROV; these attributes allow the ROV to be more successful by allowing a greater amount of time for task completion, earning more points during the mission. With this fundamental objective in mind, ZO_3 Robotics Inc. has been cognizant of each component as it was incorporated into the design of GEN4, aiming to decrease weight while increasing mobility. This principle has guided the team in making critical decisions regarding the frame, dry housing, tether, actuators, motors, tools, and sensors.

Frame

Our frame engineers chose Low Density Polyethylene (LDPE) as the main frame construction component of GEN4 for its high strength to weight ratio and low mass. 80/20 aluminum cross members are another main structural component. The basis of the ROV, LDPE, is a plastic with a density of .940 g/cm^3—a slightly positive buoyancy, meaning LDPE works with the dry housing to extremely effectively counter the negative buoyancy of GEN4's Tsunami motors (0.941 N), 101XD linear actuators (5.516 N), and electrical components with multiplexer (6.84 N), and yield near-neutral buoyancy. The structural engineers focused on Newton's Second Law of Motion as their guiding principle—Acceleration = Force / Mass—and sought to engineer an ROV with low mass and high acceleration. The LDPE design was drastically modified from previous years' designs to maximize structural strength and increase hydrodynamics; for example, the frame has been angled on both ends for hydrodynamic purposes, as well as to reduce mass.

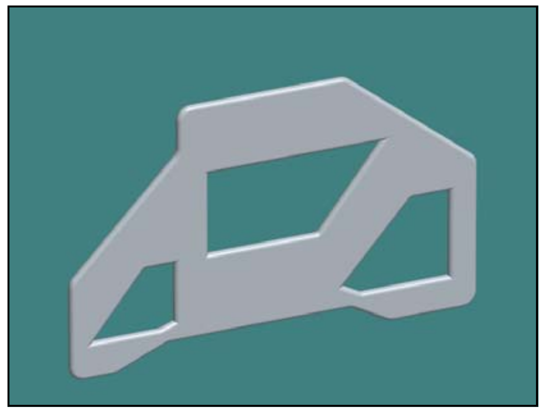


Figure 2. *Student CAD of one side of GEN4's frame*

There are no loose corners on the frame, and all components, including bilge pump motors, underwater cameras, and cross members, are integrated securely into the ROV. 80/20 cross members, with a density of 3.6 g/mL, proved both versatile and strong in construction and testing. 80/20's adaptability allowed ease in the integration of components, including motors, tools, and cameras. Coupled together, the LDPE and 80/20 aluminum create a lightweight, strong, yet adaptable frame.

Dry Housing

The dry housings are arguably the simplest yet most critical components to GEN4's success. The mission-critical electrical systems, such as the microcontroller, range laser and motor drivers, are not waterproof, and any intrusion of surrounding water would damage functionality. In researching enclosures, the electrical and mechanical engineers agreed a durable, waterproof, and preferably clear dry housing box was the best option; in GEN4, we have met these needs by including a IP68 polycarbonate submersible electrical junction box with a transparent cover to house the components.

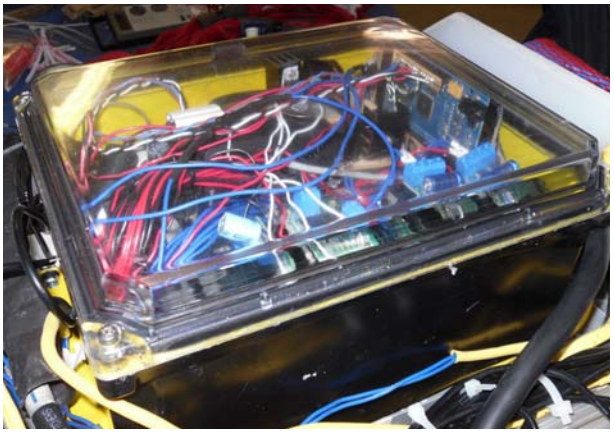


Figure 3. *Main dry housing protecting electronics*

To best position the range laser, an additional, smaller dry housing measuring 15 cm x 10 cm x 8 cm was added to the ROV's gripper arm. Our dry housing used here is a "dry box," intended for kayakers to keep valuable electronics in for water protection. Its position counteracts the weight of the 19 Newton aluminum gripper with the dry box's buoyancy, helping the ROV stay neutrally buoyant and parallel to the ground. The added advantage of this position is that the pilot can control the laser by angling the arm, thus accurately recording the length more quickly.

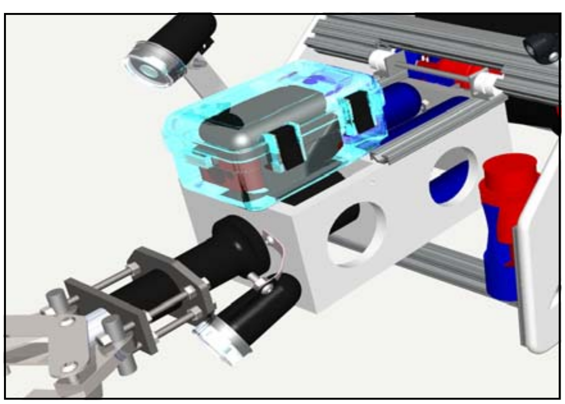


Figure 4. *Student CAD of laser dry box angled by gripper*

Along with protecting the electrical components, the dry housing provides positive buoyancy for the ROV, counteracting the negatively buoyant components—namely, the motors and aluminum cross members of the frame. Seeking a neutrally buoyant ROV, the Electrical and Mechanical Engineering Departments chose an enclosure large enough to house the electronics, small enough to fit the frame, and that would hold the appropriate volume of air to yield near neutral buoyancy. In addition to both dry housings, plastic bottles were added under the dry housing and gripper. Together, these additions have achieved neutral buoyancy for GEN4 in water.

Figure 6. *SubConn bulkhead connectors*

BULKHEAD CONNECTORS

The electronics inside the dry housing must be able to receive power from the tether and send power to the motors and receivers, yet cannot encounter water. The electrical engineers accomplished this using waterproof bulkhead connectors. The team possessed several bulkhead connectors provided in the past by SubConn Inc, and this year's Business Department contacted SubConn Inc. to receive a new 16 pin bulkhead connector and plug for use in GEN4's laser dry housing. ZO_3 Robotics utilizes a two pin 25 Amp bulkhead and plug used for electrical power, an eight pin bulkhead and plug used for the Cat5 Ethernet communications, and three 16 pin bulkheads and plugs for use in the other 43 cables used for motors, sensors, cameras, and other components. The SubConn bulkhead connector system lets the team easily remove the dry housing for service or transport by simply unplugging the bulkhead connectors and unscrewing four wing nuts. Each bulkhead connector is attached to the dry housing with a 3M Scotchcast 2130 epoxy, which provides a waterproof and flexible seal.

TETHER

Two types of cables run up the tether to transmit the analog video signals from the eight on-board cameras. A 17 meter shielded video cable transmits the multiplexed video signal from the four black and white cameras. This shielding prevents any electromagnetic energy generated by the motors from interfering with the analog signal. To transmit the video signals generated from the four color cameras, each camera's stock 17 meter, 28 AWG, 100 newton sheer-tested, cable runs up the tether. The cables are extremely flexible, so they do not limit the team's goals of mobility and maneuverability. Additionally, a flexible, fully submersible SubConn CAT5 ethernet cable runs up the tether to communicate with the microcontroller and the laptop.

The electrical engineers regarded the decision of appropriate wire gauge for power cables with mobility, maneuverability and efficiency in mind. First, the engineers compared the resistance, in ohms, of several different wires. This resistance was then used in Ohm's law, V = R * I, where V is the voltage drop (volts), R is the wire's resistance (ohms), and I is the current running through the power cable (amperes). The electrical engineering department measured 8 AWG wire's resistance as .08 ohms over the 18 m tether. With a constant resistance and a current draw ranging from 2.5 to 17 amps, Ohm's law states there should be a voltage drop of approximately .2 - 1.36 volts. In addition to consideration of voltage drop, power cables in the tether must not restrict GEN4's movement. The 8 AWG power cables are relatively flexible due to their braided wires and have an acceptable voltage drop the electrical engineers inevitably chose 8 AWG wire for powering the ROV. Moving to a lower AWG would only restrict the maneuverability and mobility while providing negligible performance improvements in voltage drop.

The video, communications, and power cables are all bundled together into a single braided cable sleeve. This keeps the multiple cables organized and reduces cable tangling. The sleeve retains the wires' ability to freely slide past one another, while granting additional mobility, maneuverability and flexibility to the tether and ROV. To maintain neutral buoyancy, grey foam was added in 0.8m increments along the tether. This also minimized resistance through the water, allowing more freedom to GEN4's operation.

Figure 5. *Umbilical cord of GEN4*

PROPULSION

Mobility and maneuverability play no more a key role in any other component of GEN4 than in propulsion. ZO_3 Robotics has learned from past experiences that although precision is critical underwater, speed is equally so. A combination of these elements is necessary to accurately and quickly complete the mission tasks. With electrical power at a premium, GEN4 must rely on motors and propellers that most effectively utilize the allotted 300 watts of 25 ampere, 12 volt power. To accurately compare different motor and propeller combinations, the Mechanical Engineering Department constructed a testing apparatus that utilizes Newton's Third Law of Motion to measure the reactive force as a rotating PVC rig is pushed by the motor. The team utilized a Vernier dual force sensor, with accuracy up to .001 Newtons, to determine the most powerful motors. It is also important to measure the current drawn, and accordingly the team measured both current and force while the motors were powered by a high current variable voltage DC transformer set to 3, 6, and 12 volts.

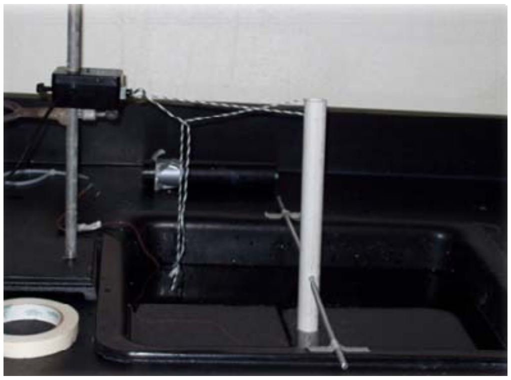


Figure 7. *Testing apparatus using force meter and lever to test motor efficiency*

Despite the major reductions in weight and improvements in hydrodynamics the team still wanted GEN4 to accelerate faster without adding more or new motors. This was accomplished by trimming the hard plastic motor guards down as thin as possible and adding new netted guard. By reducing the amount of plastic between the propeller and the outside water more water is able to flow through the guard with less friction and resistance. With both improvements made, GEN4 is able to deliver over 28 Newtons of forward force at an acceleration of 1.544 m/s^2.

The four thrust motors draw 16.8 amperes at full load and voltage. Our electrical engineering department is confident this current draw will not overload the 25 ampere limit when combined with electrical usage from other components.

Four lift motors are used on GEN4. The power of our lift motors allows GEN4 to descend to the bottom of the MATE ROV pool in thirty seconds.

To allow for greater speed and maneuverability while completing the mission tasks, GEN4 has two strafing motors. Strafing enables the pilot to quickly and precisely make lateral movements around obstacles or get closer to a task. This ability eliminates the need for Y-turns, saving precious time during the mission tasks.

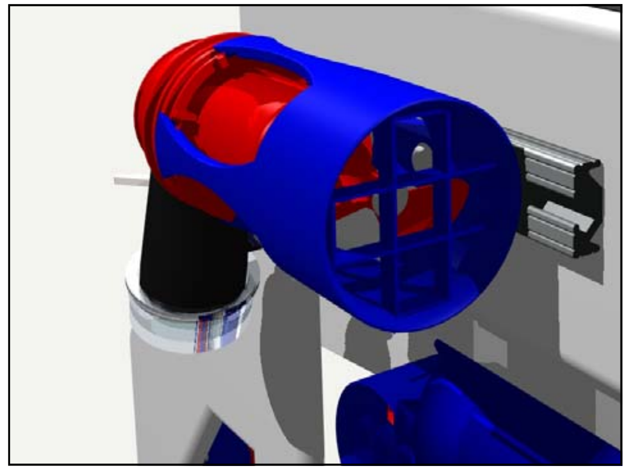


Figure 8. *Student CAD of motors and motor guards*

CONTROL SYSTEM

Hardware

GEN4's advanced electrical hardware includes Polulu 15V18 motor controllers and an Arduino Mega microcontroller with both digital and analog input pins. These were selected by our electrical engineers based on success in previous MATE ROV competitions. The digital control system gives the ROV pilot both precise control and the ability to complete the mission tasks smoothly.

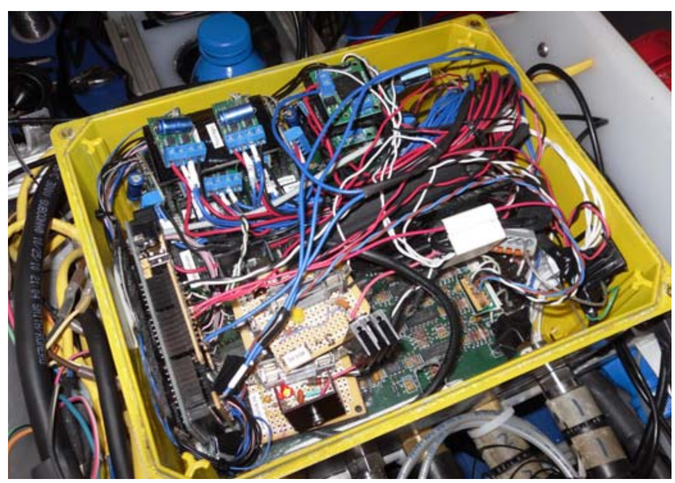


Figure 9. *Our hardware components, safe inside dry housing*

The electrical engineers' main objective in designing the hardware system was controlling the thrusters and actuators with the highest accuracy and precision attainable. The pilot's need to adjust the amount of power and vary the voltage sent to the motors soon became an issue GEN4 resolves using a motor controller called a full H-Bridge. A full H-bridge allows the team to adjust the amount of voltage and polarity being sent to each motor. Our Polulu 15V18 motor controllers incorporate a full H-bridge into their circuitry and have proven successful in previous ROVS. This particular controller allows for a maximum current draw of 15A each, at a max of 18V, and comes with 150 µf capacitors built in for filtering electrical noise. Additionally, the Polulu motor controllers are able to receive a Pulse Width Modulation (PWM) signal from the Arduino microcontroller. This PWM signal pulses on and off signals, with a varying ratio between the on and off signal at a high frequency, to control the amount of electrical power sent to the motors with exceedingly high precision.

The Arduino Mega microcontroller platform serves ZO_3 Robotics admirably, simply because the Arduino Mega is one of the most advanced and powerful Arduinos available. The Mega features 54 digital input/output pins, 16 analog pins, 128KB of flash memory for program storage and a 16MHz Atmel microcontroller/processor. Of the 54 digital pins, 14 can be used to send PWM signals, utilized in GEN4 to adjust the thrusters and actuators through the motor controller boards. The 16 analog pins are used to interface sensors and analog probes, such as the current sensor, depth sensor, electrical compass, and laser distance finder. Thanks to the powerful Atmel microcontroller and 128KB of flash memory, GEN4 processes the software code without lag or hesitation. To comply with MATE specifications, the microcontroller is powered by the top side 12V battery through an onboard 12V DC to 5V DC converter.

While controlling the ROV, the control system must be both easy to use and familiar to the pilot. GEN4 accomplishes this with the ever-popular PlayStation 2 (PS2) DualShock 2 controller. The ROV utilizes the dual analog joysticks for "tank-style steering," where the left joystick controls the left thrusters and vice versa. By using the analog joysticks for control of the thrusters, the pilot precisely controls the ROV's speed, crucial to adequately controlling GEN4 during mission task completion. The controller also has a variety of other buttons utilized for control, tools, and navigation.

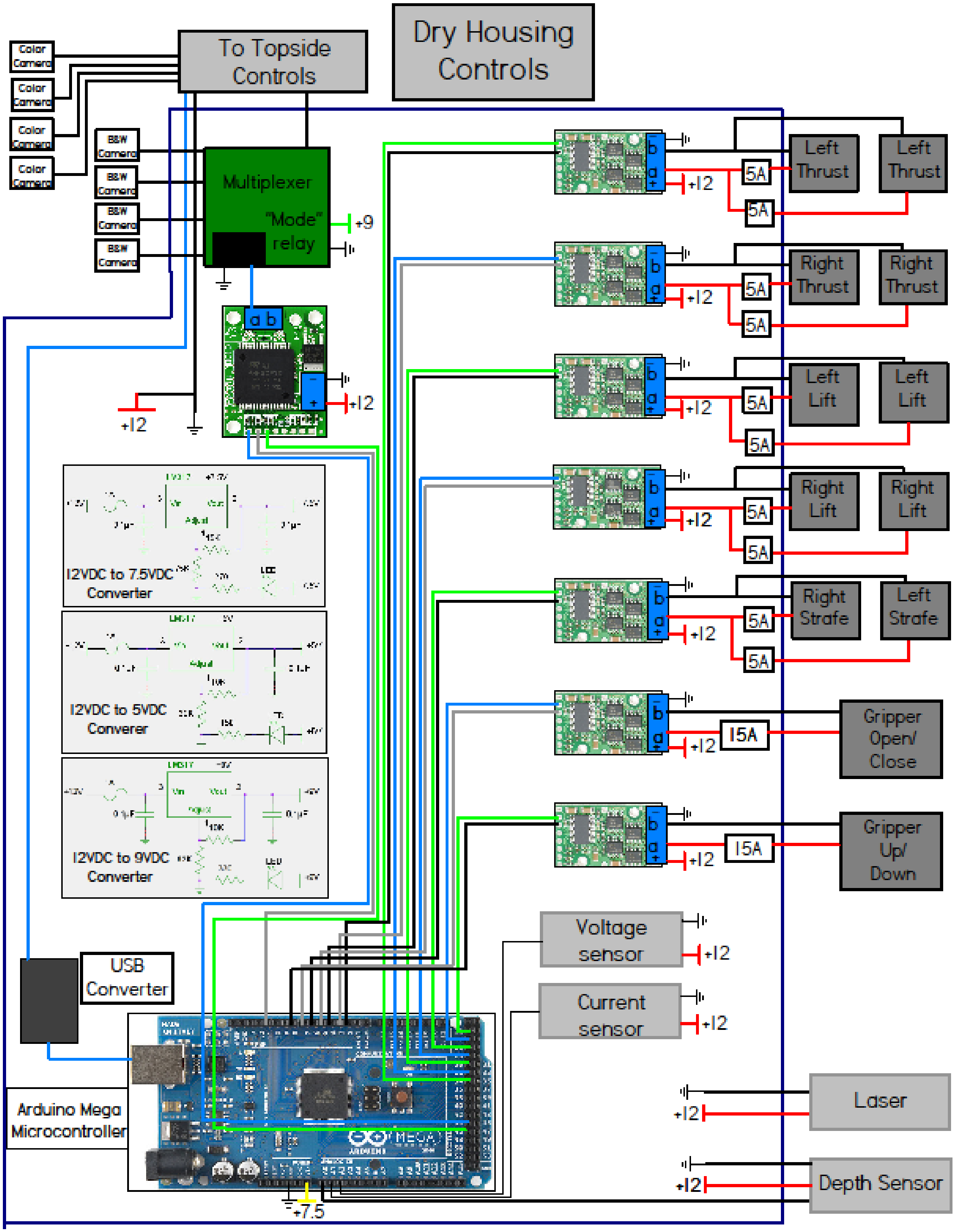
Figure 10. *PS2 Controller, with level analog sticks*

Software

GEN4's student-coded software can be broken into two main areas: software running the Arduino microcontroller and additional software running on the laptop. These software applications are equally vital in controlling the ROV and receiving usable feedback from the on-board sensors.

The microcontroller executes instructions stored on the 128K on-board flash memory that have been uploaded from a host computer over a serial connection. The microcontroller's code was written by the Software Engineering Department in C++ using the Arduino's integrated development environment (IDE). With the code in place, the microcontroller is able to send Pulse-Width Modulated (PWM) signals to motor controllers, which operate the thrust, lift motors, and actuators powering the gripper. In utilizing PWM, precision and control while operating the ROV is maximized due to the variable output signal strength. Additionally, the microcontroller collects analog signals from the on-board electronic compass, depth sensor, current sensor, laser, and accelerometer, converting them into human readable numbers to be displayed on the laptop graphical user interface (GUI). Accurate data collection is especially important when determining the orientation of the ROV, with regard to both the depth and the orientation relative to due north in the mission task.

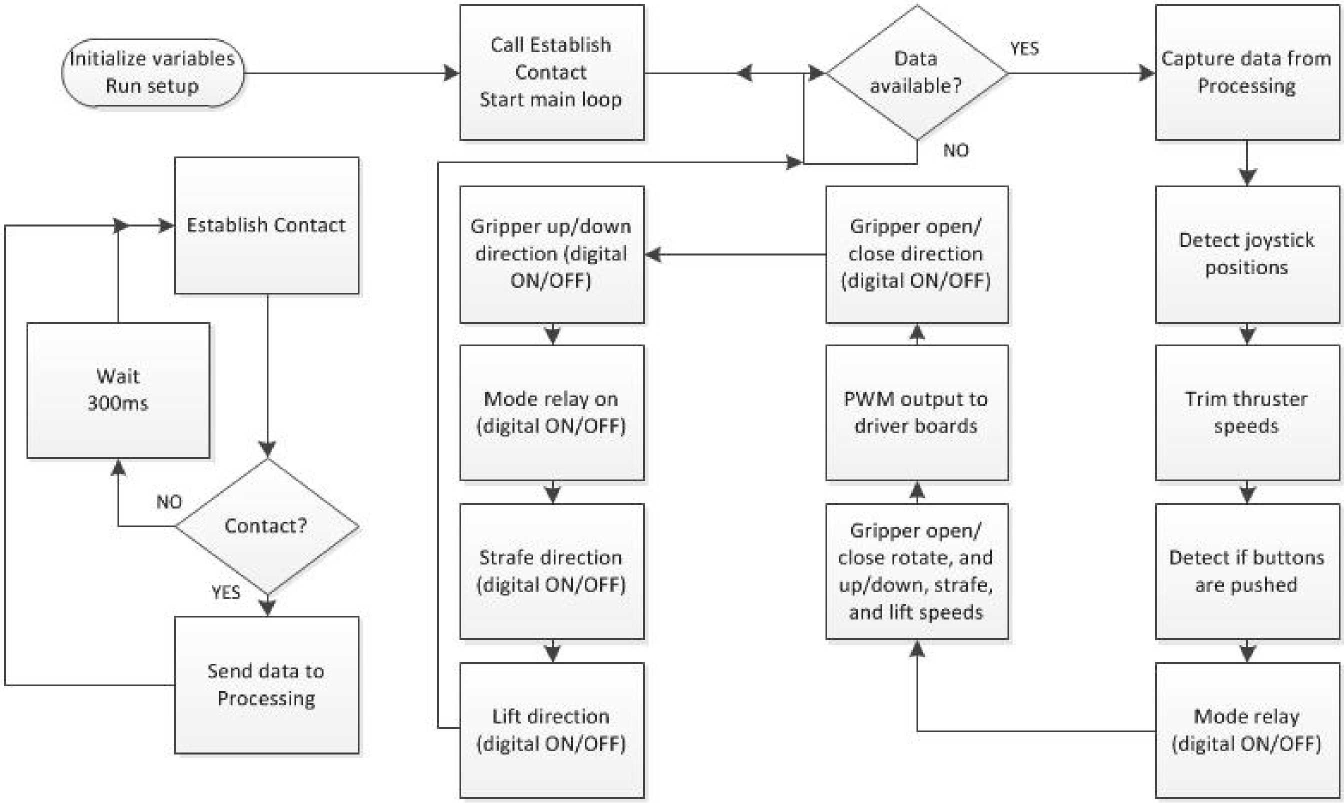
ELECTRICAL SCHEMATIC, DRYHOUSING



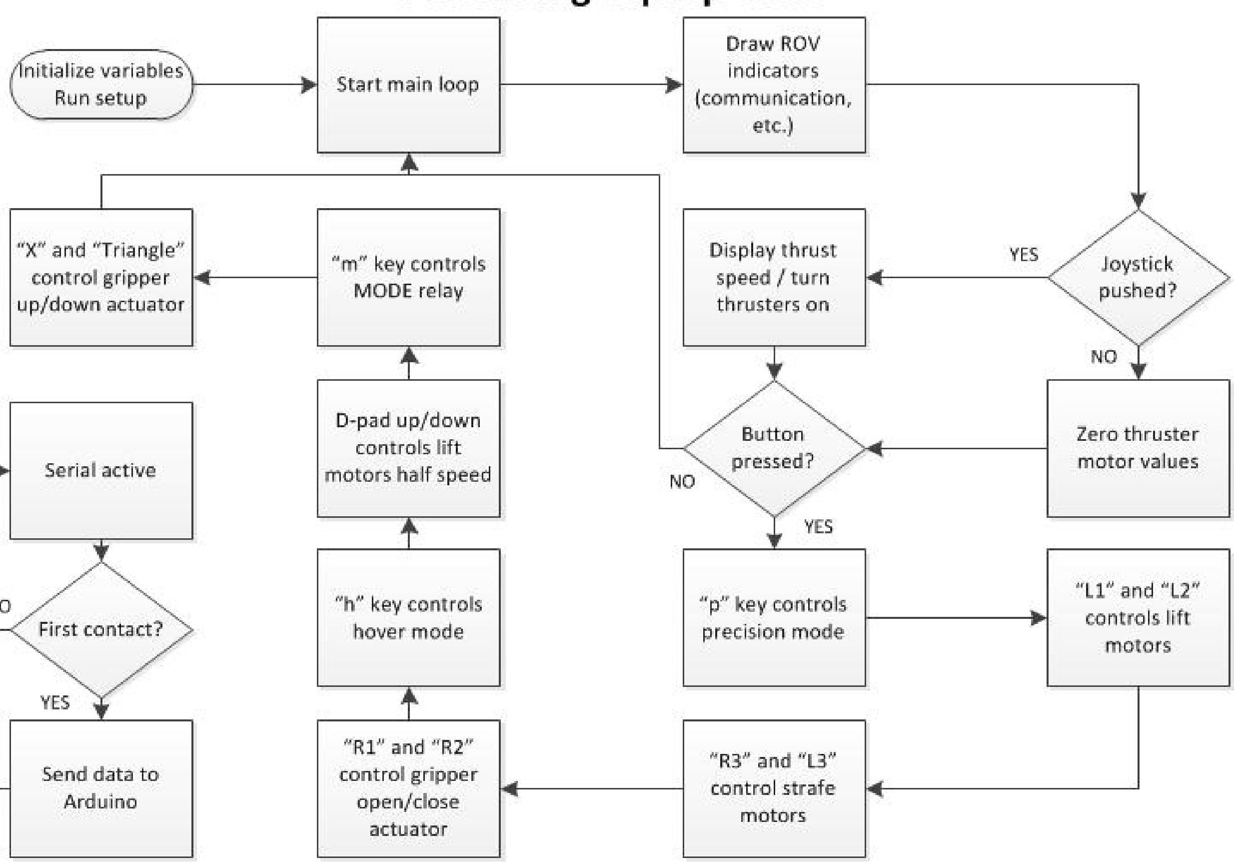
See Page 19 for the Schematic of Topside Electronics

SOFTWARE FLOWCHART

Arduino Microcontroller Code



Processing Laptop Code



The laptop executes software written in Processing. This software's primary responsibility is to monitor the ROV and send signals to the microcontroller. These signals alert the Arduino what and where it needs to reroute each signal, powering motors and actuators with high precision due to PWM. The program displays all necessary data regarding the ROV on the laptop for the pilot. This includes a thrust meter for both left and right motors, the status of the ROV's operation (gripper open/close, electrical current drawn, et cetera), a real time depth readout, and the magnetic heading. Additionally, the laptop collects input from its keyboard and a connected Playstation 2 controller. These physical inputs are then converted and relayed to the Arduino for additional processing. For a full listing of ROV controls and their corresponding action, see Appendix I.

Figure 11. *GUI screenshot on laptop of student-created code to control on-board Arduino Mega*

MODES

To ensure maximum maneuverability, different software modes were created for navigation and manipulation with tooling and on-board sensors. Each mode has a different purpose aimed towards completing specific mission tasks. In precision mode, the software code cuts the voltage supplied to all thrusters in half, enabling the pilot to easily make precise maneuvers and fine movements while still using the full range of the analog joysticks when picking up coral, piercing the oil tank, and attaching the lift bag. Another mode programmed into the microcontroller is ground mode, which engages all lift motors downward at 50%, keeping the ROV stable on the pool floor. This stability is imperative to the success of tasks such as moving the coral and testing the metallic properties of debris. An additional mode, reverse mode, is important for the pilot as it allows the ROV to move backward with the same joystick input commands as if it were traveling forward. To develop this mode, the software engineers reversed all the code's variables, allowing the pilot to watch the rear camera and move the ROV backward with the same input commands as if it were traveling forward. This mode is particularly important in piercing the oil tank seal, as the ROV probe is on the stern, requiring "backing up." The specialized capabilities of each mode allow the pilot to deftly perform each required task.

VIDEO

ZO_3 Robotics Inc. has experienced many difficulties with video processing in the past, but the team has settled on an analog video system integrated with two quadview multiplexers This system has proven stable and reliable, goals our company determined essential. This year's video system utilizes four 420p, 53^{o} narrow-angle black and white FishVu cameras, and four 420 TVL, 150^{o} wide-angle color AquaVu microcameras. Our Business Department obtained the cameras free of charge from AquaVu, as the company owner is an avid proponent of inquiry-based education and saw a strong connection with his product and the underwater nature of the MATE competition.

Figure 12. *Camera is positioned directly at the gripper*

The MATE competition requires a liquid ingress protection (IP) 68 rating, making the AquaVu waterproof components a clear choice for our Research and Development engineers. AquaVu cameras, targeted towards ice fishers, are designed as IP-68, full immersion (20 meters), and feature a compact low-mass design. The durability, water readiness, and low mass of these cameras make them an ideal choice for use with GEN4.

The four narrow-angle, National Television Systems Committee (NTSC) analog video feeds from the black and white cameras are combined into a single video signal by an on-board quad input multiplexor. These cameras are focused on individual tools and allow the ROV captain a clear, undistorted view of tasks requiring specialized maneuvering The on-board multiplexer reduces the amount of cabling required in the tether from four shielded pairs to one. To view one black and white cameras independently on the topside display, software code was added to the Arduino microcontroller to toggle the multiplexer view from a grid with four cameras to a full view of each individual camera when the laptop's "M" key is pressed.

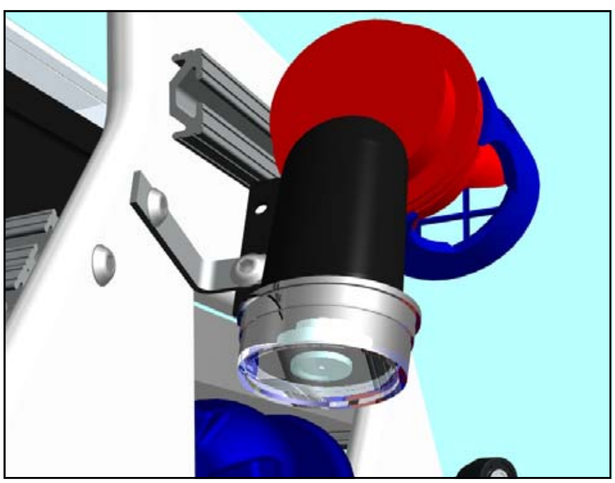


Figure 13. *Student CAD of one AquaVu black and white camera*

The four 150°, wide angle, color analog video signals travel independently up the tether through 17 meter, 28 AWG, 100 Newton shear test cables. This added cabling has negligible affects on the tether's flexibility, while allowing us to utilize a topside color multiplexer, video processing boards, and Phase Alternating Line (PAL)-to-NTSC video converter.

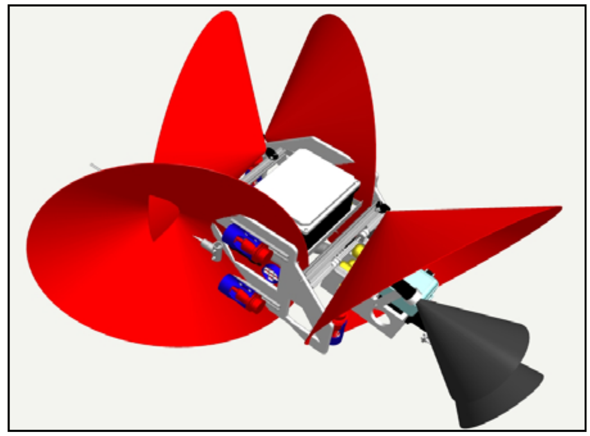


Figure 14. *Student CAD showing the view around GEN4 from each camera on GEN4*

GRIPPER

A major hindrance encountered with the gripper tool in the past was its high mass, unacceptably limiting GEN4. The Mechanical Engineering Department redesigned the gripper and removed obsolete components deemed unnecessary to operate on the *SS Gardner*. These changes have simplified gripper design, increased reliability, and reduced mass from 3 Kg to 1.7 Kg. The scissor-hinge gripper utilizes a Lenco Marine 101XDS underwater linear actuator to power opening and closing. Although this system is powerful, it has proven troublesome in drawing a high-current load, particularly when closing tightly on an object. This high-current draw is problematic because of the 25 amp fuse. The team has overcome this problem using a Pololu motor controller, which is able to receive PWM signals from the on-board Arduino microcontroller to limit the current drawn. With a lighter, more mobile design in place, GEN4 accomplishes tasks more efficiently; for example, the redesigned gripper has proven successful in relocating coral samples and resealing the oil tank with a magnetic patch.

MAPPING TECHNOLOGY

Orientation

Magnetic fields from the Earth are difficult to measure underwater, especially when accompanied

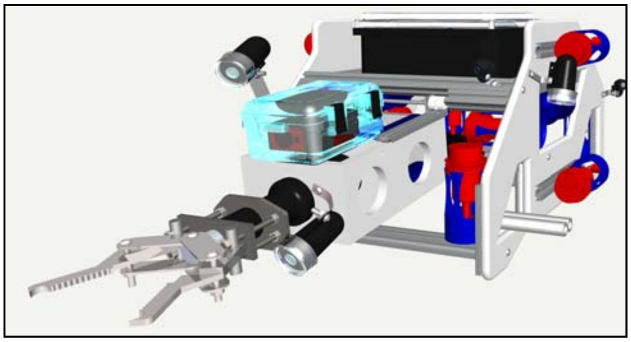


Figure 15. *Student CAD of the gripper on GEN4*

by ROV motors and other various electronics. To overcome this obstacle, GEN4 takes a magnetic and inertial approach to accurately determine the orientation of the ship. First, a tilt compensated Pololu LSM303DLM 3-axis magnetometer and 3-axis accelerometer is used to give orientation, in degrees, in accordance to Earth's magnetic field. Next an Inertial Movement Unit (IMU) consisting of an ADXL345 accelerometer and ITG-3200 gyroscope keep track of angular movement, also in degrees. The magnetometer is unstable when the motors are on, and can only be accurately used with the motors temporarily turned off. When the IMU is used alone, the gyroscope begins to drift and produce inaccurate results, but it is still stable when operated with the motors on. When both devices are combined, we have an orientation system able to keep track of angular rotation without drifting when motors are on or off. Such a system is commonly used on real ships and airplanes—where it is crucial to obtain accurate orientation in areas with large amounts of magnetic interference.

The orientation of the ship is represented on the on-screen GUI with an image of a compass, and can be calibrated to a new north at the press of the '0' key on the laptop. Additionally, a 3-axis model of the ROV showing its exact orientation is rendered in real time on the laptop's screen, giving the pilot a better perception of the ROV's position in the water.

Length Measurement

The ROV measures the length of the shipwreck in the water using a Banner L-Gage LT3 long range laser scanner. The laser is mounted on the gripper's arm to easily angle and point the laser at its target. Conveniently, the laser allows the team to choose the range at which it will "look" for objects and will not update any values unless an object is found in that range, because we calibrate it for a set distance. This is beneficial when scanning for smaller objects such as the ship's mast, as the laser only updates the distance when the laser hits the mast. The laser features 0-5 volt analog signal, which the Arduino processes. The Arduino also recalculates the laser's distance, because water is denser than air and has a refractive index of 1.33, so light travels more slowly in water than in air.

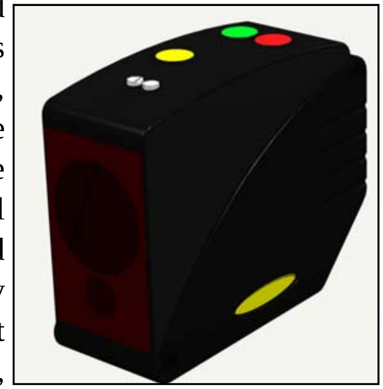


Figure 16. *Student CAD of laser*

Metal Detection

To discern between metal and non-metal debris in the mission, our engineers decided the most efficient and simple solution lay in using a magnet. The engineers designed the magnet to hang from a zip tie, attached near the front of the ROV on a threaded rod by the actuator. This location prevents the magnet from interfering with the gripper hardware or any other ferrous metal components of GEN4. To test the metallic character of the debris, GEN4 hovers over the grid point so the magnet hangs and will either attach itself to the debris if metal, or bounce harmlessly off if non-metal. One narrow-angle camera is positioned directly at the magnet, enabling the pilot to determine if the magnet has attached itself to the debris. The magnet utilized in GEN4 is the same type used to hang pictures from a refrigerator The research and development team members found this type of magnet strong enough to attach to the debris, but not too powerful for GEN4 to remove.

SENSORS

Depth Sensor

To make the ROV's hover mode feasible, the team's electrical engineers utilize a Keller submersible level hydrostatic depth sensor. The Arduino interfaces with the sensor by reading an analog signal from the sensor ranging from 0V - 5V, with a scaled maximum depth of six meters. The microcontroller scales the analog signal linearly and displays the depth on the GUI in real time. The depth sensor is accurate up to .02 cm. However, the microcontroller cannot take full advantage of the depth sensor's sensitivity due to the Arduino's limitation of reading only 1024 different analog values between 0V - 5V (.0049 volts per unit). Despite this limitation, the Arduino and probe are still capable of reading values accurate within two centimeters of the ROV's depth, accuracy more than sufficient for GEN4 to hover during tasks.

Figure 17. *Keller depth sensor*

Electrical Sensors

To ensure GEN4 does not blow the 25 amp fuses, the ROV uses a current sensor. The on-board CSA-1V Mini Bus Bar current sensor reads current by sensing the magnetic field formed when current passes through the wire. This sensor is capable of reading 30 RMS amps continuously and 50 amp peaks for under a second, making it more than adequate for the team's needs. The Arduino microcontroller reads analog values from the sensor and displays the current on the laptop screen. To safeguard against blowing the fuse the Arduino has code built in to limit the electricity going to the thrusters and linear actuators when it reads a value of 23 amp or greater.

The team uses a simple voltage divider that uses two resistors of 66.3K ohms and 27.4K ohms to bring the voltage to 3.5-4.0V. The Arduino is then able to directly read this analog value and display the scaled value on the laptop screen. Knowing the voltage, the pilot can verify the power source is not completely drained and that it will be capable of safely powering the ROV.

OIL EXTRACTION PROBE

When the second task culminates in collecting an oil sample for above-surface examination, GEN4 utilizes our custom-engineered and -built oil extraction probe (OEP). A 5-mm FESTO tube runs from poolside to the oil-collection proboscis, connecting two topside syringes to the shipwreck's oil tank. The tube runs alongside GEN4, where it is bolstered by an aluminum rod underneath, and protrudes from the ROV's edge for collection. During the second task, GEN4 inserts the proboscis through the plug. However, the end of the tube is sealed, to prevent the ship's seal from clogging our sucker system. The collection holes are instead carved into the side of the proboscis. When GEN4 is positioned with the sucker system probe in the oil tank, one engineer on the top uses the two syringes connected to the other end of the FESTO tubing to collect a sample of oil. Shortly near the abovewater end of the cable is a valve, which keeps the sucker system closed until utilized—at which time it is opened and the syringes are filled with air, emptied, and then filled with sample.

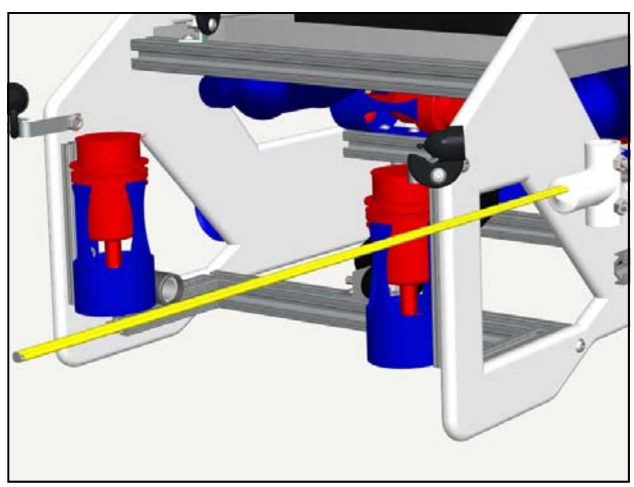


Figure 18. *Student CAD of Oil Extraction Probe (OEP)*

CHALLENGES FACED

TECHNICAL

To differentiate between colors underwater, GEN4 required on-board color cameras, four of which we received from AquaVu. The cameras the team received had their own LCD monitors (with a built-in video processing board), but these screens were too small and had poor viewing angles. As these did not fulfill our standards for viewing GEN4 underwater, we opened the LCD monitors/ processing boards to hook up a RCA cable for viewing on a TV. Once this cable had been carefully soldered on to processing board, the team connected the camera to a standard NTSC TV and discovered the frame rates did not sync properly. After research and contacting Aqua Vu about this issue, it was determined that the cameras output a 50Hz PAL signal—which is incompatible with a standard NTSC TV running at 60Hz. This challenge was overcome by passing the PAL signal through a PAL-to-NTSC converter. However, this only synced the frame rate for one camera. When the 4 cameras were passed through a multiplexer, the video output was black and white—and there were still syncing problems despite the PAL-to-NTSC converter. This was unacceptable in our search for a stable, color video signal. The team's electrical engineers concluded the problem lay with the multiplexer, and began research on a new multiplexer, finally finding one that supported PAL and ran off a DC power source. This solution was found elegant, fast and reliable—namely, ideal for GEN4.

INTERPERSONAL

The most difficult challenge for ZO_3 Robotics Inc. was connecting team members from Ozaukee High School and Oostburg High School. With 28 kilometers separating the two schools, the team utilized technology to close the distance gap Communication technology included texting, Google Docs, email, conference calls, Google chat and video conferencing. The team selected one member as the Director of Communication and utilized his talents to organize meetings and keep a line of communication open between the two parts of ZO_3 Robotics. CEO Eric Hartnett was also instrumental, as he had the greatest familiarity with everyone in both schools. With perseverance, and the willingness to seek open communication, all work on GEN4 was successfully integrated.

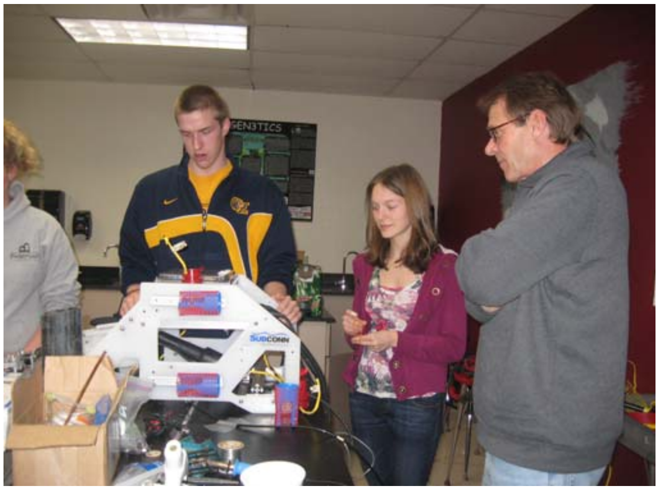


Figure 19. *The team displaying GEN4 to substitute teacher*

SAFETY

Dealing with ROVs mandates careful adherence to safety protocol. The most potentially dangerous parts of GEN4 include electrical shocks from the 12 volt, 25 amp power supply, spinning thruster propellers, and sharp edges, particularly on the gripper. ZO_3 Robotics, was careful at every step of the design and fabrication process to minimize all inherent risks. GEN4's positive leads are fused to all its motors, actuators, and pumps, so in the event of a motor overload or blown fuse, only the disadvantaged component will lose functionality. The electrical components are further protected due to our proper use of 18 gauge wire. Components consuming extremely high currents—for example, the actuator—are wired through the bulkhead connectors in parallel to split the current through several cables, reducing electrical resistance and heat.

Several precautions were also taken to protect team members, judges, and anyone else examining the

ROV. First, hazard stickers label potential perils such as sharp edges and electrical components, warning of possible dangers. Our propellers are protected with motor guards built ourselves from PVC cylinders, mesh, and Eggcrate wire light diffusers. Not only do these guards serve as a safety precaution, but also prevent MATE props from catching in the propellers, and allow our engineers to securely fasten the motors to the frame. The sharp sides of the gripper are wrapped in electrical tape, both as a visual warning and protection against cuts. As regarding personal safety, all team members wear safety glasses when engineering and piloting the ROV, preventing any danger to the face or eyes

TROUBLESHOOTING

An example of the trouble shooting process involves our placement of cameras to view every necessary area. To hook the lift bag onto the mast, we needed to have one camera trained on the J-Hook. However, a problem was observed when the camera's original placement—beneath the gripper—meant it would be crushed against the pool floor when Gen4 was at the bottom of the pool. The situation was carefully analyzed, and the team decided to attempt a solution. To remedy the situation, we tested the position of the camera in multiple positions, none originally satisfactory or even possible, until it was determined that we would attach it on the side of the gripper's holder. Upon observing the problem was resolved, the team concluded the troubleshooting phase.

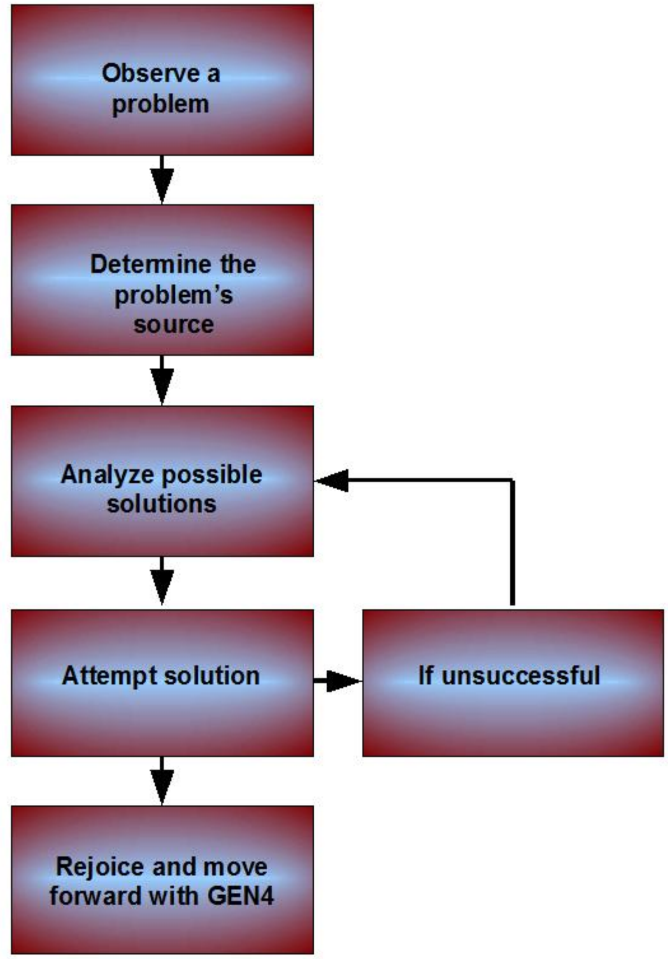


Figure 20. *Our troubleshooting process, utilized to great success*

LESSONS LEARNED

TECHNICAL

In a venture as momentous as the building of GEN4, a multitude of technical lessons are a given, but one concept our entire team studied was laser refraction in water versus air. When initially testing our laser, we realized it was measuring distance inaccurately in water. Beyond resolving the immediate problem, we saw the educational potential in the scenario. Some of the team realized it was due to a combination of refraction and reflection of the laser and brought everyone to the same level of understanding on the topic. The entire team was then able to develop a system to convert the laser's reading into an accurate measurement of distance. We also incorporated an examination of how the laser refracted in different types of water (e.g., chlorinated versus tap). In the end, not only did we utilize our troubleshooting process, but also took away knowledge.

INTERPERSONAL

The demanding challenge of cooperating and building a frame of teamwork provided the most valuable lessons for the members of ZO_3 Robotics. Collaboration was required at every turn for design, fundraising, construction, and connecting with the community. Every step leading to the completion of GEN4 demanded ideas and teamwork from a multitude of individuals. Although at times team members were hesitant to work together, inevitably results were better achieved when efforts were fully combined, whether in brainstorming, design, or construction. Engineering is a demanding field requiring much involvement stemming from many walks of life. Solving the tasks of the competition necessitated team members to not hold back, to unreservedly share all they had to give. Integrating our departments' multitude of skills and talents taught us that teamwork, as cliché as it may seem, does conquer all.

Figure 21. *ZO_3 Robotics, with GEN4 frame and AquaVu cameras.*

Future Improvement

In designing the ROV, our engineers discussed many technical options for proceeding with GEN4. One was the choice of propulsion power. An option considered was the purchase and utilization of Seabotix thrusters over our current Tsunami bilge pump motors. The electrical engineers calculated the Seabotix thrusters would have provided the same force with less motors, and so would have allowed more space on GEN4's frame. Unfortunately, due to the prohibitive cost of the Seabotix thrusters, we inevitably decided against their purchase. Even with the best efforts of our business department, they were beyond our means. We hope in future years, our team will find themselves prosperous enough to revisit a more powerful propulsion system.

"This **company, team, family** has been beyond excellent."

Reflection

"Nothing nears the experiences I have taken part in with the MATE ROV program and Ozaukee Robotics. It truly has been an intriguing two years of participation Besides the exciting times of Houston and others, my organizational and professional skills have vastly improved. Being the CEO of ZO_3 Robotics and attempting to balance athletics with academic work has been a struggle at times, but as cliché as it sounds, it returns the most remarkable of rewards. As well, my position has allowed me to acquire the professional skills required to create strong relationships with other corporations. Moving into the team aspect, this company, team, family has been beyond excellent. The challenges I have faced with the ROV team have been unique compared to all other teams I have been a part of. Albeit mostly athletic teams, and there have been plenty, I never had to coordinate nor plan events, or make critical decisions on the fly. All of these skills will become ever more essential in the great steps I will take in the near future. In close, I would like to thank all who have been associated with the program, and lastly Terry Hendrikse for his undivided support not only to the team but to the building of his students' lives."

–Eric Hartnett: CEO, Frame Engineer, CAD Designer

"I could not have asked for a better team to work with over this past ROV season. It has been great getting to know my physics teacher Mr. Hendrikse better along with getting to know some great mentors and students from Ozaukee High School. At first I thought it would be a challenge to work with students that I had never met before. However, this was not true and was quite the rewarding experience. All of the team members always kept me updated on GEN4's status despite the fact that I was not able to always be at Ozaukee working on the physical ROV, which really made me feel like part of the team and made the entire experience more enjoyable."

–Seth Opgenorth: Electrical Engineer, Technical Writer

"This [...] was quite the **rewarding experience.**"

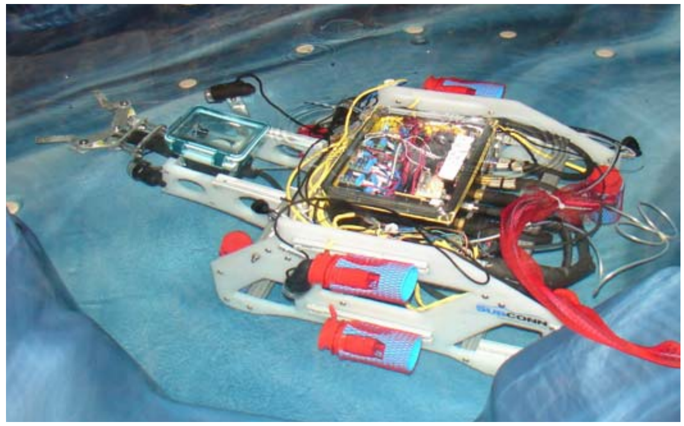


Figure 22. *ZO$_3$ Robotics, Inc. presents our underwater remotely operated vehicle, GEN4*

ACKNOWLEDGEMENTS

The team would like to thank all organizations, and individuals who donated supplies to and advised our members:

AquaVu Video—Donation of 5 color cameras
SubConn—Donation of bulkhead connectors
Atwood Marine—Donation of Tsunami motors
US Plastic Corporation—Donation of LDPE
Collins Engineering—Donation of dry housing
Platypus—Donation of Platypus bag
Steffen's Plumbing & Heating—PVC pipe, adapters donations
Anchor Plumbing—Dremmel tool and PVC adapters donations
Lenco Marine—Donation of linear actuators
80/20, Inc.—Discount on 80/20 Aluminum
Culver's of Port Washington—hosting fundraisers
Pick N' Save of Saukville—hosting fundraisers
Electrical Systems LLC and **Mr. Hartnett**—tool donations
MATE—hosting a great competition
Thomas Jefferson Middle School—providing a practice pool
Cedar Grove-Belgium High School—providing a practice pool
Ozaukee High School—providing facilities and support
Oostburg High School—providing facilities and support
Families of team members—for support

The ROV team also owes many thanks to a few individuals for their help, support and advice. Our fantastic instructors, **Eric Meinnert** and **Terry Hendrikse,** deserve thanks for giving team members focus and drive and helping the team reach its fullest potential. The team would also like to thank Mr. **Terry Browne** and **Randy Vogt** for their advice, insight, and support this season. Finally, the team would like to thank **Dustin Richter** for mentoring the technical writers at each step of creating the sometimes frustrating but inevitably rewarding report before you today.

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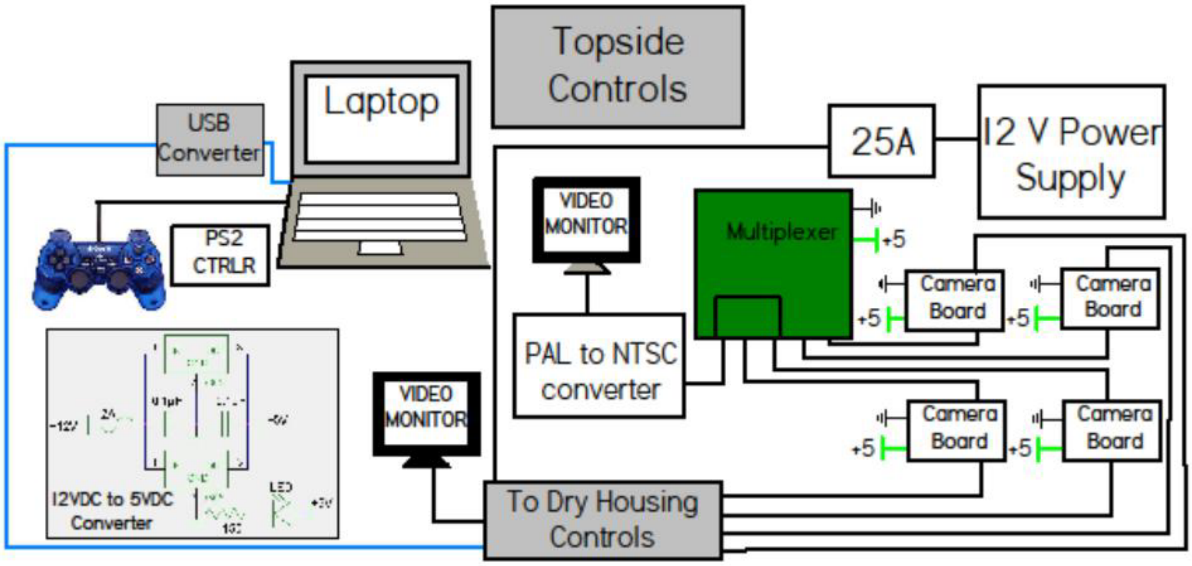
BUDGET/EXPENSE REPORT

Date	Transaction Type	Description	Donated Material	Amount	Balance
11/15/2011	Deposit	Funds from 2011		259.00	259.00
12/15/2011	Expense	Web Cam		-73.20	185.80
12/17/2011	Donation	Camera Donation – Aqua Vu	1549.45		185.80
12/20/2011	Donation	SubConn bulkhead connector donation	500.00		185.80
12/22/2011	Deposit	Candy Cane Fundraiser		65.34	251.14
1/3/2012	Donation	Monetary Donation – Sharon-Cutwell Co.		250.00	501.14
1/5/2012	Donation	Monetary Donation – Exxon Mobil		500.00	1001.14
1/6/2012	Donation	Monetary Donation – UWM Water Institute		200.00	1201.14
1/6/2012	Donation	Tsunami Motor – Attwood Motors	17.96		1201.14
1/6/2012	Donation	Monetary Donation – Eernisse Funeral Home		100.00	1301.14
1/12/2012	Donation	Monetary Donation – Neuens Fredonia Lumber Co., Inc.		100.00	1401.14
1/20/2012	Expense	Money paid to Stephen’s Plumbing for PVC pipe		-39.00	1362.14
1/25/2012	Donation	Monetary Donation – Lucy Janke		15.00	1377.14
1/25/2012	Expense	Material Expense paid to waterproof heat shrink		-50.69	1326.45
2/3/2012	Deposit	Profit Earned – Winter Brat Fry Fundraiser		182.39	1508.84
2/8/2012	Donation	Dry Housing Donated by Collins Engineering	87.00		1528.84
2/10/2012	Donation	Platy Bottle donated by Platypus	13.00		1528.84
2/10/2012	Expense	Money paid for 6 RCA-BNC Connectors		-3.67	1525.17
2/10/2012	Expense	Money paid for video security camera		-65.57	1459.60
2/10/2012	Expense	Money paid for video converter		-101.91	1357.69
2/10/2012	Expense	Money paid for swimming pool		-389.22	968.47
2/10/2012	Expense	Money paid for compass		-34.90	933.57
2/16/2012	Expense	Miscellaneous Expenses (Fundraisers)		-49.00	884.57
3/6/2012	Expense	Money paid for vacuum pump		-63.48	821.09
3/6/2012	Deposit	Money earned – T-shirt fundraiser		314.00	1135.09
3/13/2012	Expense	Money paid to Milwaukee Sporting Goods		-237.79	897.30

Electrical Schematic, Topside



Appendix I

GEN4 Controls and Action Keys

Button	Function
Left Stick	Left Thrust Motors
Right Stick	Right Thrust Motors
L1	Lift Up Full
L2	Lift Down Full
D-pad Left	Pump 1
D-pad Right	Pump2
D-pad Up	Lift Up Half
D-pad Down	Lift Down Half
L3	Strafe Left
R3	Strafe Right
X	Gripper Down
Triangle	Gripper Up
R1	Gripper Open
R2	Gripper Close
Start	Reverse Thrust Motor Control
M Key	Mode Relay To Switch Camera View
H Key	Hover key (to remain at constant depth)
G Key	Switch to ground mode (lift motors slightly down)
P Key	Precision Mode (for precise maneuvers)

APPENDIX II

MATE ROV TASKS AND CORRESPONDING GEN4 COMPONENTS

Task	GEN4 uses
Measure the overall length of the wreck	Banner Laser (see page 13), Laptop readout (see page 8, 11))
Determine the orientation of the ship on the seafloor	Pololu LSM303DLM 3-axis Magnetometer and 3-axis Accelerometer (see pages 12-13), Laptop readout (see page 8, 11)
Create a map of the wreck site with a sketch, length, orientation, and location of debris	Above-water Velcro mapping system
Determine if debris is metal or non-metal	Refrigerator Magnet (see page 13), Ground Mode (see page 11)
"Scan" ship at two target locations	Precision Mode (see page 11), AquaVu color cameras (see page 11-12)
Transport and attach a lift bag to the U-bolt on a fallen mast	Gripper (see page 12), Precision Mode (see page 11)
Inflate the lift bag so the mast ascends to surface	Gripper (see page 12), Integrated Lift Bag System—copper tube and supplied air pump
Remove and transport endangered coral from the hull to an unoccupied square in the grid	Gripper (see page 12), Ground Mode (see page 11)
Place the ultrasonic thickness gauge sensor on the hull	Gripper (see page 12), Precision Mode (see page 11)
"Calibrate" the neutron backscatter device by placing it on the calibration tank	Gripper (see page 12), Precision Mode (see page 11)
Place neutron backscatter device on the hull	Gripper (see page 12), Precision Mode (see page 11)
Simulate drilling a hole into fuel tank through a layer of petroleum jelly and retrieving a sample	Oil Extraction Probe (see page 14), Reverse Mode (see page 11)
Reseal the drill hole with a simulated magnetic patch	Gripper (see page 12), Precision Mode (see page 11)
Return a volume of sample to the surface side of the pool for company retrieval	Oil Extraction Probe (see page 14)