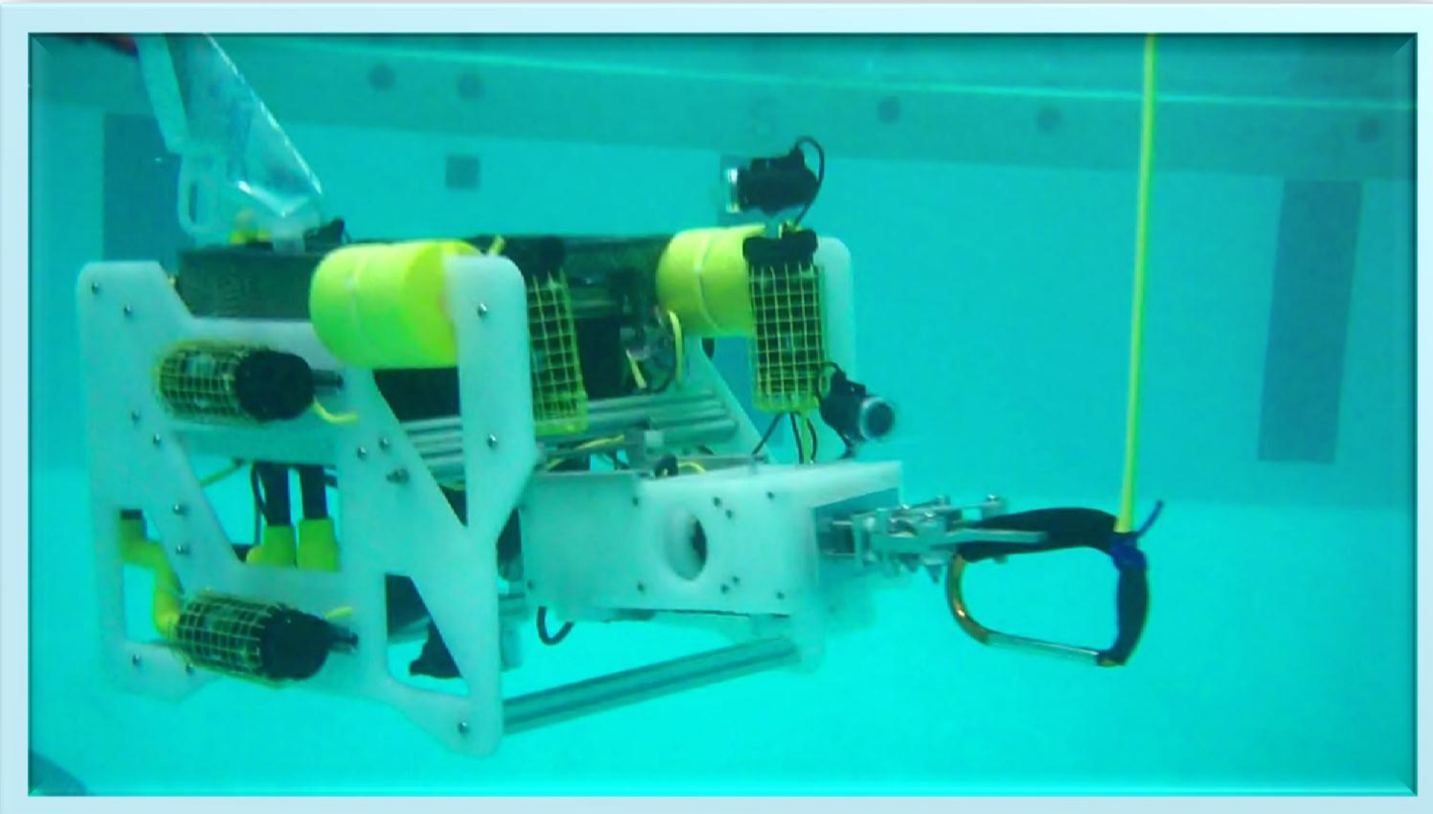
Ozaukee High Robotics

Ozaukee High School – Fredonia, Wisconsin

GEN3



Team Members

Dustin Richter – CEO
Jeff Kresse – Technical Writer
Nick Vogt – Programmer/Electrical Engineer
Eric Hartnett – Computer Aided Design
Dominic – Gripper Engineer
Matt Demler – DSS Systems Engineer
Joey Leiphart – Research and Development
Mitch Janke – Frame Engineer
Andrew Habich – Frame Engineer
Sandra Kotzian – Frame Engineer
Ali Hughes – Creative Design
Elliot Thome – Business Director
Alex Burmesch – Accountant
Clara Paulus – Practice Coordinator
Terry Hendrikse – Instructor / Mentor
Randy Vogt - Mentor

Table of Contents

Abstract……………………………………………………………………………….……3
Competition Mission……………………………..…………………………………….........3
Team and Corporate Profile…………………………………………………………………..4
Corporate Mission……………………………………………………………………….... 4
Design Rationale……………………………………………………………………………. 5
-Frame...……………………………………………………..……………… 5
-Belf...…...……………………………………………………………………… 5
-Dry Housing ……………………………………………………………...…… 6
-Bulkhead Connectors………………………………………………………… 7
-Tether……………………………………………………………………………. 7
-Propulsion……………………………………………………………………….. 8
-Control System………………………………………………………………….. 9
- Hardware………………………………………………………………………9
-Software………………………………………………………………………...10
-Electrical Schematic………………………………………………………….... 11
-Software Flowchart…………………………………………………………….... 12
-Video…………………………………………………………………………………… 13
-Gripper………………………………………………………………………………… 13
-Depth Sensor…………………………………………………………………….... 15
-Modes and Applications……………………………………………………………15
-Double Sucker System (DSS)………………………………………………… 15
Safety………………………………………………………………………………………… 15
Description of Challenges…………………………………………………………………16
-Technical Challenge…………………………………………………………….... 16
-Nontechnical Challenge……………………………………………………………..16
Discussion of Troubleshooting Techniques…………….……………………………… 16
Discussion of Future Improvement……………………………………………………… 17
Lesson Learned……………………………………………………………………………… 17
-Technical………………………………………………………………………………… 17
-Interpersonal………………………………………………………………………….....18
Reflections………………………………………………………………………………… 18
Budget Expense Sheet………...…………………………………………………………….. 19
Acknowledgments………………………………………………………………………… 20
References…..…...……………………………………………………………………………20
ROV Controls and Action Keys……………………………..……………………..….. Appendix I

ABSTRACT

The Ozaukee Robotics Corporation is focused on exceptional engineering, original work, and responsibility. The team's business orientated approach proved efficient in the fabrication process, as every team member understood their responsibilities. Even though time eventually became an obstacle, our corporation contends its specialized departments are responsible for superior vehicle systems. To achieve this goal, we designed our remotely operated vehicle (ROV) to have increased acceleration by utilizing powerful motors and a low mass frame. Another aspect of design was developing a multifunctional gripper to simplify the control system and perform numerous tasks. Its precision and utility are perhaps the most significant assets to the ROV. A student coded digital control system was chosen as the best way to display our technical prowess, as well as ensure a precise and accurate control system. The ROV was designed specifically to complete the mission tasks, similar to the way engineers built ROVs specific in resolving problems associated with the Deepwater Horizon Oil Spill. The ROV is not only quick, powerful, and precise, but it is also safe. Extensive precautions were taken to negate any risks from the electrical system, moving parts, or sharp edges. Although many technical and interpersonal challenges were faced along the way, the team showed great resolve in overcoming these obstacles. As the third generation in the line of Ozaukee Robotics, Gen3(Generation Three) proves, "GEN3-TICS IS ALWAYS EVOLVING."

COMPETITION MISSION

The Deepwater Horizon oil spill was triggered by the Deepwater Horizon drilling rig explosion on April 20, 2010. The catastrophic event quickly became the largest offshore oil spill in US history. Along with the loss of eleven lives during the initial explosion, the oil spill had vast and far-reaching affects unforeseen to many at the time.

The devastating effects of the oil quickly proved to be both destructive and unforgiving. Thousands of mammals, birds, turtles, fish, and many other species were all affected by the spill. While many animals died directly as a result of the oil intoxication, others experienced indirect problems associated with migration or reproduction. The tolls placed on the marine specimens quickly were passed onto humans, as extreme economic repercussions took place as well. Fishermen were unable to fish, and the tourist industry lost hundreds of thousands of dollars as a result of the incident. Even conservative estimates place the total monetary damage at tens of millions of dollars.

The tasks presented for this competition are intended to represent the actual tasks performed by ROV's during the Deepwater Horizon Oil Spill. In essence, the task also simulates the need for young minds to think collaboratively and create innovative solutions to future problems. The first step taken by ROV's to prevent the flow of oil included cutting and removing the damaged riser pipe, which was spewing up to 5,000 barrels of oil per day. Next, ROV's utilized a method known as a "top kill." In this procedure, heavy mud is pumped into the wellhead, attempting to slow the flow of oil. Next, a Lower Marine Riser Package (LMRP) was installed on the wellhead to fully stop the flow of oil. While attempting to stop the flow of oil, measurements such as depth, location, and water sample measurements were taken to obtain vital data. Finally, many biological specimens were collected by ROV's to help determine the effects of the oil spill, as well as attempt to provide assistance to animals and other organisms in need of assistance. As evident, throughout the Deepwater Horizon ordeal, ROV's proved very useful and played a large role in absolving the delicate situation.

Figure 1 - Initial explosion of oil rig in Deepwater Horizon Oil Spill

TEAM AND CORPORATE PROFILE

In order to tackle the daunting task of incorporating the various elements of the ROV, our team opted to develop an intricate corporate structure. Initially, all team members completed applications, as if applying for a job. Each team member summited a résumé listing strengths, weaknesses, and interests in regards to the various available positions. Our CEO, Dustin Richter, worked with Mr. Hendrikse to determine assignments for each member, with the intention of placing every member of the team in an appropriate position where they could perform proficiently. More importantly, the positions were determined by analyzing the individual skills of each member and placing them in a role where they would be most beneficial towards the cumulative effort of the entire corporation. Division of labor and specialization of tasks became key components of the corporate structure, and the stringent organization along with leadership from members such as the CEO, played a large role in the success of the team. The broad categories of the positions are as follows: Frame Engineering, Electrical Engineering, Administration, Accounting, Research and Development, CAD Design, and Business Relations. Each specific position lies in one of these corporate departments.

Once the corporate skeleton was formed, the next task was to build a virtual nervous system. With our school's integrated Google email system, each team member was issued an email address and used it to develop and share documents within our school's domain, so that the administrators (Dustin and Mr. Hendrikse) could always be aware of the work being completed. The real time editing is effective and efficient when working outside of class time; to be able to get feedback and advice from other team members while documents are being written is a unique advantage of Google Docs. The communication revolution is not only internal, as the team developed a website (ozaukeescience.com) and sent weekly updates to sponsors to inform corporate stakeholders of the Ozaukee Robotics progression.

Figure 2 – 2011 Ozaukee High Robots Team Photo

In order to stay on schedule, the corporation utilized shared Google Docs listing all uncompleted work in a logical sequence. Each member was assigned specific tasks to complete by the CEO, who worked each Sunday night and developed a detailed list of tasks needed to be completed each week. The list was constantly updated as tasks were completed, and new ones made available. To manage the urgency of each task, a simple color code of white (urgent), yellow (extremely urgent), and red ("you may not leave until this is finished") was adopted so the team would meet its various self-imposed deadlines. Because the design was partitioned into several different departments, the evolution of each system took place simultaneously. This added an unforeseen integration phase, however, which took up valuable time. Nonetheless, the team was able to work together and produce a refined and efficient ROV capable of performing all mission tasks presented by the competition

CORPORATE MISSION

The mission of the Ozaukee High Robotics Corporation is to design, engineer and manufacture the most efficient and versatile underwater ROV in the world (at least in the MATE Ranger division). ROV's just like Gen3 are utilized in real-life situations, such as stopping the flow of oil in the Deepwater Horizon oil catastrophe. It is the goal of the Ozaukee Robotics Corperation to engineer an ROV that is able to perform each of the simulated mission tasks as provided by MATE, ultimately removing the damaged pipe and stopping the uncontrolled oil flow. The corporate structure of Ozaukee High Robotics was vital to the success and accomplishments of the team. A steady leadership role and direction for the team was provided by the team's CEO, Dustin Richter. Furthermore, Dustin worked tirelessly to keep the team on track and ensure each member was accomplishing specific tasks, specifically designed to help the group collectively function as a corporation and maintain a proficient means of production.

DESIGN RATIONALE

A major epiphany for Ozaukee Robotics arose from the experience in the 2010 MATE ROV competition: a quicker ROV is better. Faster mobility and maneuverability provide more time to achieve tasks, thus earning more points in the pool. This principle has been the guiding focus for the design process this year and has been a core value in decisions related to motors, frame materials, and hull hydrodynamics

Figure 3 - Students cutting frame sides from LDPE

Frame

Prior to designing the frame, our structural engineers researched various water resistant products including 80/20 aluminum, carbon fiber, Low Density Polyethylene (LDPE) and polyvinyl chloride (PVC). It was this research that guided the team in selecting a combination of these materials in the construction of GEN3. LDPE is low density (.910–.940 g/cm^3) plastic with positive buoyancy, and it is essential in countering the heavier component's underwater weight (Tsunami motors: 0.941 N, 101XD linear actuators: 5.516 N, electrical components including multiplexer: 6.84 N, etc). The use of LDPE as the frame material supports the team's engineering goal of achieving a low mass, high acceleration ROV as engineered around Newton's Second Law of Motion: Acceleration = Force / Mass. In addition, LDPE has a high strength to weight ratio, proving beneficial for attaching various components, including the bilge pump motors, underwater cameras, and 80/20 aluminum cross members. The business department found US Plastic Cooperation very supportive as they donated a 1.27 cm thick, 1.22 square meter sheet of LDPE to our corporation free of charge. 80/20 aluminum was chosen as a cross member and motor mounting material because it is light weight and versatile; it proved essential in the attachment and adjustment of various components. 80/20 aluminum has a density of 3.7 g/ml, and is an alloy consisting of 97-99% Al, <1% Si, and <1% Mg. In addition to its low mass, this material will bear 2.413 x 10^8 Pascal's of pressure before any deformation occurs. This is roughly double the pressure found at the bottom of the Mariana Trench (the deepest part of the world's oceans) and is only a fraction of the pressure found at the location of the Deep Water Horizon catastrophe site. In addition, 80/20 aluminum has an additional layer of corrosion protection, making it essential in underwater applications such as building an ROV. The versatility of the 80/20 aluminum grants our engineers the ability to quickly and easily fine tune motor placement, tool location, and camera positioning.

Figure 4 – Student rendering of 80/20 Aluminum, the cross-member used for the frame

Belf

One of the major obstacles the team faced when designing and engineering the ROV was trying to fit all the components in a small and compact space. Faced with the stark realization there was very limited room for a biological species basket between the dry housing, rear lift motors, linear actuators, and double sucker system (DSS), our three frame engineers discussed several options. Early stages of options included a simple basket fastened to the bottom of the frame, so the gripper would retract and drop the specimens in the basket. However, the location of the linear actuators would not allow for proper basket placement or range of motion. Our new design places the basket/shelf (belf) combination on the top of the frame. The new belf permits the gripper to securely deposit its payload on top of the frame by rotating the gripper vertically 155^{o}. In this design, the belf includes a depression, which is engineered to secure and contain the glass sponge, sea cucumber, and Chaceon crab. In addition to being a biological basket, the belf serves as a shelf to hold the water sample collecting reservoir bag.

The frame engineers chose to form the belf out of a double ply carbon fiber Kevlar weave in a twill pattern utilizing a reverse mold technique. The twill pattern provides both flexibility and strength which are essential in draping the fabric around the tight corners during layup. The inwoven Kevlar provides an incredibly strong backbone for the fabric. The reverse mold technique allows for a completely customized shape straddling the dry housing and wrapping around the rear lift motors with very little added mass or volume. The Kevlar also brings the added benefit of bullet-proofing the ROV, dismantling any danger of underwater sabotage. Our

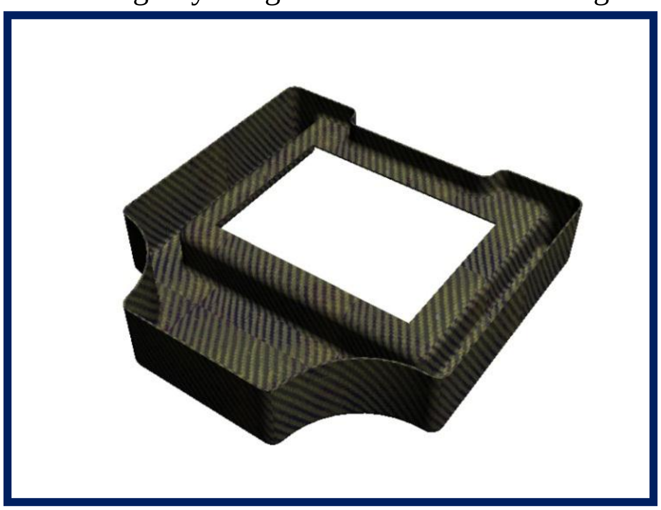


Figure 5 - Student rendering of the "belf." A basket shelf to collect biological specimens and allow the team to view into the dry housing

chosen strand count for the carbon fiber is 3K tow, meaning that there are 3000 microfilaments forming each strand of the carbon fiber. This versatile material is the most common industrial version of carbon fiber and our frame engineers feel it has a good balance of strength and weight.

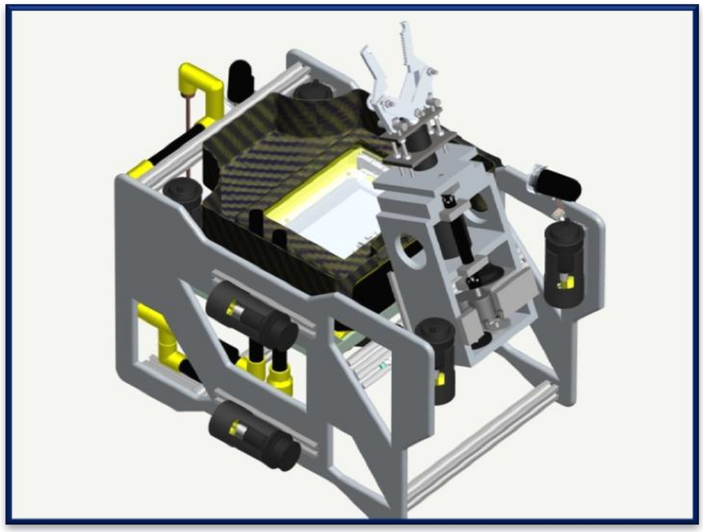


Figure 6 – Student CAD drawing of gripper arm in the upward position, placing a biological specimen in the belf

Dry Housing

The dry housing is unquestionably a very vital component of our ROV. Since all the controls and other monitoring equipment are electronic and involve complex circuitry being housed underwater, extra precautions must be taken to ensure the integrity of our electrical systems. Because of this, our electrical engineers recommended using an IP68 polycarbonite submersible electrical junction box with a transparent cover for easy viewing of electronic status LED's and potential water seepage.

Equally as important, the dry housing provides positive buoyancy to counteract large components and motors. Therefore, our dry housing was a major point of discussion in the design, and our electrical and mechanical engineers had to reach a compromise. Nick, the electrical engineer argued the enclosure needed to be large enough to safely house the electronics, yet the frame engineers argued it must not be overly large in order to maintain the goal of neutral buoyancy without adding a massive ballast system. To help make an accurate buoyancy estimate, the frame engineers precisely measured all the ROV

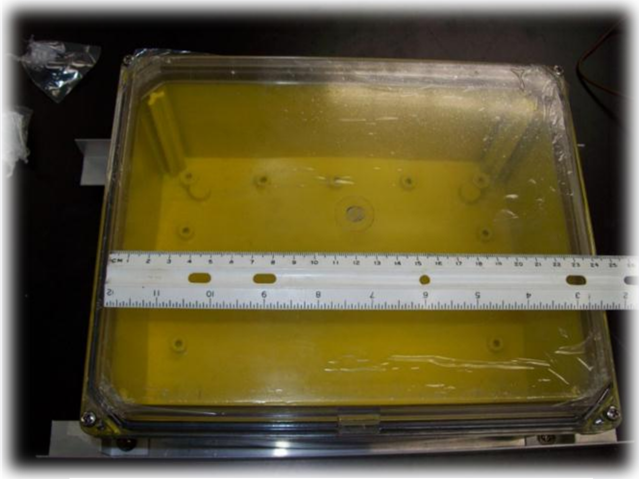


Figure 7 – Integra Enclosures Dry Housing

components and calculated the optimal size of dry housing by creating an Excel spreadsheet. After construction of the ROV, however, the team found the ROV negatively buoyant resulting in the installation of two 610 cm^2, PVC capped "buoyancy tubes."

The final decision regarding the dry housing was to use an electrical enclosure, which was graciously donated to our corporation by Integra Enclosures. The enclosure is made out of polycarbonate and has a volume of 7450 cm^3 (enough space to comfortably house all of our driver boards and other essential communications equipment), an easy access screw-on clear lid, providing the ability to easily view for leaks and read the flashing LED codes on our electronic circuits without having to open up the enclosure. The dry housing has an International Protection Rating (IP Rating) of IP68. An IP68 (or IP69) component rating is necessary in building a shallow-water ROV, signifying our enclosure is completely impervious to intrusion by dust, and is also submersible in shallow water. To test the water resistance, our frame engineers submerged the dry housing underwater at 0.0625 atmospheres of pressure for 24 hours prior to installing the electronics.

Bulkhead Connectors

In order to maintain the "dry" status of our dry housing and allow electricity to enter through the wall from the outside without water leaching in through nicks in the insulation and wicking through the braided cable, our electrical engineers made it a high priority to use waterproof bulkhead connectors. Our business department contacted SubConn Inc. and found this company helpful and generous in providing our corporation with a two pin 25 amp bulkhead and plug to use as power, an eight pin bulkhead and plug to use for the Cat5 Ethernet communication, and three 16 pin bulkhead connectors to use for the other 43 cables used for motors, sensors, cameras, etc. Another added advantage for using the SubConn bulkhead system is the dry housing can easily be removed for service or transport by simply unplugging five connectors and unscrewing four wing nuts. All electrical bulkhead connections were potted using 3M Scotchcast 2130 epoxy (donated from a local electrical distributor), which provides a waterproof and flexible seal.

Figure 8 – SubConn bulkhead connectors drilled into dry housing

Tether

As the alternative term "umbilical" suggests, the tether is both metaphorically and literally a life giving piece of equipment for any ROV. The constraints of the MATE Competition required a tether capable of three main capabilities: video, power, and communication.

In order to transmit the analog video signals, the team utilized a 75 ohm shielded video cable, preventing any disturbance in the video feed. The shielding functions to intercept electromagnetic energy generated by other components, which would otherwise reach the center of the coax cable, affecting the ability of the cable to conduct the analog signals. After much discussion concerning the power cables, the team decided to make use of 8 AWG wires. The electrical engineers recommended this size wire by calculating the voltage loss associated with different wire gauges. After carefully considering the limited (.08%) loss of less than one volt, and its relative flexibility, the team was able to agree on 8 AWG. Finally, the team upgraded to a fully submersible, flexible and water-proof SubConn CAT5 Ethernet cable for communication.

To complete the tether and combine the individual components, the video, power, and communication wires were wrapped in a braided cable sleeve. Aside from the obvious benefits of grouping and organizing the series of cables, the sleeve allows for the wires to retain the ability to slide past one another, granting extra maneuverability and flexibility to the tether. Finally, foam was added in .8 meter increments along the tether in order to maintain neutrally buoyancy and minimum resistance while operating the ROV.

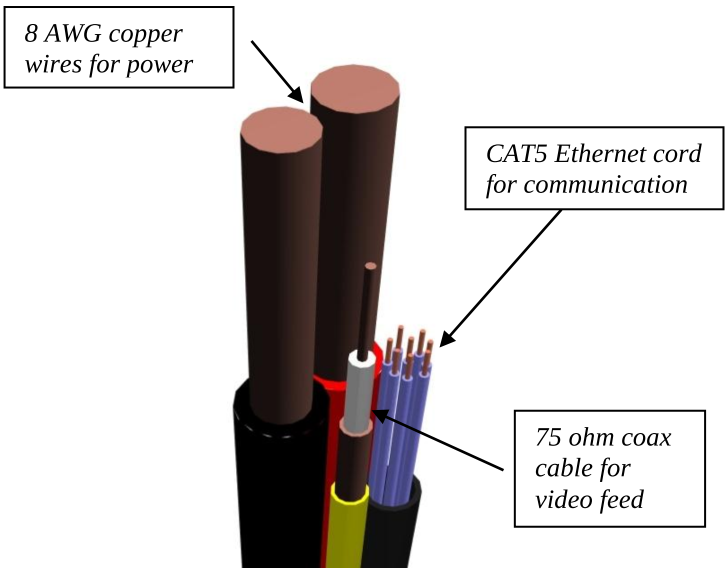


Figure 9 – Student rendering of tether and components

Propulsion

Propulsion is a fundamental element of the ROV, as pertaining to both motility and stability. One of the greatest lessons learned from the Gen-1 ROV in the 2010 regional competition is that a precise combination of fine motor control and speed is necessary in accurately and quickly completing mission tasks. Our Research and Design specialists' primary task was to acquire a bilge pump motor / propeller system that could efficiently utilize the allotted 25 amperes. To achieve this goal, they constructed a basic testing apparatus, which employed Newton's Third Law of Motion to measure the reactive force as a rotating PVC rig was pushed by the motor. Data was collected with a Vernier dual force sensor, providing data accurate to .001 Newtons. In testing the force, our research team used a potentiometer to regulate voltage being converted by a 12 volt, high current, DC transformer. The team used several multimeters to measure the current and voltage while measuring the motor force at three, six , and twelve volts.

As efficiency was identified as being our primary concern, the data was plotted on the basis of force per amp: efficient amperage to force ratio and the system. Our R&D recommendation for thrust included using four Tsunami T1200 motors and counter rotating Octura 1250 propellers, which our business department acquired free of charge from Attwood Marine. The evolution in using four T1200 thrust motors provides significantly more force and acceleration over the 2010 G1 ROV. Specifically speaking, Newton's 2nd law calculates the 2010 G1 ROV at .31 m/s^2 and our new G3 acceleration at 1.875 m/s^2, which is a 600% increase in horizontal acceleration! At full voltage and load, the thrust motors will draw 16.8 Amps, a usage our electrical engineers feel comfortable will not overload the 25 amp limit when combined with the electrical usage from other components. Additionally, four identical motors were used for lift. These motors were

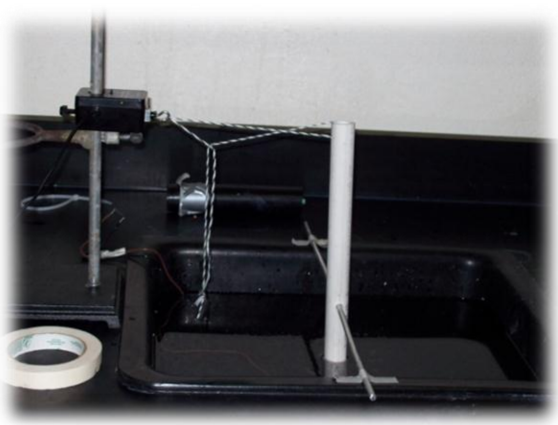


Figure 10 – PVC rig measuring force generated by different combinations of motors and propellers

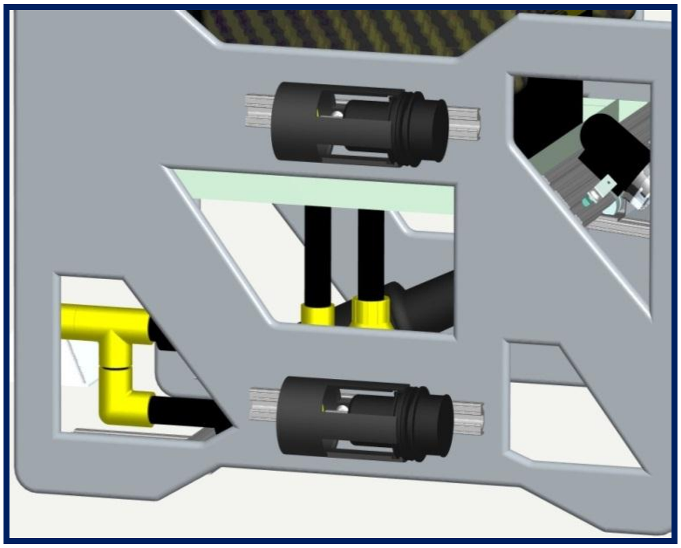


Figure 11 – Tsunami T1200 thrust motors found on side of GEN3's frame

strategically placed as far to the corner as possible, not only to ensuring the gripper and actuator system would be able to travel its full range of motion unimpeded, but also because it offers maximum stability to the ROV, particularly when attempting to turn the valve 1080 degrees in task one. Newton's 3rd law states the reaction force on the ROV frame will be equal and opposite to the action force of the gripper turning the valve. In the event our ROV starts to roll while completing this task, our pilot will press the "Select" button, which automatically causes the starboard lift motors to pull up and the port lift motors to pull down, thus counteracting any detrimental ROV roll.

Two, T500 have been included in the ROV underbelly for the purpose of strafing. Strafing ability allows the pilot to quickly shift position laterally around obstacles, rather than having to back up and turn to one side or the other.

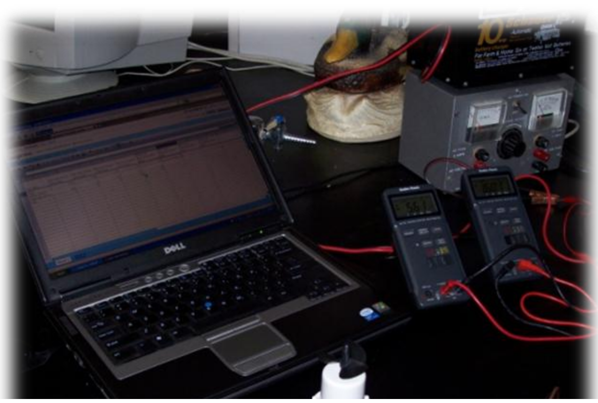


Figure 12 -Laptop and multimeters being used to measure current and voltage while motors are powered at different voltages

A surprising result of the motor tests is that smaller props are more efficient than larger props. This is likely due to the much lighter weight of the props, which are only 2.4 grams, compared to the other 17.17 gram props. Our chosen propellers are a mere 50 mm in diameter, and are made out of lightweight plastic. Other tests featured beryllium-copper propellers with a diameter of 5.08 cm. Our hypothesis in motor testing was the wider props would provide more thrust, but in reality we discovered the pitch of the propeller plays a greater role in thrust generation.

Control System

Hardware

The Ozaukee ROV Corporation has never seriously considered any other control scheme besides digital, as simple double throw double pole (DTDP) switches would not be appropriate in the digital age of the 21st Century. More importantly, our corporation places great value in the precision and maneuverability that metal-oxide-semiconductor field-effect transistors (MOSFET) provide when utilized in a Pulse Width Modulation (PWM) capable H-bridge circuit. In harnessing the power of the MOSFET, our business department worked with Polulu and negotiated a deal (50% off of all purchases) making them our exclusive motor driver representative.

The team seized the opportunity to create a control system mimicking one of the digital delights of pop culture: video game controls. Nick Vogt, the tech-savvy programming prodigy of the company, was assigned several tasks relating to digital function and control of the ROV. Building off a background in coding, Nick created the control system governed by a PlayStation 2 controller.

This particular controller was chosen because of its joystick layout. The controller is mapped so the left and right analog sticks control the left and right thrust motors, respectively. This analog input is essential for producing variable thrust because it is easily translated into digital PWM by the microcontroller and variable speed by the motors. With the PS2 controller, the analog sticks are level and set evenly on the controller; unlike the controllers of some newer consoles (the popular Xbox 360 controller has one stick lower than the other). This perfect symmetry allows for more precise and natural control of the motors, creating a smooth and accurate trip for the ROV.

The Arduino Mega is a superior micro-controller, and is a piece of equipment bearing paramount importance to the function and well-being of our ROV. The team opted to reuse the Mega from G1, as its sophisticated interface allowed for an easier and familiar programming assignment. The Mega has 54 digital pins that can be used for input or output, and fourteen of these can be used for the PWM voltage transmissions that control variable power the ROV's thrusters. There are also 16 analog pins, which set the Mega apart, allowing for interfacing various analog probes and sensors including the onboard depth and current sensors. In order to comply with MATE specifications, the Mega is powered externally through an on-board DC to DC converter, although it is capable of receiving power through Universal Serial Bus (USB).

Figure 13 – PS2 Controller, with level analog sticks

Software

The Arduino Mega receives its instructions through a program (developed with the Processing-derived Arduino IDE) hosted in flash memory on the board itself. This program, developed by Nick, interprets the inputs from his separate Processing program (which also builds the graphical interface) and appropriately shuffles voltage to the appropriate places in order to complete the commands of the pilot.

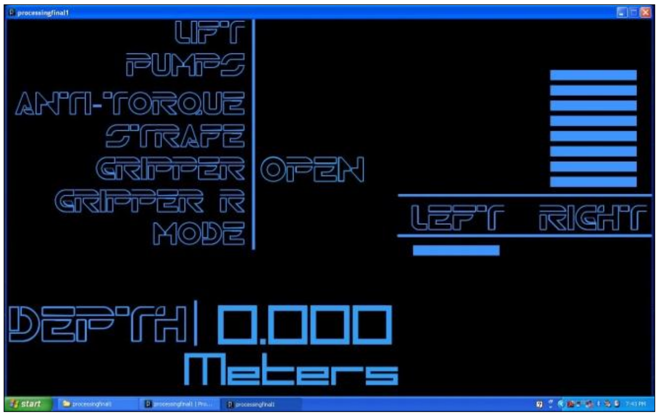
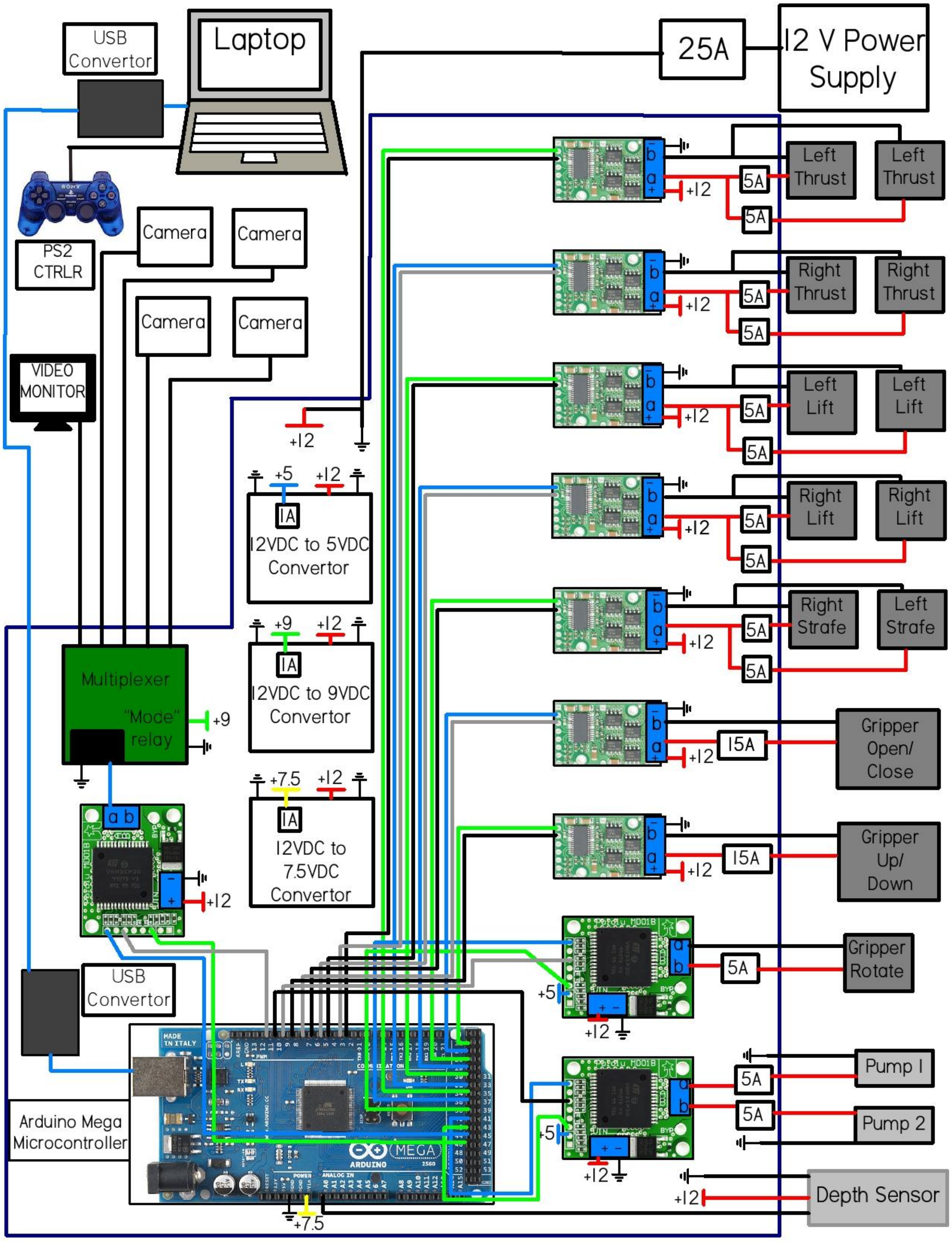


Figure 14 – Program created and written by student, to control the on board Arduino Mega

Both home-brew programs for controlling the ROV and monitoring its performance were developed by Nick Vogt using the Java derived programming languages Processing and Arduino. The Arduino program is uploaded to the Mega board's 128k on-board memory, and its primary function is to distribute signals to the motor boards and to relay the depth sensor readings to the primary user interface. This interface, written in Processing, displays all of the necessary data for the pilot: a thrust meter for both left and right motors, toggle-type displays for the status of all ROV operations (gripper open/close, suck, anti-torque etc.), as well as a real time depth readout. This program is also the interpreter of all physical inputs, and is responsible for relaying control signals to Arduino. For a listing of ROV controls and their corresponding action keys, see Appendix I.

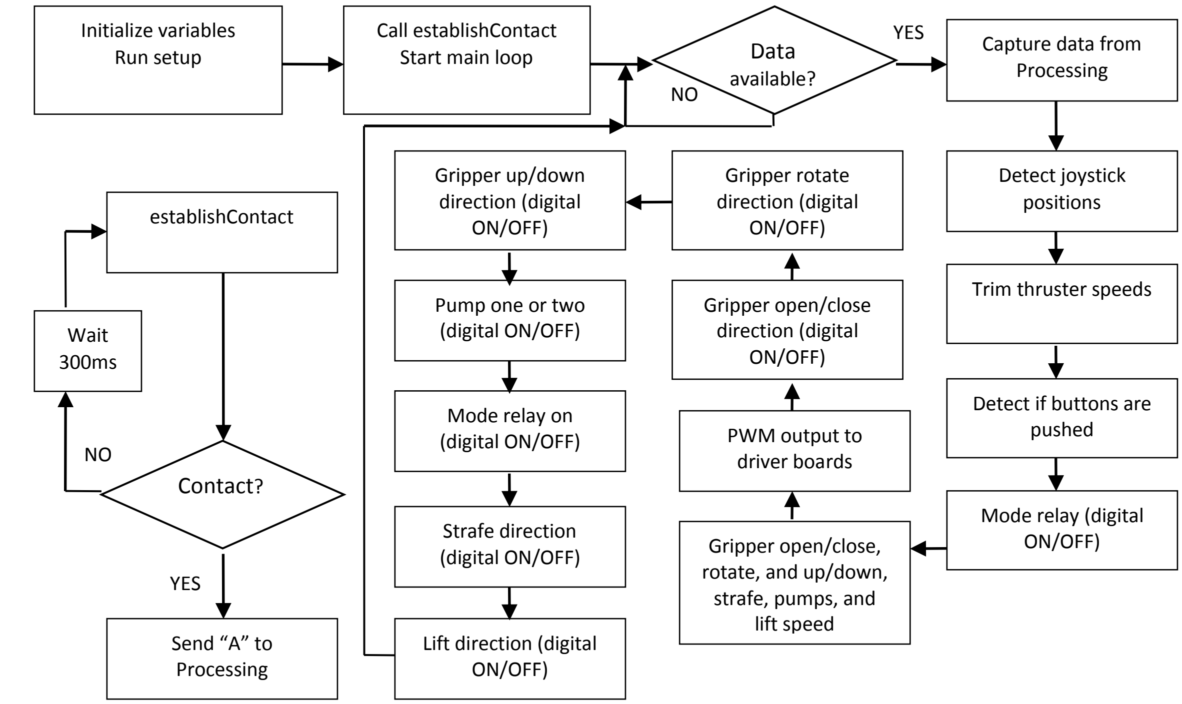
The Arduino serves primarily as a router for low current electrical signals used to control the motors through motor drivers. Nick and Dustin did considerable research in this area and decided on Polulu 15V18 motor drivers because of their small size, high power 15 amp capacities, and PWM ability. In addition they are sold with a 150 μF capacitors that reduces electrical noise, a problem that plagued G1 by scrambling communication between the computers. Without these MOSFET driven H-bridge chips, the motors could not receive the required voltage and high current loads, and G3 would be dead in the water. The new motor drivers use the input motor voltage to run the processing chip requiring fewer wires than the older models used in G1.

Electrical Diagram

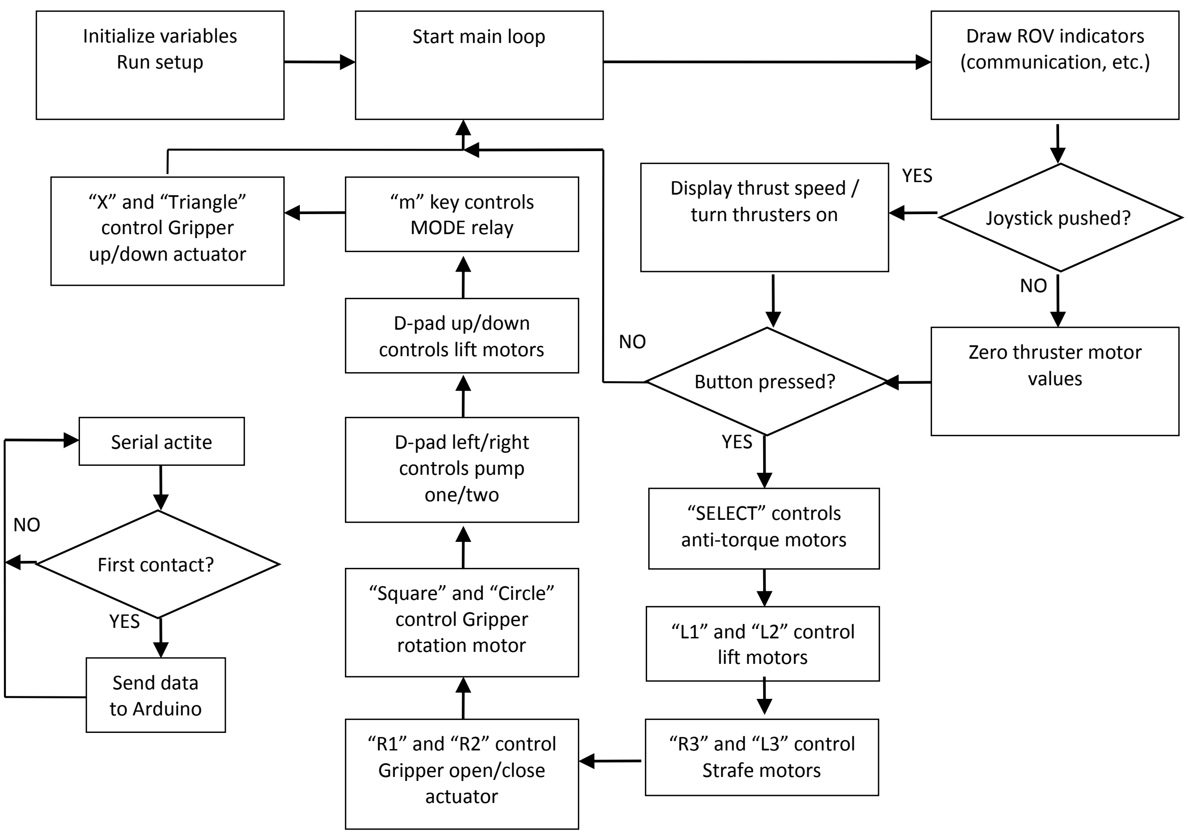


Software Flowchart
Block Diagram

Arduino Code



Processing Code



Video

The cameras last year were the company's ultimate downfall; the processing power required to run the two on-board pan, tilt, and zoom (PTZ) webcams simultaneously was beyond what the Core 2 Duo 1.83 GHz fueled laptops could handle. A lagged video feed was periodically produced or the computer crashed altogether. To prevent this in the 2011 competition, our Research and Development department explored all options (faster computers, lower quality webcams, closed circuit cameras (CCTV)) and recommended analog video as they are able to stand alone from any complicated circuitry or processing requirements. By contacting the manufacturer, our business department was able to obtain four standard definition (480p x 640 pixels) FishVu black and white cameras free of charge.

Figure 15 – FishVu camera

These analog signal cameras are integrated by an on-board quad input multiplexer to allow up to four video feeds to appear on the same screen. The decision was made to expend extra effort in mounting the multiplexer in the dry housing because it would significantly reduce cabling in the tether. Nick, our electrical engineer, was able to network the Arduino microcontroller with the multiplexer and write code in the Graphical User Interface (GUI) so that pressing the "M" key on the laptop keyboard changes the camera view from a grid with all four cameras to a full view of each individual camera. To ease the installation process and increase reliability, the team unanimously agreed a waterproof video solution was necessary. The FishVu is marketed as an ice fishing camera, and we were able to strip the heavy lead plates normally cloaking the camera without removing the waterproof shell. By reducing the mass of each camera by 335 grams, we achieved our goal of a quicker ROV while still maintaining the reliability of analog video.

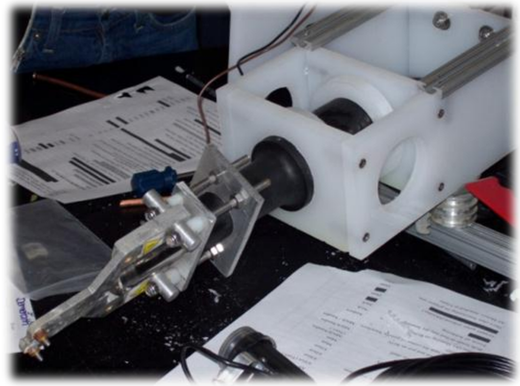


Figure 16 – Photo of gripper arm

Gripper

Our team started the entire ROV building process with a brainstorming session with the goal of designing a multipurpose tool to accomplish the majority of the mission tasks. The team quickly closed on a multi-axis claw-shaped gripper. This common tool allows for accessible and versatile manipulation of objects and accomplishes several tasks, including pulling off the Velcro from the riser pipe, picking up the biological samples, rotating the shutoff valve, clipping a line to the U-bolt, placing the T-handle for the "top kill," as well as capping the well. The claw is opened via a scissor hinge connected to 5.7 cm stroke Lenco Marine 101XDS linear actuator with fail safe slip clutches on both

Figure 17 – Bottom view rendering of gripper arm

ends of the stroke. The slip clutch prevents the actuator from electrically overloading as it extends or retracts to its maximum limit. This was one of the main problems faced in testing the claw closing in on an object. Since the full range of the actuator is not reached when the claw is partially open, the slip clutch is not engaged and the motor begins to strain. At 12 volts this strain produced a 30 amp draw which would surely blow its fuse. To remedy this, our programmer Nick changed the PWM / voltage received by the gripper from the Arduino; from a full 12V to only 3V while closing, and 6V while opening. These measures reduced the maximum amp draw to 7 root square mean (RMS) and 11 peak amps, while still allowing enough power to the actuator to firmly grip all targets.

Our gripper was designed from the start to be mobile, rotate clockwise and anticlockwise up to 1500^o, as well as tilt up and down 155^o. To rotate the gripper, our tool engineer Dominic connected a 1900 L/hr bilge pump motor to a series of gears that provide a mechanical advantage of 170:1. The objective of turning off the oil flow control valve is greatly simplified by having the capability to rotate our manipulator. The tilting capability is essential for picking up the biological samples and depositing them in the belf on top of the ROV frame. This is accomplished by an 11 cm stroke length Lenco Marine 102XD trim-tab linear actuator providing the input force for a type III lever. This type of lever is similar to the hinge joint of an arm. Because the gripper needs to hinge a considerable distance (38 cm arch) from the pool floor to the over frame belf, Dominic had to engineer the lever with a 0.29 mechanical advantage. With any other system, power availability would have been a concern in this type of maneuver, but we found it is easily within the actuator's 3375 N maximum force limit.

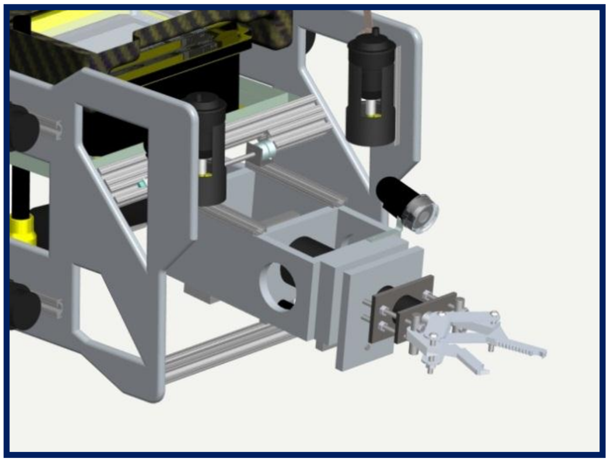


Figure 18 –Top view rendering of gripper arm

An initial problem the team faced in regard to the gripper was the plastic RC car gears being used to enable arm rotation, which were frequently stripping from the torque generated by the load on the arm. As a result, the team purchased more reliable and larger module one stainless steel gears. 303 ss was chosen for the smaller gears because of its high level of hardness and corrosion resistance. The larger gear needed to be milled to fit around the linear actuator, so Dominic decided on a 416 ss gear, compromising lower corrosive resistance for softer more workable material.

Power Sensors

After facing problems associated with inadequate power in the regional competition, the team decided to incorporate additional sensors to monitor and regulate the performance of the ROV. For safety reasons and due to the 25 amp limit placed on all electrical components, the team installed a CSA-1V current sensor from GMW Associates. The current sensor is wired in line with the main positive power entering into the dry housing and measures the current passing into the ROV. It then sends a 0-5V scaled analog signal into the Arduino Mega, which then communicates with the onboard laptop and displays a real time display of the current usage on the on screen interface. In addition, Nick has added coding ensuring that if the current draw reaches a limit of 23 amps, the Arduino immediately commences a shutdown sequence, lowering the PWM output to certain high current consuming components. This negative feedback loop ensures the ROV does not collectively draw 25 amps or greater at any given time.

Additionally, the power was run through a parallel circuit into the Arduino Mega input pin, scaled and displayed on the GUI. This allows the caption to be certain that 12 volts of power is being supplied to the ROV at all times, a condition not provided at the regional competition, as uncharged batteries were supplied.

Depth Sensor

Figure 19 – Keller depth sensor

The few tasks the gripper will not be involved in are the depth measurement and water sample extraction. The team researched several options for measuring the depth, including floating a graduated rope from the surface of the pool. The team ultimately opted to use a Keller submersible level hydrostatic transmitter because of its ease of use and accuracy. Nick, our electrical engineer, was able to wire the probe directly into the Arduino microcontroller analog input and write code linearly scaling the 5 volt analog input to read out real time on the GUI as depths up to six meters. Specifications for the Keller probe suggest accuracies up to .02 cm; however, some accuracy was lost as Nick had to code around the 8-bit Arduino processor. Testing of the probe resulted in accuracy within two centimeters of actual depth, well within the required 25 cm tolerance.

Modes and Applications

Desiring to further the applications of the sensors and improve the functionality of the ROV, the team worked to design several modes which could be utilized in various scenarios encountered throughout the mission. For example, in "precision mode" coding was written to cut the amount of power being supplied to all components in half. This makes picking up props and precise maneuvers much easier to control. An additional mode was "ground mode." This mode automatically turned lift motors to thrust downwards so the ROV would stay stable on the pool floor. This added stability is essential while performing tasks such as picking up the biological specimens and collecting the water sample. Additionally, a "reverse mode" was designed in order to switch the entire code so pressing forward resulted in actually moving backwards. This mode proved vital in proper placement of ROV while collecting the water sample. Finally, the most advanced and technological mode the team was able to devise became known as "hover mode." This mode incorporated the on board depth sensor with the microcontroller to enable the ROV to remain at a specific depth without requiring any manual control. The Arduino was coded to recognize the depth of the ROV when the mode was initiated by the laptop. Subsequently, the ROV simultaneously initiates the lift motors in order to compensate for any changes in depth. In this manner, the ROV remains at the precise depth as desired by the team, in order to allow for the performance of several of the depth specific mission tasks.

Double Sucker System (DSS)

The second part of task three is accomplished by a custom engineered and built double sucker system (DSS). The DSS easily couples with MATE's PVC pipe bucket prop by using a sliding, weighted funnel to guide the DSS proboscis into the tube. This process will be easily piloted as there is a dedicated rear facing camera zoomed in on the funnel. To ensure the integrity of the CDOM (Colored Dissolved Organic Matter) harvest, the primary pump (Whale 12 volt, 5 amp, submersible, in line pump commonly used for ground water testing) in the sucking system is designed to flush pool water out of the plumbing and release it through the ROV blow hole. The pilot will be able to identify that the system is flushed when the belf camera shows colored water being released from the blow hole. At this time the first pump is deactivated, and the second pump is turned on to

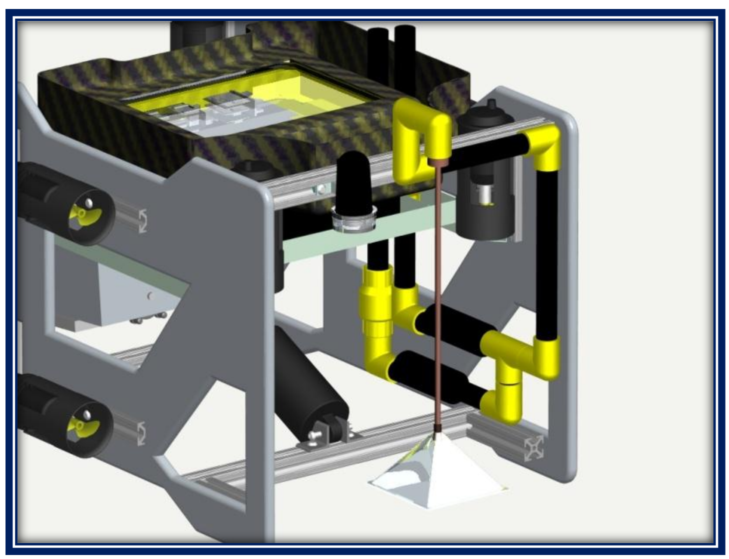


Figure 20 – DSS located on back of ROV

extract the CDOM into the waiting receptacle (1000 ml expandable bag that was donated by Platypus) in the belf. This process promises that the sample will not become diluted or emulsified (if it was an actual organic lipid based solution) whatsoever, and also collects enough solution (greater than 100 ml) to attain maximum points for the sample collection. There are low volume / low pressure check valves present in both of the blow out pipes, assuring that no pool water will regress back into the pump itself. The sucking system is easily accessible from the rear of the ROV, and the receptacle for the CDOM solution can be easily removed from the belf for presentation to the judges.

Safety

ROV safety is always a factor in any design decision. The main areas of concern for safety with our ROV are current overload, spinning propellers, and sharp edges. To counter the potential threats any of these could possibly cause, several precautions were taken at every step of design. Beyond the MATE requirement of one 25 amp fuse on the positive lead of our tether, we individually fused the positive leads to all motors, actuators, and pumps on the ROV. The individual fusing guarantees that even if a motor overloads and the fuse blows, only that one component will lose functionality. To further protect our electrical components, all wiring was performed with the appropriate 18 gauge wire. Extremely high current consumers, like the actuators, are wired in parallel through the bulk head connectors in order to split the current load through several cables and reduce electrical heat.

Not only does the ROV have safety features to protect itself, but also to safeguard the fingers of our team members and judges as they explore the frame. Our Octura 1250 propellers are blocked from access by custom built propeller guards. These polyvinyl chloride (PVC) cylinders serve a triple purpose: blocking the props from getting caught in stray debris, streamlining the output flow of the propeller wash, and creating a surface that is easy to fasten to the frame. Warning decals are also clearly positioned in visible spots around the frame to warn against possible danger. Vorpahl Fire and Safety generously donated 25 pairs of safety glasses for the ROV team's use. All throughout the building process, and at the competition, these glasses protect the eyes and faces of our members.

Description of Challenges

Technical Challenge

The ROV construction proceeded swimmingly until the first day of testing. Before entering the pool, the team was testing various components when the ROV produced a loud "pop." Everybody immediately thought "That was not good." Within minutes, the problem was diagnosed as an exploded capacitor, the largest such component on the ROV's multiplexer. The source of the problem was two cables that had somehow been switched as they were attached, so that the circuit was proceeding backwards in polarity. The flow of electricity immediately blasted the capacitor and the multiplexer lost all functionality. Fortunately, our electrical engineer Nick Vogt was able to diagnose the multiplexer problem as local to the capacitor and an adjacent voltage regulator. With an unbelievable amount of patience, knowledge, and skill, Vogt picked individual components off of the circuit board and replaced all of the damaged parts. The team was incredibly relieved the next morning when he announced that the multiplexer was once again functioning properly. An alternative to the on-board multiplexer was to simply run the video cables from each camera up the tether to a multiplexer on the surface, if the original rig could not be repaired. This inelegant solution would have preserved the quad-view converted by the pilots at the expense of tether diameter and maneuverability.

Non-Technical Challenge

The direst obstacle to the team's success was meeting the time limits. At the start of the building schedule, each department set their weekly goals for development based on the total amount of work that they needed to accomplish. However, numerous perfectionists caused development to fall behind the hypothetical timeline of construction. At this point, our CEO stepped in, removed some personal liberties, and began to assign tasks to the various departments. To keep everyone on track and ensure the ROV would be done before competition day, Dustin detailed out each individual's tasks which needed to be completed each week. Even this rigid structure did not generate sufficient efficiency to finish the ROV within the remaining planned out time, and the team started to stay many late nights to solder wires, attach bulkhead connectors, finalize the sucker system, and finish the technical report. Nonetheless, the team persevered and was able to complete all the necessary tasks by the competition date.

Discussion of Trouble Shooting Techniques

Faced with the adversity of a non-functioning gripper arm, the team was forced to become inventive and quickly develop vital trouble shooting techniques. Initially, the team encountered difficulties in attempting to make the gripper rotate. In early practice sessions, the arm would rotate several times before it was rendered completely useless and would stop functioning. After close examination, Dominic, the gripper engineer, found the plastic gears being used to provide mechanical advantage were being stripped by the torque created while rotating the arm. Nonetheless, the team quickly purchased aluminum and stainless steel gears, in order to alleviate the problem and ensure the gears no longer became stripped.

Another initial problem was the driver board connected to the large Lenco Marine 102XD linear actuator malfunctioned as a result a current overload. Accordingly, the team decided the best option was to reduce the voltage input to a maximum of six volts while the gripper arm was functioning. Still not satisfied and wanting to take further precautions, however, the team felt further action needed to be taken. After much discussion and team collaboration, a solution was decided upon. Along with reducing the voltage limit to six volts, Nick programmed the Arduino Mega to curve the voltage input when functioning moving the gripper up or down. This eliminated the chance of spiking the current by gradually providing power, making certain to take care of the new driver board. Although a solution may have not been reached immediately, persistence and creative thinking enabled the team to overcome many problems and exhibit their enigmatic trouble shooting techniques.

Figure 21 – Linear actuator powering gripper arm

Discussion of Future Improvements

There are multiple ideas that made their way into the hypothetical design of the ROV, but never coalesced into a material change. The team continues to believe these additions or changes would have improved the function of the ROV, and truly regret that they were not ready for the international competition. The first desired improvement is a specialized tether. The ROV’s current tether is simply a bundle of wires bound by a braided cable sleeve; extensive labor must be performed to make any additions to the tether. The current tether serves its purpose, sufficient as it is. The team has had minor problems with the flexibility of the tether, as well as the excessive weight it adds to the rear of the ROV. This extra weight puts unnecessary strain on the rear lift motors, potentially reducing stability. Our business department was in contact with several commercial tether providers for months, trying to negotiate a deal for the perfect tether at the perfect price. In the end, the deal fell through, and the team was forced to do something they hoped they would never have to: compromise.

Lessons Learned

Technical

Many technical lessons were learned along the way, but our corporation desires to highlight the insight and lessons learned relating specifically to electricity and its applications.

Early on in the design process, the team was forced to quickly acclimate and become comfortable discussing and using electrical circuitry. Although many team members had no former background in working with electricity, the team realized the importance in understanding the properties and characteristics of electrical processes. First and foremost, the team explored basic terms associated with electricity. For example, the team discovered an ampere is used to measure electrical current, which is the actual flow of electrons. Voltage is used to describe the electrical potential, which describes the capacity of an electrical field to perform work. As relating to safety, the team learned amps were much more dangerous, and an electrical current passing through the body would present a large safety concern. Accordingly, the proper safety precautions were taken whenever dealing with electricity, in order to reduce the risk of any bodily harm.

The engineering of the tether presented an excellent opportunity for the team to use their newfound knowledge pertaining to electrical circuitry. The team focused on creating a tether with minimum voltage loss, while retaining flexibility. Voltage loss depends on three variables: diameter of wire, length of wire, and the conductor material. After calculations using online voltage loss calculators, the team decided on utilizing 8 AWG wires. While only presenting a voltage loss of less than one volt, the diameter of the braded wire still allowed for both flexibility and versatility. In order to further minimize voltage loss, the team calculated the optimum tether length to be 20 meters. This allows for the ROV to reach all mission tasks, but prevents unnecessary voltage loss by eliminating extra any extra length of wire. Overall, the team was pleased with the final tether, as it proved to be both flexible and provided adequate power to the on board systems.

Interpersonal

A plethora of interpersonal lessons were learned throughout the competition, but the team felt lessons learned in teamwork and collective cooperation were by far the most significant. Many team members had previously participated in athletics or other team related activities, but the MATE ROV Competition allowed for a unique opportunity to discover a whole new type of teamwork experience. The pure scope of the competition and nature of the tasks to be completed required a new and innovative form of cooperation that surpasses basic teamwork skills found during athletic competitions. Instead, the team formed a corporate system with intricate and overlapping spheres of responsibilities. Dustin, the team CEO, personally professed to the leadership and organization skills gained from the experience, as he was responsible for overseeing and managing the entire team. The rest of the group learned lessons about teamwork as well, as they had to work with other individuals for nearly every task. Ideas, methods, and creative thinking were all shared by group members, enabling the team to collaboratively solve problems and create innovative ideas for the ROV. At the conclusion of building the individual systems, the team then faced an integration phase, which was carefully coordinated in order to yield maximum efficiency.

The lessons learned concerning teamwork are steadfast principles which can be applied to all aspects of life. Upon the completion of the ROV, the Ozaukee High Robotics team truly understood the potent nature of cohesive and dedicated teamwork. The team truthfully realized the sheer magnitude of tasks that can be completed with teamwork, and the unthinkable goals that can be accomplished.

Reflection

The team had no idea of the scope of this project in the early goings. However, the team now understands willpower and cooperation can combine to create a marvelous product. During the course of the work, the project has transformed from simply a conglomerate of hastily lashed together components, to a quite polished and professional looking machine. This dramatic change was surprising, and it has revealed the complexity of engineering and coordination that is present in real-world situations. The starkest realization for the team was the importance of meeting deadlines and completing tasks in a timely and efficient manner. Also, an important lesson taken from this epiphany is persistence; although having one's plans apparently crumble is disheartening, one must carry on.

Figure 22 – Team poses with GEN3 at Regional Competition in Milwaukee, Wisconsin

Budget / Expense Report

School: Ozaukee High School
Instructor: Mr. Terry Hendrikse

Date	Transaction Type	Description	Material Donation	Amount	Balance
12/01/10	Deposit	Funds from 2010		$5,500.00	$5,500.00
12/01/10	Deposit	UWM Deposits		200.00	5,700.00
12/15/10	Donation	Fish Vu underwater cameras	450.00		5,700.00
12/16/10	Donation	Tsunami t1200 bilge pump motors	138.00		5,700.00
12/23/10	Donation	Linear actuators	792.50		5,700.00
12/23/10	Expense	Inline water pumps		-92.60	5,607.40
01/03/11	Expense	Multiplexer		-52.00	5,555.40
01/06/11	Donation	Safety Glasses	20.00		5,555.40
01/07/11	Donation	Mission Prop Materials	100.00		5,555.40
01/07/10	Expense	Mission Prop Materials		-71.00	5,484.40
01/07/11	Donation	Propellers	23.00		5,484.40
01/11/11	Expense	Keller Depth Sensor		-263.00	5,221.40
01/13/11	Expense	RC car transmission for gripper		-37.00	5,184.40
01/18/10	Donation	80/20 Aluminum	116.00		5,184.40
01/18/11	Expense	80/20 Aluminum		-116.00	5,068.40
01/18/11	Expense	Pololu Motor Drivers	170.00	-170.00	4,898.40
01/20/11	Donation	Platypus Bags	30.00		4,898.40
01/20/11	Donation	Integra Enclosures Dry Housing	117.00		4,898.40
01/21/11	Expense	Check Valves		-10.63	4,887.77
01/21/11	Expense	Carbon / Kevlar Fiber		-66.43	4,821.34
02/01/11	Donation	SubConn Bulkhead Connectors	500.00		4,821.34
02/01/11	Expense	SubConn Bulkhead Connectors		-372.15	4,449.19
02/03/11	Expense	Misc. Hardware		-180.00	4,269.19
02/20/11	Donation	Monetary Donation from ITT Sanitare		635.00	4,904.19
05/13/11	Deposit	T-Shirt Sales and Brat Fry		1,625.00	6,529.19
05/15/11	Deposit	Travel Stipend From Veolia and UWM		5,500.00	12,029.19
05/15/11	Expense	Coach Bus Travel		-10,000.00	2,029.19
05/15/11	Expense	Hotel Expenses		-5,500.00	-3,470.81
05/15/11	Donation	Local Businesses*		$ 4,000.00	$ 29.19

*See team website for extensive list of local donors

Final Summary

Total Material Donations	$2,456.50
Total Cost of ROV	$3,867.31
Total Cash Revenue	$16,90.00
Total Cash Expenses	-$16,930.81
Ending Cash Balance	$29.19

Acknowledgements

The team would like to thank all organizations and individuals that contributed supplies, discounts, or advice to any or all team members during research or construction:

Aquavu Video – Donation of cameras
Polulu- 50% discount on motor drivers
Attwood Marine – Donation of Tsunami Motors
US Plastic Coop – Donation of LDPE
80/20 Inc – Discount on 80/20 aluminum
UWM Water Institute – Facilities for poster printing
MATE – Putting on an excellent competition
Lenco Marine – Donation of Linear Actuators
A&B Props – Donation of Test Props
Vorpahl Fire and Safety – Donation of safety goggles
Cedar Grove High School – Providing practice pool
ITT Sanitaire – Monetary Donation
Families of all team members – For support
Integra Enclosures – Donation of Dry Housing
Platypus – Donation of Platypus bag,
CRC Hobbies – Donation of RC Gears
Subconn – Donation and discount on bulkheads
Electrical Systems LLC and Mr. Hartnett
-Donation of potting compound
Ozaukee High School – Providing facilities and support

The Ozaukee High Robotics team would also like to personally thank several individuals for help and support along the way. First and foremost, we hold our instructor Mr. Hendrikse in the highest of regards, and would like to thank him for inspiring us to achieve our dreams and believe anything is possible. Also, the team would like to thank Mr. Vogt, for his advice, guidance, and enthusiasm he provided along the way. Lastly, the team wishes to extend our most sincere gratitude towards MATE and Jill Zande for respectively hosting this competition and being extremely kind and helpful in many situations.

The team would also like to acknowledge and give photo credit to teammates Sandra Kotzian and Ali Hughes, who took the photos used in the report. Also teammate Eric Hartnett provided Pro/DESKTOP drawings, and the team would like to recognize Eric for his outstanding efforts.

References

"Aluminum." *Virtual Chembook*. 14 Feb. 2010. <http://www.elmhurst.edu/~chm/vchembook/102aluminum.html>

"Arduino Mega." Arfuino. 19 Feb. 2010. <http://arduino.cc/en/Main/ArduinoBoardMega>

"This Day In Deepwater Horizon Spill Rate Estimates." *The Huffington Press*. 7 Aug. 2010. 26 Feb. 2010. < http://www.huffingtonpost.com/2010/06/07/this-day-in-deepwater-hor_n_602871.html>

"IP Classification Codes." Bourns. 10 Feb. 2010. <http://www.newenglandlaser.comattachments/File/pdf/IP_codes.pdf>

"Kevlar / Carbon Hybrid (Yellow)." *Fibre Glast Developments Corporation*. 15 Feb. 2010. <http://www.fibreglast.com/product/Kevlar_Carbon_Hybrid_01065_1/cosmetic_fabrics>

Wiseman, Paul. "Future losses from BP oil spill worry Gulf Coast businesses." *USA Today*. 6 June, 2010. 26 Feb. 2010. <http://www.usatoday.com/money/economy/2010-06-09-gulfbiz09_ST_N.htm>

ROV 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
Select	Anti-torque (Lift Left Up and Lift Right Down)
L3	Strafe Left
R3	Strafe Right
X	Gripper Down
Triangle	Gripper Up
Square	Gripper Rotate Left
Circle	Gripper Rotate Right
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)