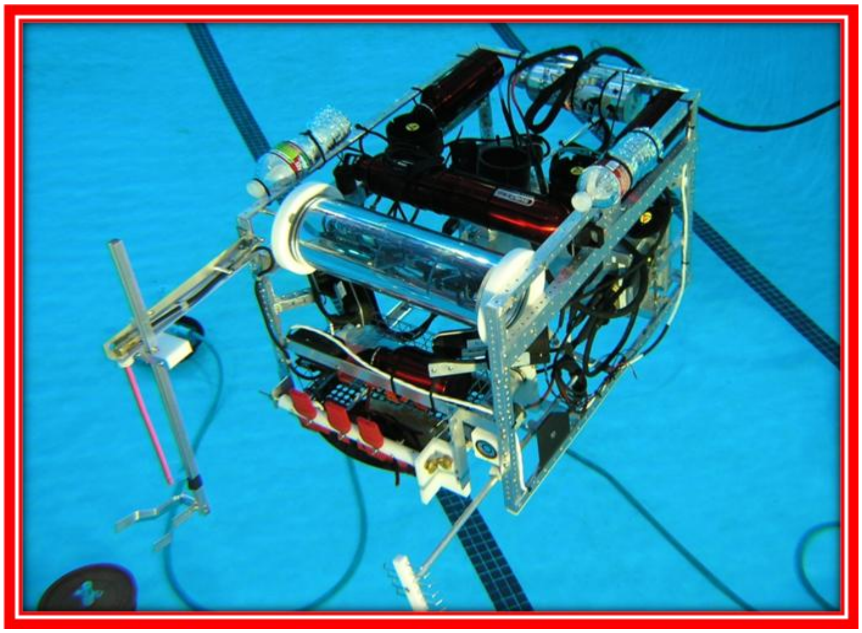
Jesuit AquaCorp
Presentation to MATE Center

Jesuit High School | Carmichael CA



Phorcys

(Greek god who presided over the hidden dangers of the deep)

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Abstract

Phorcys is a work class ROV designed to compete in the Marine Advanced Technology Education (MATE) International ROV Competition. Envisioned and created by Jesuit AquaCorp, *Phorcys* ultimately made its way from the drafting board to the pool deck through a structured build process that included several design reviews, prototypes, and revisions.

Phorcys utilizes an open frame design, common to many professional work class ROVs, to provide flexibility for mounting accessories, access for field service, and the ability for water flow from the leaking wellhead to pass through the vehicle without disturbing its position. Four of *Phorcys'* six thrusters are positioned at the frame's corners to allow for vector control, giving the ROV the necessary precision to complete this year's tasks. Custom built accessories designed specifically for the mission enable the ROV to complete its necessary tasks in a quick and efficient manner. These accessories enable the collection of depth and temperature data, as well as water and biological samples. Poolside, *Phorcys* is controlled via a joystick that is interfaced with a custom written C# program. This application reads input commands from the joystick and pilot Graphic User Interface and then communicates with the ROV via a tether to produce movement and control of accessories. The application also reads and processes sensor information sent up the tether from the ROV.

Originally designed in CADD, and brought to life through mockups, manufacturing, and testing, *Phorcys* is a well engineered product that is ready to meet the demands of this year's MATE competition.

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Jesuit AquaCorp

Jesuit AquaCorp is a privately-held corporation that specializes in designing and operating custom ROVs for deep-sea exploration and retrieval. Founded in 2003, Jesuit AquaCorp has successfully delivered over 5 ROV systems to various clients worldwide. With the strength of the current ocean-exploration market, Jesuit AquaCorp expects to continue holding a strong position in its field.

Each fall, Jesuit AquaCorp recruits qualified employees who are eager to learn and take part in the company's mission. All new hires are given an apprenticeship with a senior employee so that training, knowledge, and skills, are passed down as part of the corporate succession plan. Figure 1 shows the structure of Jesuit AquaCorp, with asterisks denoting first year employees. This year, Jesuit AquaCorp interviewed over 30 individuals to fill 5 open positions in the company.

Jesuit AquaCorp has served several clients in the past, all of which have required the company to complete missions with the same dexterity and precision that are required in this year's Marine Advanced Technology Education Center (MATE) mission. For example, just last year, Jesuit AquaCorp was hired by the National Underwater Robotics Challenge, which required the company to design and operate an ROV with the ultimate goal of tagging the infamous Loch Ness Monster with a tracking device. This mission also included many smaller tasks, such as activating bait containers to lure Nessie out of her underwater cave and recovering Nessie's egg for testing. Additionally, this past summer, a Jesuit AquaCorp ROV investigated the Loihi Seamount, located off the coast of Hawaii. This mission included resurrecting the Hawaii Undersea Geological Observatory, collecting biological samples, and taking various depth and temperature measurements.

Headquartered in Carmichael, CA, Jesuit AquaCorp employs 18 people, and has a long-standing tradition of quality, excellence, and leadership. The company is dedicated to producing robust and reliable products that are able to withstand some of the harshest conditions in some of the most remote pools on the planet. Working in tandem with its clients, Jesuit AquaCorp strives to raise the standards of the ROV industry.

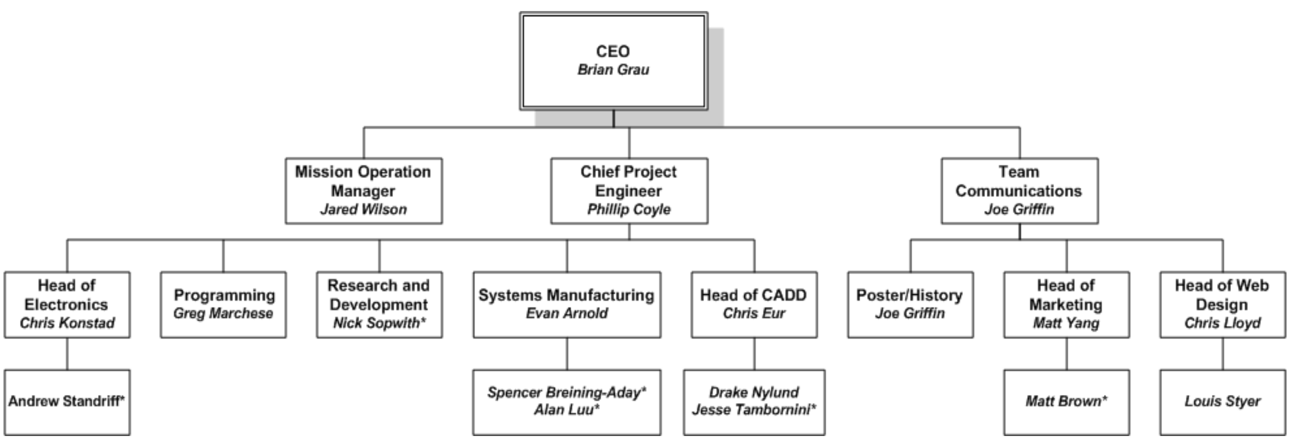


Figure 1: Jesuit AquaCorp Organization Chart

Design Rationale

Frame

The frame of *Phorcys* is a simple, sturdy, and lightweight design that is constructed out of 1.91cm [3/4"] by 0.32cm [1/8"] angle aluminum and riveted together at the corners (see Figure 2). The frame was initially created in SolidWorks®, and was then refined and constructed after concepts for the ROV accessories were finalized. To allow for easy mounting and adjustment of the many components attached to *Phorcys*' frame, holes are drilled every 1.27cm [1/2"] on the frame's vertical bars, and every 2.54cm [1"] on the horizontal bars. The standard fastener on *Phorcys* is the 8-32 nut and bolt, reducing the amount of hardware needed to support the ROV and enabling rapid response should issues arise. The entire frame weighs only 2.2 kg [4.85 lb] and easily supports the needs of this ROV.

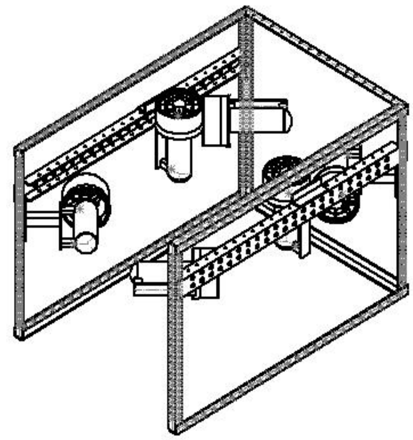


Figure 2: ROV Frame

Thrusters

Phorcys uses six Seabotix™ thrusters, which were chosen for their size, power, and reliability. Four thrusters are positioned at 45-degree angles at each of the frame's four corners to enable vector control, giving *Phorcys* the ability to move in any direction about the XY plane. The software for vector control was developed by Jesuit AquaCorp (see Appendix B) and also provides the ROV with 2.5 times the thrust of a single motor when moving horizontally. The thrust profile of a single Seabotix™ thruster can be seen in Figure 3. The two remaining motors are positioned along the vertical axis of the ROV's center of mass, giving *Phorcys* maximum downward thrust when placing the wellhead cap. See the CADD diagram in Figure 2 for thruster placement.

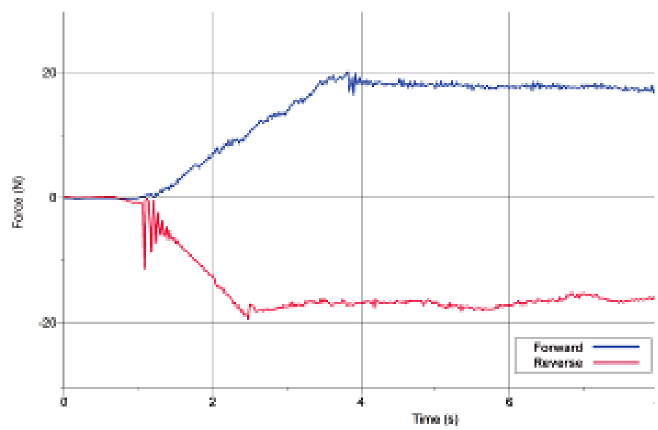


Figure 3: Seabotix™ Thrust Profile

Electronics Containers

In previous years, Jesuit AquaCorp has used one large electronics container mounted near the center and top of the ROV to provide buoyancy and stability. However, after receiving MATE's specifications and beginning the initial concept design stage, it was determined that this approach would not be feasible. The ROV's center was the only place to accommodate the large and heavy wellhead cap, which also needed to be placed in line with the vertical thrusters to provide maximum downward force when installing it on the wellhead. After several ideas were proposed, Jesuit AquaCorp decided to place *Phorcys'* electronics in two containers, connected by a conduit.

The rear electronics container (see Figure 4) is made from six 0.95cm [3/8"] aluminum plates that are welded together, forming a box. A clear, 1.27cm [1/2"] thick polycarbonate lid presses against a rectangular O-ring, sealing the container. This plate also acts as a window, allowing one to view the electronics inside and ensure that they are working properly, and that there is no water leakage. The thickness of the container and lid was selected after calculating the stress that the container will have to endure at depth. See Appendix A for these calculations. In addition to the electronics, the rear electronics container also contains 160 degree wide-angle camera to provide a rear view for the pilot. The tether, thrusters, and other accessories are connected to this electronics container using SubConn® underwater connectors. In total, the container houses six brushed speed controllers, a video balun, five control relays, and a 48 to 12V battery eliminating circuit (BEC) voltage regulator.

Figure 4: Rear Electronics Container

The front electronics container (see figure 5) is made out of a 10.8cm [4.25"] inside diameter (ID), 11.43cm [4.5"] outside diameter (OD) polycarbonate tube (see Figure 5). This material was chosen because it does not crack and is clear. A camera, mounted on a servo limited to 180 degree motion, allows the pilot to see any area in the front of the ROV. Also mounted inside the container are the depth sensor and the Arduino control board, both of which are connected to the rear electronics container via a conduit. There are also various sensors including an internal temperature and humidity sensor, a compass, and two voltage sensors, one to measure the main line voltage, 0 to 48V, and the other to measure the power line to the front container, 0 to 15V.

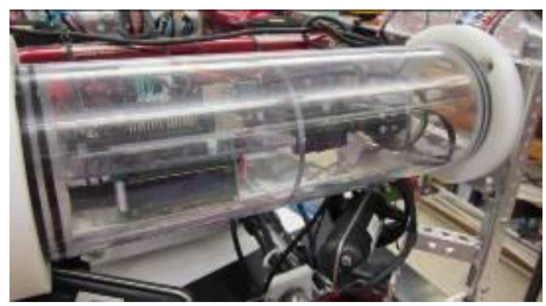


Figure 5: Front Electronics Container

The conduit that connects the two containers is a 1.59cm [5/8"] ID braided polyvinyl tube that contains several wires. Figure 6 at the right shows the complete wire list. These are used to control the motors and all the other functions of the ROV. There is a spare line so that our client can expand the capability of the ROV.

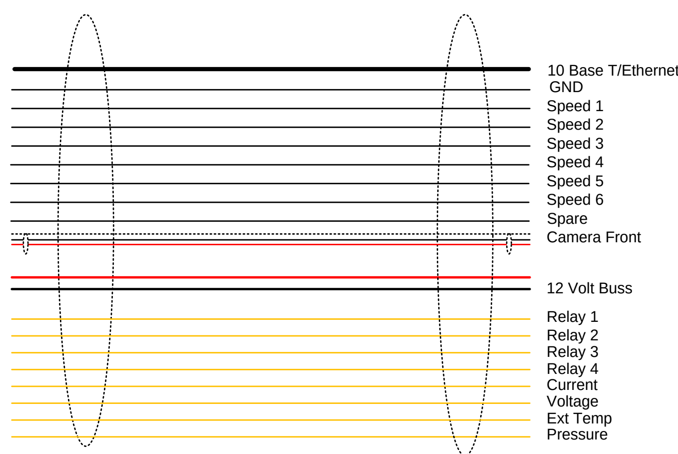


Figure 6: Wire diagram in conduit

Video System

Our design for the video system is based on many years of research with pan-tilt cameras which allow the pilot to see the entire operating area without moving the ROV. We have achieved this by using two wide-angle cameras, one in the front and one in the back of the ROV. The front camera is housed in the clear acrylic tube on the front of the ROV and is mounted on a servo so that we are able to tilt the camera up (+90 degrees) and down (-90 degrees). Because it has a 140 degree field of view, we did not need to include a pan function. The rear camera is a 160 degree wide-angle camera. These two cameras serve as our main drive cameras. We also have two mission-specific cameras. We have one Lights Camera Action camera that has our front hook in its field of view and another that is used to accurately place our cap over the wellhead.

These four cameras' signal lines are sent to the surface using a video balun device. This method is a well proven feature of our ROVs. This system uses a standard Ethernet wire to handle all of the camera feeds. At the surface we separate the cameras and have control of what images are displayed on our monitors at any given time. Overlaid on the video is critical ROV information including a compass heading, depth of the ROV, the internal temperature and humidity in the electronics container and the thrust of the vertical thrusters.

Tether/Tether Control Unit

Figure 7: Tether Diagram

With the depth of the mission and the length of tether required, minimizing the weight and managing the tether buoyancy are even more crucial than past missions. After careful research of closed cell foam, and knowing that the ROV must be capable of diving to a depth of over 10 meters, we concluded that we could not use the same type of foam we've used in the past, as it compresses and loses its buoyant force at these depths. We tested various tubes that could provide buoyancy for the tether and concluded that the tube that would be needed would be too stiff and restrict the movement of the ROV. After much thought, rigid foam pods were strategically placed along the tether to support the tether between each foam pod. Our tether consists of three groups of wires; power, communications, and video, from our Tether Control Unit (TCU). After much testing of power drop with different gauges of tether we concluded that a pair of 12 gauge wire was the right balance of weight and power. For data communication and video to and from our topside TCU, two standard CAT5 lines were chosen. This combination has worked in the past for ROVs we have designed for other clients so we are reusing the concept. Figure 7 shows a diagram of the tether.

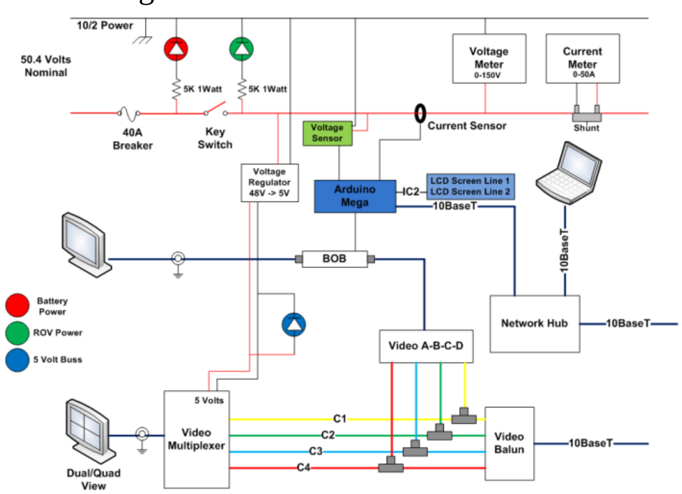


Figure 8: TCU Diagram

The control of the ROV is interfaced through the TCU at the surface. The TCU is housed in a Pelican case so it can be moved easily and is durable. The three lines from the tether—power, video, and control—plug into this control box. To this box we also connect our two video monitors as well as our control laptop. A functional diagram of the TCU is provided in Figure 8. This design allows all the systems that support the ROV to be completely modular and easy to transport. In order to activate the ROV, a 40amp circuit breaker must be switched on as well as our main power switch.

Various LEDs alert the deck crew to the status of the power and can alert of potential malfunction. There are also voltage and current meters that allow a deck crew member to easily see how much power the ROV is using. Each of the video signals is split into two signals with one going to a video multiplexer and the other to a video switch. The multiplexer allows the pilot to see the video feed from all four cameras on the ROV via a single monitor. The video switch allows the pilot to see an enlarged image from one camera on a second screen. This signal line is wired through the breakout board (BOB), which overlays a compass reading, a current reading, and internal temperature and humidity on the screen with the video. An Arduino Mega microcontroller receives the sensor readings and the BOB is wired to it and displays them over the video. This allows the pilot to see all vital information including thrust from each thruster in one place and have complete control of the ROV.

Electronics

Processor

The ROV's microprocessing unit, seen in Figure 9, is an Arduino Mega 2560, which is based on the ATmega2560. We chose the Mega over the more commonly used Arduino Uno because we needed access to more pulse width modulation compatible ports to control the motors. Furthermore, we wanted to have enough analog input pins for future ROV designs and sensors. The complete electronics schematic is located in Appendix C. The Mega is powered off of the 12V bus in the electronics container. It is connected to the topside computer via an Ethernet cable. The two communicate using User Datagram Protocol (UDP) with a predefined packet structure.

Figure 9: Arduino Mega

Motor Control

The brushed Seabotix™ motors are controlled by the Mega via DeviceCraft electronic speed controllers (ESC). DeviceCraft speed controllers can handle up to 50V at 20A. They have built-in ramp-up and ramp-down potentiometers to protect the thrusters from sudden startup and reversal, and interface with the Arduino via an analog signal. Arduino has a servo library, which uses Pulse Position Modulation to send predetermined commands to the thrusters.

Relays

There are two Phidget solid state relays that operate at 12V to control the critter collector and water sample mechanism. There are three mechanical relays on the high-voltage bus to control the lights, solenoid for the water collection arm, and solenoid for the tail hook.

Sensors

Phorcys is outfitted with several sensors. First, a SHT1x digital sensor line measures temperature and humidity inside the electronics containers. The SHT1x is easily available and has premade libraries, which were modified to fit the ROV's needs. Next, *Phorcys* has a Hitachi HM55B compass module, which is made by Parallax. The sensor can detect microtesla variations in magnetic field strength, allowing it to measure to within 6 degrees. The compass sensor only causes a delay of about 30-40 milliseconds, eliminating our need to edit the source code to improve speed. Two Phidgets 1135 precision voltage sensors, which can read values between -30V and 30V, are also installed on the ROV. Because *Phorcys* is powered by 48V, half the voltage is measured across a voltage divider, and the value is multiplied by two to obtain an accurate reading. Finally, a TDH30 series pressure transducer made by Transducers Direct is used to measure ROV depth. It has an input voltage between 12V and 36V. To deliver the recommended power, a BEC is used to supply constant power. It is a sensor based on piezoresistive elements that measures gage pressure. One drawback is that it needs a certain amount of pressure before it can make an accurate reading. Because of this drawback the sensor does not begin to work accurately until the pressure reaches 21 kilopascals [3 pounds per square inch] or once the ROV is at a depth greater than 2 meters [6.56']. This drawback is not a problem as the work area is at a far greater depth. The sensor pressure is converted in software to a depth from the surface.

Programming

Phorcys is controlled via a poolside laptop running a custom C# program with a graphical user interface (GUI) and joystick. The program takes control inputs from the joystick and converts the movement into a signal that is transmitted through the tether to the ROV's Arduino processing unit.

Top-Side Code

Graphical User Interface:

The control laptop displays a GUI, seen in Figure 10. The GUI shows all vital information about the ROV and allows the pilot or copilot to use the onscreen buttons in the event of a joystick malfunction. It displays a mission clock that changes colors and gives alerts as the time remaining decreases. This gives the pilot visual as well as audible signals and allows the mission captain to make critical decisions about how to use the remaining time to the fullest extent. This screen also displays the ROV health including internal temperature and humidity in the electronics containers as well as the depth and temperature of the water. All of this information can be used to ensure that the ROV remains in good working condition and can warn of potential hazards such as water leakage.

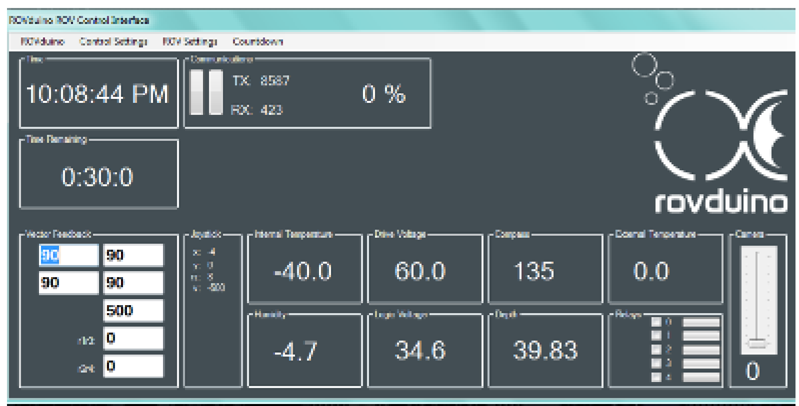


Figure 10: GUI

Vector Thrust Control:

In order to keep an open frame in the middle of the ROV for the mounting of the wellhead cap, it was decided to incorporate vector thrust for multidirectional control, while minimizing water flow through the middle of the ROV.

Jesuit AquaCorp's topside human interface controller is a joystick that has vertical (z) and horizontal (x,y, and w-rotational) control. The horizontal control input signals must be converted to motor values for each thruster for synchronized movement. First we created a null zone for movement so that a slight deviation of the joystick from the center would not change the position of the ROV. The horizontal x,y input must be incorporated with the rotational w input to create a smooth integrated movement. This was calculated using geometry and calculus by Chris Eur, our head of CADD. This math equation was then translated into C# and incorporated into our team-written program. These equations and the development of them can be found in Appendix B.

Bottom-Side Code

All subsections of the code are written in different libraries. The libraries are combined into one file, called "Core Build," that operates the ROV. "Core Build" is a firmware developed to be fast, non-blocking, modular and easily editable. Due to the fact that the Arduino Mega has only one processing core, Core Build had to be optimized and non-blocking. By creating non-blocking code, the usage of the delay function, which essentially pauses the micro controller, was avoided. Figure 11 shows the software flowchart.

Aside from the non-blocking code that we had to implement, we had to deliver a minimum of five packets a second to the Mega for a smooth control and response experience. To lessen the clock cycles needed to execute the code, we inlined many functions. When a function is inlined, the compiler copies the code to wherever the function is called, thus eliminating the need to jump to the function called. Through inlining, we decreased the amount of time needed to execute the code.

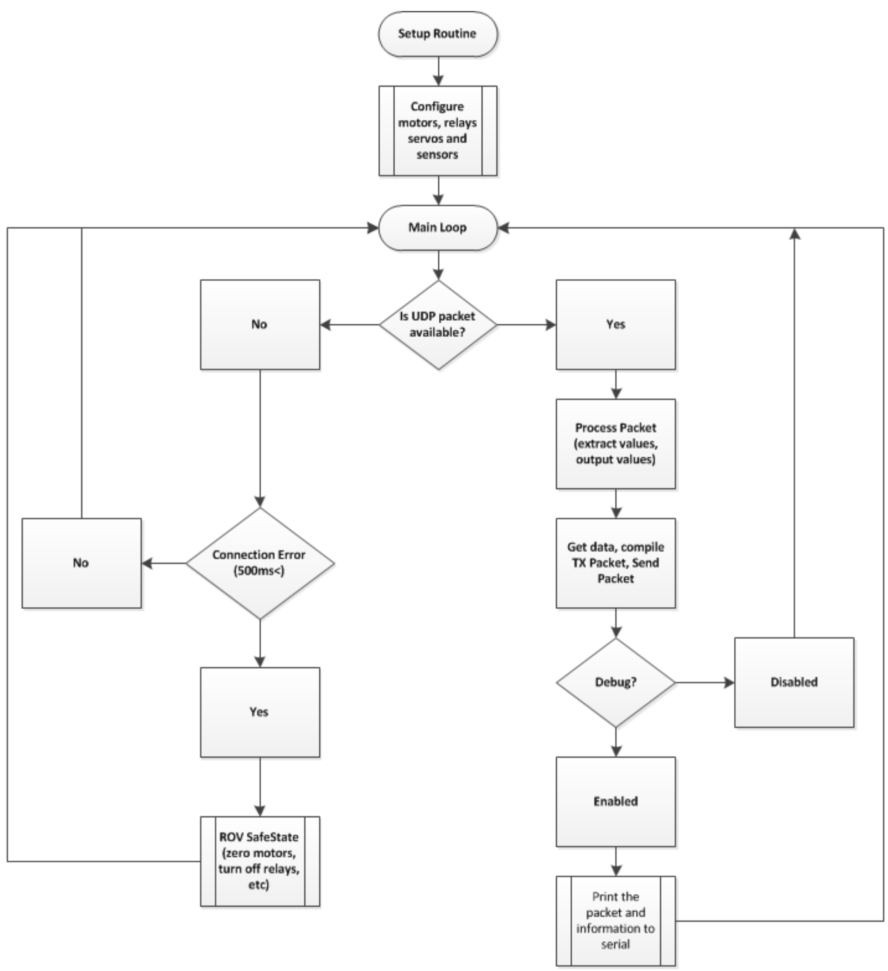


Figure 11: Software Flowchart

Core Build, like all software, has a specific flow that it must follow. After leaving the "setup()" function, which initializes all objects and variables, the Arduino begins the "loop()" loop. This loop serves as the main body of the code, in which other functions are called. To increase readability, modularity, and integrity of our code, many blocks of code are split into sub-routines that are called by the main loop routine and many more lines of code are stored in libraries. The sub-routines and libraries give the program enough abstraction so that it can be easily added to, yet keeps the "under-the-hood" code readily available.

Safety

Safety is a major concern of Jesuit AquaCorp, and several steps are taken to ensure that incidents are avoided or minimized. For example, at the beginning of the year, the company holds a training day, during which a safety PowerPoint is presented and senior employees give hands on training to new hires. Additionally, during testing, a fuse is always hooked up to the ROV's electrical source to prevent overload. Likewise, all electrical equipment is powered through a ground fault interrupter, preventing any damage. Prior to the ROV being deployed, the deck crew reviews a checklist to prevent overlooking important pre-launch details. Finally, all thrusters are shrouded to reduce the possibility of objects being caught in the propellers.

Mission-Specific Accessories

Hooks

There are two hooking devices on the ROV; one located in the front to remove the Velcro tab, and one in the back to aid in retrieving the riser pipe. The front hook, seen in Figure 12, has several talons to facilitate attaching to and cutting the riser pipe. The rear hook is a carabiner that detaches and remains on the riser pipe. A rope is attached to the carabiner, allowing a deck crew member to remove the riser pipe from the work area.

Figure 12: Front Hook

Critter Collector

A key requirement for the critter collector (see Figure 13) was that it did not damage the specimens. This was accomplished by using soft basting brushes on a slow rotating arm that gentle sweeps the creatures from the sea floor. The basting brushes are attached to a rotating Delron® rod. One side of the rod is drilled and tapped, and is connected to a stainless steel piece of all-thread. A 90 degree gear system connects the all-thread to a brushed motor with a planetary gear box which spins at 12.5 revolutions per minute. To prevent water leakage, the brushed motor is encased within a polycarbonate tube filled with dive gel and sealed on both ends using o-rings.

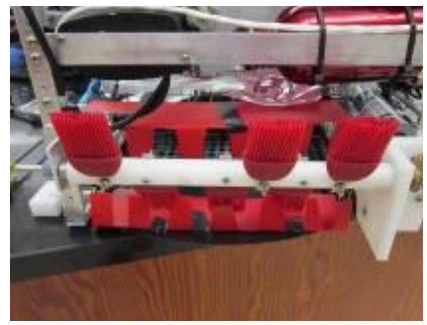


Figure 13: Critter Collector

Wellhead Cap

The entire ROV was build around this component. We knew that this was the most important task of the mission so it was the first item we started to prototype and build. After many different prototypes and knowledge gained from each we have a solid wellhead cap that will stop the oil that is flowing from the wellhead. We have successfully tested our product to a pressure of 331 kilopascals[48 pounds per square inch].

Prototype 1---Design
The first idea for a well cap was a plug that would seal from the inside and top of the wellhead (see Figure 14). This was built out of PVC, and machined to a taper to fit 3.18cm [1.25"] and then dipped in Plasti Dip® to improve the seal.

Prototype 1---Result
After testing this prototype, we found that it would take an excessive amount of pressure to seal it, which we were never able to achieve, and the idea was abandoned.

Figure 14: Wellhead Cap Prototype 1

Prototype 2---Design

Our second idea was an external seal. This cap goes over the wellhead and clamps 3.81cm [1.5"] down on the outside of the wellhead pipe (see Figure 15). This external seal is made of these parts, starting from the top: A check valve with a 3.18cm [1.25"] slip is attached to the inside of a 3.81cm [1.5"] PVC coupling. This coupling is connected by means of a hose clamp to a 5.08cm [2"] to 7.62cm [3"] reducer bushing. A 10.16cm [4"] length of 7.62cm [3"] schedule 40 ABS pipe was glued into the bottom of the reducer bushing. The sealing mechanism was a rubber seal with a 3.81cm [1.5"] hole in the middle that was sandwiched between an upside down closet flange and one that was right side up. These three parts were bolted together and connected to the ABS piping. A 15.24cm [6"] length of schedule 40 ABS was glued inside the of the bottom closet flange. Aluminum clips machined out of 0.32cm [1/8"] aluminum were slotted through the bottom of the ABS to grip the pipe once the cap was in place.

Figure 15: Wellhead Cap Prototype 2

Prototype 2---Result

Initially this designed worked and sealed the wellhead. After less than a minute the seal began to leak and water began to leak out of the cap. Using what went wrong with this wellhead cap, we started another prototype.

Prototype 3---Design

Our third idea was a diaphragm seal, or a seal against the top of the well head. This type of seal would transfer the upward force of the water downward and make a tight seal against the top of the wellhead. As shown in Figure 16, we started off with the same top assembly, a check valve and ABS piping. A rubber gasket with a hole drilled in the center to match the diameter of the wellhead is attached between two PVC closet flanges. The two closet flanges with the rubber gasket in-between are bolted together with eight 0.64cm [0.25"] bolts so that no water escapes when the well is sealed. Below this, a 15.24cm [6"] section of schedule 40 ABS piping was connected to the bottom of the closet flange with screws so it is adjustable up or down. Into the bottom of the ABS, 3 latches are slotted into slots cut into the ABS piping. These latches protrude 1.27cm [0.5"] and are attached to springs which pull upward on the latches to latch on to the wellhead and insure that the cap stays in place after it is inserted and also so it does not come off because of the water pressure.

Figure 16: Wellhead Cap Prototype 3

Prototype 3---Result

After testing this prototype we found that the distance from the top of the wellhead to where we latched had to be within millimeters of perfection. We found that when everything was perfect, water leaked out around the seal because we did not have enough bolts. The ABS failed after time because we had cut one of the notches for the latches a little deep and the pressure widened it. This in turn caused one of the aluminum latches to fail, which redistributed the force of the water onto the two remaining clips. This pressure on the remaining two clips caused one of the 0.32cm [1/8"] thick aluminum clips to bend. We abandoned this idea because of the drawbacks of accuracy and the overall failure of the seal and clips, although the clips were used in Prototype 2 to great success.

Prototype 4---Design

Prototype 4 is a condensed version of prototype 2, and uses smaller parts to make the final version a third the original size (see Figure 17). This design uses an external seal. The top of the well head cap is a 2.54cm [1"] mini check valve which is connected to a female screw thread which is connected to a slip PVC connector. This connector is fitted into a 2.54cm [1"] to 5.08cm [2"] reducer bushing. This bushing is fitted into a 5.08cm [2"] to 7.62cm [3"] reducer bushing which in turn connects to the sealing mechanism, a rubber seal with a 3.18cm [1.25"] hole in the middle sandwiched between two closet flanges and bolted together with 14 3.18cm [1.25"] long bolts to ensure no leaking. To the bottom of the sealing mechanism a 2.54cm [1"] length of PVC is attached. To the bottom of this PVC extension a 3.81cm [1.5"] piece of 7.62cm [3"] schedule 40 ABS is glued. Three slots were machined into this piece of ABS to support the latches made of 0.32cm [1/8"] thick aluminum. A piece of elastic was laced through the holes and acts as a compression spring that ensures the wellhead cap is properly secured on the wellhead.

Figure 17: Wellhead Cap Prototype 4

Prototype 4---Result

After the initial test we immediately saw two major problems. The first problem was that the clips with the elastic on the outside were difficult to fit over the wellhead because they would not slide back to allow for the wellhead to fit through. The second problem was that there was too much of a gap between the wellhead and the side of the wellhead cap. This caused the seal to invert and consequently not seal. We also found there was a circular depression around the bottom of the second closet flange that helped the seal invert because there was nothing to support the seal from below.

Final Product

This final version (see Figure 18) starts off with a mini check valve. Attached to this check valve is a cable and pin that is pulled by the ROV to stop the water flow. Attached to the check valve is a 2.54cm [1"] female threaded PVC pipe fitting. A couple of PVC reducer bushings are attached under this. Below this is the sealing mechanism which is comprised of two custom-machined flanges and a rubber seal with a hole in the middle. Twelve #8-32 x 2" machine screws clamp this assembly together. The bottom of the assembly has three slots that hold the grippers that clamp onto the wellhead. These are one-way latches that spring into place to hold the cap on.

Figure 18: Wellhead Cap Final Product

Water Sampler

The water sampler device (see Figure 19) consists of a motor-driven pump that sucks water from the sampling site, through a hose, and into an expandable bag. An expandable bag was chosen so that the ROV will remain neutrally buoyant when the bag fills with water. A camera has the bag in its view allowing the pilot to collect the specified amount of sample. The device is kept in a retracted position on the side of the ROV until needed, at which point a solenoid activates a spring system, causing the device to swing into place. This keeps the device out of the way until needed and allows for bucket clearance and keeps the ROV off the seafloor in case the bucket is on the floor.

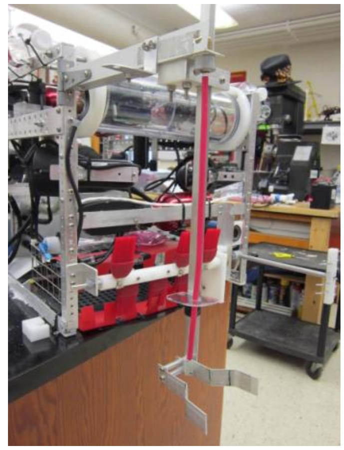


Figure 19: Water Sampler

Lights

Concerned that the ambient light at depth may be insufficient, the ROV is equipped with a lighting system (see Figure 20) to ensure good task visibility. First, all of the ROV's cameras operate with low light levels, and two are infrared. To maintain the color quality, there are three light bars on the ROV; two in front, and one in back. The light bars consist of a simple printed circuit board and 42 LEDs running at 3V. Each LED produces 10,000 millicandela with a beam angle of 15 degrees, resulting in 22.5 lumens of light per bar. The lights are housed in a 2.54cm [1"] ID polycarbonate tube that is sealed at both ends with o-ring end caps.

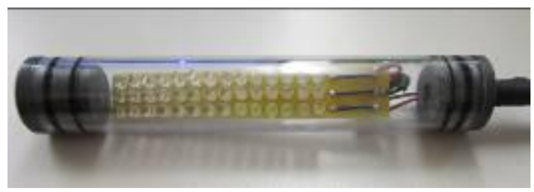


Figure 20: Light Bar

Mission Objectives

Task 1: Cut Riser Pipe

This task will be completed by the ROV in two steps. First the ROV will descend to the damaged riser pipe and connect a vinyl-coated cable to the U-bolt on the top of the riser pipe. The connection mechanism is a carabiner-style hook ensuring the cable will not come free. Once the cable is connected, the ROV will remove the Velcro strip from the pipe using the front hook. Finally, a deck crew member will be available to haul the cable, and the riser pipe will be pulled completely clear of the wellhead. With the wellhead clear, the ROV will proceed to cap the wellhead.

Task 2: Cap Wellhead

The production wellhead cap that Jesuit AquaCorp designed relies on three mechanisms. The first is a check valve at the top of the wellhead cap to ensure ease of placing the cap on the wellhead, alleviating the resistance of the water by letting it flow freely through the top of the cap. The check valve is held open by a pin connected to the ROV via a cable. When the ROV releases the wellhead cap and pulls up, the pin is removed, and the valve seals the wellhead cap onto the wellhead. The pressure then increases inside the cap and tightens the second mechanism, a seal, around the outside of the wellhead. This second mechanism is a rubber seal that is clamped between two pieces of PVC. The rubber seal is a circular, 14.5cm piece of rubber with a 4.5cm hole in the middle. When the wellhead cap is on the wellhead, the seal looks like an upside down funnel. The seal rests around the outside of the well head and the pressure pushes and seals it around the wellhead. The third mechanism are the aluminum grippers that grip the wellhead and ensure that the cap stays seated on the wellhead. The grippers slide over the well cap when it is placed on the wellhead and because they are one way latches do not let the wellhead move up with the water pressure. The latches are attached to springs that deploy into the space between the couplers and 3.81cm [1.5"] PVC pipe. These springs keep the seal from inverting and allowing the water to escape the seal through the bottom of the well cap.

Task 3: Collect a Water Sample

Our water sampler is spring loaded and located on the side of the ROV. When we get to this task we will trigger a solenoid that releases it. The tube is ridged and is inserted into the water sample container. A pump is activated to extract the water to a storage container on board the ROV.

Task 4: Collect Benthic Organisms

After analyzing the different creatures that we need to return to the surface for our client (a sea cucumber, a glass sponge, and a Chaceon crab), we brainstormed ideas on a device that could easily control all of them. In order to collect the varied benthic organisms, Jesuit AquaCorp designed a critter container similar to a broom and dustpan. A small motor will rotate a group of seven brushes around an axle running across the top edge of a box. The brushes will sweep each organism into the box and keep them from rolling or floating out.

Conclusion

Challenges Faced and Overcome

Jesuit AquaCorp's main challenge this year was undergoing a coaching change that led to delays early in the season. At the beginning of the school year, the team had no adult leadership, which prevented any formal meetings from occurring. As a result, the students of Jesuit AquaCorp had to adapt to a new kind of team dynamic for the first few months of the season. Despite these setbacks, Jesuit AquaCorp worked together to start the new year; they successfully hired new team members and started preparations for the year. Once the school selected team coaches, the team quickly brought them up to speed on the year's progress, and official brainstorming for the ROV design began. The overall bond between team members helped maintain the robotics team during the period of transition.

The returning members valued their experiences at MATE and worked hard to ensure the continuation of the team. Even though the season started behind schedule, Jesuit AquaCorp worked together and turned the complication into a positive bonding experience. The team worked hard to make up for lost time and was able to get back on schedule by spring.

Lessons Learned and Skills Gained

Every year, one of Jesuit AquaCorp's most important goals is to enact its corporate succession plan, which consists of more seasoned employees passing on their knowledge to new trainees so that the company will continue to thrive in the future. Our new hires learned skills such as how to solder and de-solder, and how to use the different machines in the lab.

Our seasoned employees also learned new skills. A few have mastered the art of machining parts on the lathe and can accurately make any part designed by the CADD department. The CADD department spent the beginning of the year learning about tolerances of parts and setting a standardized chart so all parts will fit together and have room for error. The programmers honed their skills as did the machinists.

In addition to learning specific skills, the employees of Jesuit AquaCorp learned about the entire engineering process—seeing a project through from the initial concept stage to final testing and production. This included setting a schedule and maintaining it. Members had to plan into the future and work together. They had to know what parts they needed for subsequent work days in order to maintain this schedule. This also meant that different departments had to work together when changes were made. For example, the electronics containers were designed for one type of speed controller, but after they were changed by the electronics department, the containers needed to be enlarged. These new skills show that Jesuit AquaCorp has a bright future ahead of it.

Future Improvements

Each year we are challenged to come up with future improvements that we would like to see on our vehicle. This has led us to using Ethernet communication, pan cameras, and telemetry data such as a compass. We have new features that we would like to incorporate into future models of our ROVs. We believe that these will serve our future customers even better. We want to use video over Internet Protocol so we can eliminate one of our CAT5 cables in our tether, making the tether smaller. We have also explored the possibility of using a fiber optic cable for our tether. This would be expensive and difficult but a good challenge. In previous years we have used active buoyancy on our ROV and we would like to use this in the future so our customers can lift heavier loads and also return to the surface more rapidly. However, this would require the addition of an air hose down the tether. This year we attempted to use more powerful, brushless, thrusters but we had difficulties finding off-the-shelf speed controllers that were rated to the voltage and current that we needed. Next year we would like to try to start our season earlier in order to address this problem, work through it, and succeed in using thrusters that are more powerful.

Build Schedule

As noted earlier, this year we got off to a slow start as the adult leadership changed greatly. Our new adult leadership limited our work days strictly to weekends, forcing us to plan the work days to be used efficiently. This meant that the students led much of the prep work for this year. We began our season by exhibiting our ROV at our school's open house so we could encourage younger students to become involved in robotics. Once the MATE mission was released in December, we worked most weekends and a few weekdays to accomplish everything. We had key milestone dates that we needed to achieve to be successful. We developed a Gantt chart at the beginning of the year and maintained our schedule. See Figure 21.

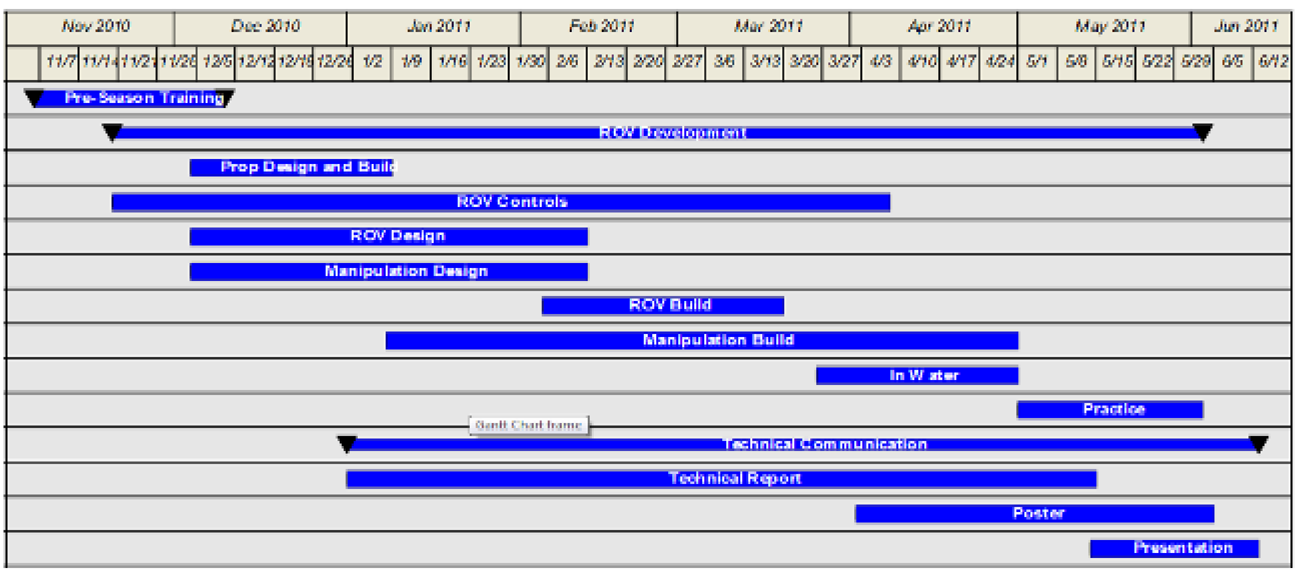


Figure 21: AquaCorp Build Schedule

Budget

We had to be careful with our limited financial resources. At the beginning of the season we budgeted the cost of everything and then did our best to adhere to the plan. We kept careful track of our expenses and our Chief Financial Officer made sure there were no unnecessary costs. This allowed us to have an ROV that cost $3,970.00 to make . See Table 1 for a complete budget.

Contributions	
Description	Amount
Jesuit High School	$14,000.00
Dues ($100 x 18members)	$1,800.00
School Magazine Sales	$1,000.00
Anonymous (Shipping)	$2,000.00
Helen and Neil Zinn	$500.00
Subconn	$500.00
David Borden (CNC Machining)	200
James Claybrook (Welding)	200
	$20,200.00

Expenditures	
Description	Amount
Research, Development, and Demonstration	$2,500.00
Bulk Materials	$970.00
Seabotix Thrusters (2)	$990.00
Electronics	$890.00
Cameras	$160.00
Tether and TCU	$210.00
Wellhead	$50.00
Other ROV Expenses	$700.00
Lab Equipment (laptop and tools)	$1,630.00
Shirts	$500.00
Prop construction	$300.00
Travel, Lodging, Shipping, MATE Fee	$5,000.00
	$13,900.00

Table 1: Jesuit AquaCorp Financial Statement

Senior Reflections

Phillip Coyle: Chief Project Engineer

My three years on Jesuit Robotics and competing in the MATE program have given me invaluable knowledge. I will be able to use this knowledge as I continue my education at Santa Clara University, majoring in mechanical engineering, and later in the real world. I am thankful for wonderful opportunities that I had and the many friendships that I made as a result of being involved in the robotics program, and I know that the experiences that I had caused me to grow as a person.

Figure 22: Phillip Coyle

Chris Eur: Head of CADD

Thanks everyone on the team in the past and at present for the wonderful experience I've had for the past four years, and a special thanks to MATE and all who make MATE possible. I learned not only CADDing on Solidworks but workmanship skills that will carry me far. I saw how higher-level mathematics can be put directly into use as I designed the vector thrust module, and further consolidated my decision to major in mathematics at Harvard University this fall.

Figure 23: Chris Eur

Brian Grau: Chief Executive Officer

Being involved with the MATE program for the past four years has led me to a love of engineering. I have learned many skills from basic design and CADD to more complex skills such as theoretically stress testing parts. Being the CEO of Jesuit AquaCorp has allowed me to enhance my leadership skills which I know will serve me greatly in the future. Next year I will be attending Santa Clara University and will be majoring in Mechanical Engineering.

Figure 24: Brian Grau

Jared Wilson: Mission Operations Manager

Working on the Jesuit robotics team was something that I never expected to be doing until I decided to join last year. Since joining, I have been able to learn many important skills about engineering, management, deadlines, and working towards a common goal. The MATE competitions last year and this year have both pushed me to become better at managing my own work as well as the work of those around me. Next year, I will be studying Earth Sciences at California Polytechnic in San Louis Obispo.

Figure 25: Jared Wilson

Matt Yang: Marketing

My two years on Jesuit Robotics have contributed to my decision to major in engineering at Creighton University. The skills I have learned through the MATE competition will help me in my major as a bio-medical engineer. I am grateful for the social experience that MATE has given me as well as the additional knowledge I have gained from competing. The problem-solving and teamwork skills will be a great asset to me in college and for the rest of my career.

Figure 26: Matthew Yang

Acknowledgements

None of this would be possible without the help of companies, our school, and different individuals. We would like to thank our parents for all of their support on this endeavor and the following people:

MATE—Sponsoring Underwater ROV Competition
Jesuit High School—Monetary Donation
Mr. Rolf Konstad—Head coach who gave up many weekends to work with us
Mr. Jay Isaacs—Mentor for six years
Dr. Daniel Styer—Mentor for two years
Mr. Peter Brown—Mentor for one year
David Borden—CNC machining of electronics container O-ring groove
James Claybrook—Welding
SubConn® Corp.—Underwater Connectors
SolidWorks®—SolidWorks® CADD Program
Seabotix™—Discount on thrusters
Anonymous—Shipping of the ROV
Helen and Neil Zinn—Monetary Donation
Parents—Food and emotional support

References

Young, Warren C (1989), "Roark's Formulas for Stress and Strain, Sixth Edition", New York: McGraw-Hill, Inc., pg. 458.

Appendix A: Displacement Calculations

Due to the depth that the ROV has to travel, we built the electronics container to withstand the increased pressure from the water down to 13 meters. These calculations are meant to take into account the type of material used and how much a given thickness would flex under a specific amount of pressure. Using these calculations we were able to determine a safe thickness for the electronics container to ensure that it would not fail at depth.

We used SolidWorks® to perform the displacement calculation on the lid (shown in Figure A-1) and then confirmed the results using the appropriate equation from *Roark's Formulas for Stress and Strain, Sixth Edition*. SolidWorks® showed that the center of our electronics container lid would have a displacement of 0.72mm. Our calculations (shown below in Figure A-2) showed that the center would deflect 0.031 inches or 0.79mm.

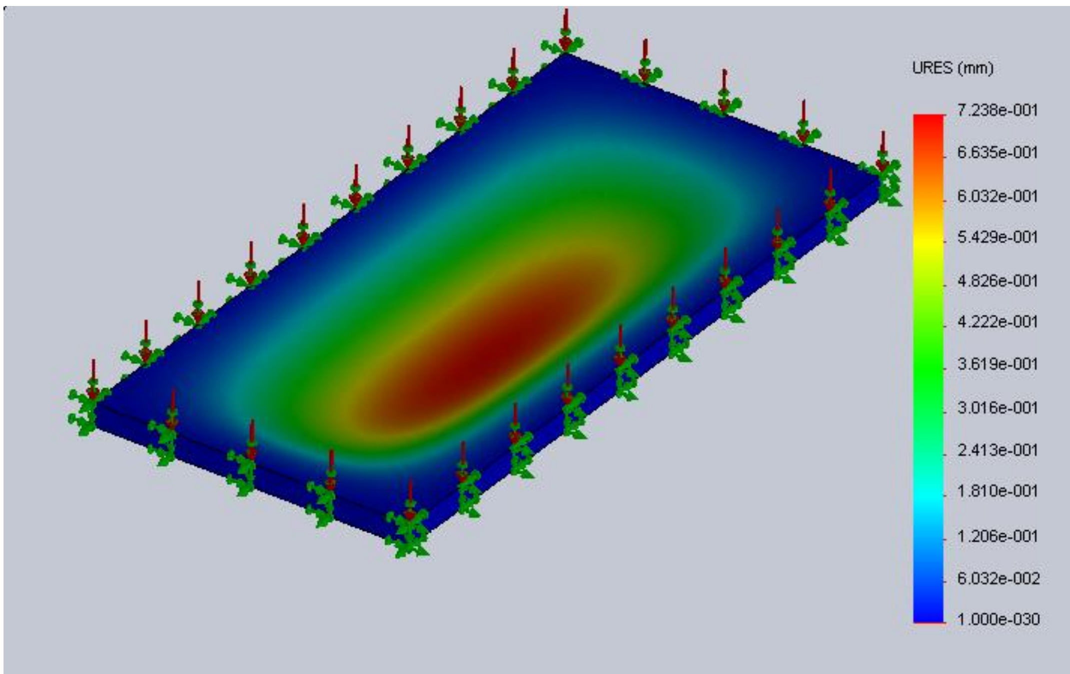


Figure A-1: Displacement Calculated by SolidWorks®

α	13 Inches	$$\max y = \frac{-\alpha q b^4}{E t^3}$$
q	17 Pounds Per Square Inch	
b	5.125 Inches	
E	3.33E+05 Pounds Per Square Inch	
t	0.5 Inches	

Figure A-2: Roark's Formulas for Stress and Strain, Sixth Edition Calculations

Appendix B: Calculations for Vector Control

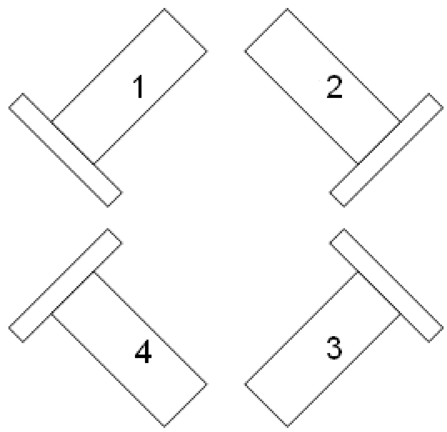


Figure B-1: Thruster Configuration on ROV

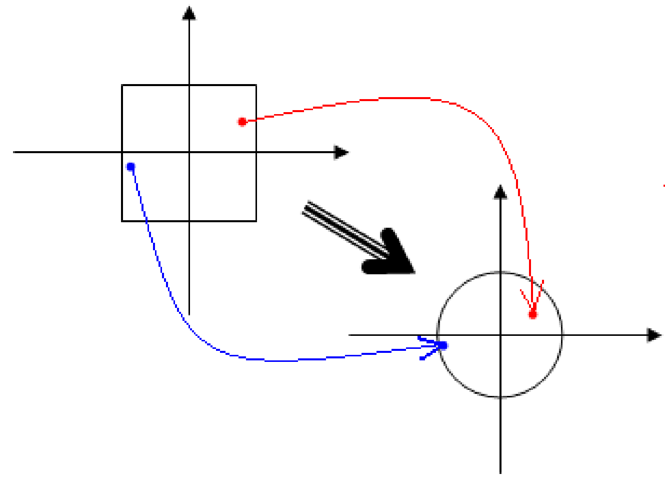


Figure B-2: Mapping Rectangular Domain to Circular Domain

The mathematics of our vector thrust code consists of three major components that assigns an output value, O_i $(i = 1,2,3,4)$, for each of the four thrusters as numbered in Figure B-1. The first component determines the translational thrust (T_i), the second the rotational thrust (R_i), and the third creates the composite of the two when simultaneously triggered and gives the final value (O_i).

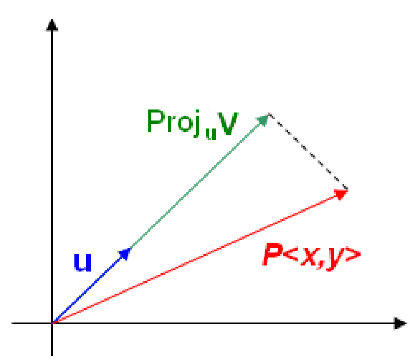
The translational component is composed of two parts as follows.

The first part creates an objective, continuous mapping from the rectangular domain of the translational input $(x, y) \in [-500,500] \times [-500,500]$ onto the circle of radius 500 centered at the origin as illustrated in <Figure 2>. Using simple geometry of similar triangles, it can be shown that this function essentially maps (x,y)→P(x,y) where

$$\begin{cases} P = 0, \ \ if \ \ (x, y) \in (-50,50) \times (-50,50) \\ P = \dfrac{1}{\sqrt{\left(\dfrac{\min(|x|,|y|)}{\max(|x|,|y|)}\right)^2 + 1}}, \ \ if \ \ (x, y) \notin (-50,50) \times (-50,50) \end{cases}$$

The null zone is created by domain restriction $(x, y) \in (-50,50) \times (-50,50)$ for P=0.

The second part assigns the translational value T_i (i=1,2,3,4) to each of the thrusters. It is determined by considering the P(x,y) as a vector **V** = $P\langle x, y\rangle$ and by projecting it onto the respective unit vectors of each thrusters as shown in the figure to the right.



For example, T_1 points at $45°$ and hence its unit vector **u** is $\langle \cos 45°, \sin 45° \rangle = \left\langle \dfrac{\sqrt{2}}{2}, \dfrac{\sqrt{2}}{2} \right\rangle$. The projection of the vector $P\langle x, y\rangle$ onto this vector is given by, Proj$_{\mathbf{u}}$**V** = $\left(P\langle x,y\rangle \bullet \left\langle \frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2} \right\rangle\right)\left\langle \frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2} \right\rangle$

Its magnitude with orientation is $P\langle x,y\rangle \bullet \left\langle \frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2} \right\rangle = \frac{P\sqrt{2}}{2}(x+y)$

Similarly, the following can be obtained in a likewise manner:

$$\begin{cases} T_1 = \frac{P\sqrt{2}}{2}(x+y) \\ T_2 = \frac{P\sqrt{2}}{2}(-x+y) \\ T_3 = -\frac{P\sqrt{2}}{2}(x+y) \\ T_4 = \frac{P\sqrt{2}}{2}(x-y) \end{cases}$$

The rotational component value assigns the rotational values R_i for each thrusters. They are determined by $z \in [-500, 500]$ where z > 0 implies clockwise rotation and z < 0 counterclockwise rotation of the joystick. The null zone is set to be $z \in [-100,100]$.

$$\begin{cases} R_1 = R_3 = \begin{cases} 0, \ if \ z \in [-100, 100] \\ z, \ if \ z \notin [-100, 100] \end{cases} \\ R_2 = R_4 = \begin{cases} 0, \ if \ z \in [-100, 100] \\ -z, \ if \ z \notin [-100, 100] \end{cases} \end{cases}$$

Lastly, the final component is a function of two variables, the translational (T_i) and the rotational (R_i) value, that creates a single output value by making a compromise between the two when they are simultaneously running. The function is given by,

$$f(T_i, R_i) = \left(1 - \frac{|R_i|}{1000}\right)T_i + \left(1 - \frac{|T_i|}{1000}\right)R_i = A_i$$

Note that $A_i = T_i$ *or* $Ai = R_i$ when R_i=0 *or* T_i = 0, respectively, and $A_i = \frac{1}{2}T_i + \frac{1}{2}R_i$ when $|T_i| = |R_i| = 500$ (i.e. their maximum values in either direction).

The value A_i is the output value that ranges from -500 to 500. The interval can be mapped onto any range that fits the output range suitable to the thruster. In the case of our ROV, the domain [-500,500] was mapped to [0,179], the final output range.

Appendix C: Electronics Schematic