HALF-CUT

THE LINCOLN GROUP LLC

GAHANNA LINCOLN HIGH SCHOOL

GAHANNA, OHIO - USA

The Lincoln Group's ROV: Half-Cut

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ABSTRACT

The Lincoln Group presents a new top of the line ROV that will fulfill the needs of The Port of Long Beach and win the contract. The ROV, lovingly referred to as Half-Cut, features four motors and three cameras placed around the bot. This allows for swift movement in all directions and multiple viewpoints of the surroundings.

To make the ROV even more adaptable, The Lincoln Group has incorporated modularity into the design. Modularity is the ability to easily and quickly interchange parts depending on the requirements at the time. This approach grants our ROV a level of adaptability that sets it apart from its competitors.

To achieve this, we utilized 3D modeling and printing throughout the construction process. One example of this was our creation of PVC to LEGO piece hybrid adapters. These were used to integrate the frame and tool package systems into one cohesive unit. This also led to an increase in modularity as these adapters can be moved to different areas on the PVC frame quickly and easily. 3D printing was also utilized to create motor shrouds to provide an additional layer of safety. Finally, we created 3D printed housing for the EV3 motor chips that regulate the motors and prevent pulsating during operation.

SAFETY

SAFETY PROTOCOL

While The Lincoln Group may be a fun and educational underwater robotics team; with fun, there must also come rules regarding safety. The goals of these rules and guidelines are to keep us as safe as possible. This protocol includes safety guidelines that the team has followed in order to have a safe and successful year.

Communication

When testing our robot, communication will be key. There are several dangers that come with testing, mainly focusing around the thrusters. To prevent injury, drivers and poolside personnel must communicate effectively about the thrusters being on or off. Before powering on our robot, the co-pilot should ask if the person(s) handling the bot poolside are "all clear". This means that their hands, fingers, and any other body parts are away from the motors and any other moving parts. If, for any reason, troubleshooting needs to be done while we are operating our ROV, the poolside personnel must communicate to the pilots when to turn off the power flowing to the motors, using the phrase "power off." When hearing this, the pilot or co-pilot will stop the program from sending commands to the motors by exiting out of the EV3 program. Exiting this program effectively cuts off all electricity from following to the motors. When this is successfully completed, the pilot/co-pilot will repeat "power off" to confirm that the ROV is now safe to handle.

Precautionary Measures

When constructing the robot, several precautionary measures must be taken to ensure that it not only functions, but functions safely. Our robot has many components that are powered by electricity; electricity that is transferred to parts of the robot through wires. Our wires are waterproofed so that any exposed wire connection is soldered, coated with silicone, and wrapped in shrink wrap to provide a waterproof connection. We also waterproof our hobby motors to allow them to power our tool packages safely underwater. To waterproof our motors, first we cover any exposed holes on the motors with electrical tape. Then we prepare a prescription bottle to hold the motor by drilling a hole at the bottom to allow the shaft to pass through and adding Vaseline to it. Vaseline's hydrophobic properties helps keep the motors dry during submerged conditions. Finally, we insert the hobby motor into the prepared pill bottle and fill the remaining space inside the pill bottle with hot wax to finish the waterproofing process.

In addition to our waterproofing methods, we utilized well-ventilated rooms and wore the proper safety equipment, such as goggles and face-masks through the construction process. Other miscellaneous precautionary measures include checking for any loose connections on the electronics board or the ROV, and checking the functionality of all controls and motors before submerging the ROV in the pool.

Equipment

Courtesy of the 3D printing team, this year we have implemented a variety of 3D printed modules in our ROV's design. One module was created to house the chips that allow the integration of our MOSFETs and EV3 controller systems. The product of this integration allows us to regulate the speed and direction of our thrusters. Due to the importance of these chips, the 3D printed housing was an effective way to keep the chips in position and grant them greater protection on the electronics board. Another key 3D printed module is our motor shrouds. They are printed in bright yellow plastic to help them stand out from the rest of the ROV as well as provide a visual reminder of "caution".

Additionally, there are other safety aspects of our electronics board. On the electronics board, there are several types of differently colored wire. Each color depicts its purpose, allowing the team to troubleshoot easily and be able to identify electrically active parts of the board during testing. As per standard, the red wires (positive) and the black (ground) wires are representative of power going in and out. The Lincoln Group uses green (ground) and white (positive) wires for the thrusters, as well as, purple (ground) and yellow (positive) for the control. These wires visually "talk" to our team's electricians to remind them of the wire's purpose and the path electricity takes on our electronics board. In addition to the color coding, proper fuse calculations have been performed to help determine the appropriate fuse amount to incorporate into our design. By utilizing a 25-amp fuse, we were able to create a 150% or greater electrical overhead to protect our board from any electrical spikes.

Beyond the electronics board, the wires on the tether are braided together to help prevent them from getting tangled and to provide the tether greater flexibility. This was important not only from a functionality standpoint, but also to reduce the risk of the tether being damaged during missions by reducing the risk of entanglement of the wires in the motors. Another safety measure taken was the addition of strain reliefs, specifically on both ends of the tether and electronics board. To achieve this, we utilized clamp connectors top side and a strain relief gland at the connection point of the tether and ROV.

Finally, our construction process utilized many zip ties. To limit the possibility of entanglement as well as improve the aesthetics of the tether, the ends of the zip ties were snipped off. To prevent injuries to personnel handling the bot, the snipped ends are covered with hot glue to eliminate sharp edges. The added benefit is that the hot glue often adds an extra layer of reinforcement to the zip tie itself.

Conclusion

In conclusion, safety is The Lincoln Group's number one priority. By following these guidelines and implementing unique safety features, such as the 3D printed modules, the team is able to complete missions safely and effectively.

DESIGN RATIONALE

ROV STRUCTURE

This year, our ROV has been designed as a trapezoidal prism. Over the summer of 2016, our team members brainstormed multiple unique designs for the frame of the ROV (Figure 1). These designs included the trapezoidal prism (bottom right), a hexagonal prism (top center), and a cube with a pyramidal front (bottom left). The trapezoidal prism frame was selected by the team since we decided the design to be superior to the other designs in terms of room for tool packages, attachment points for buoyancy and ballast, and water flow.

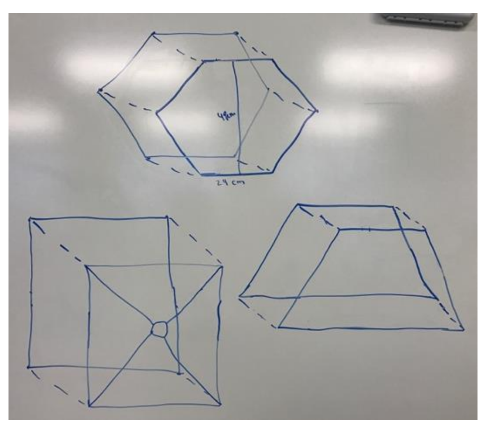


Figure 1: Sketches of the different designs.

The hexagonal prism design was eliminated due to concerns with its ability to provide sufficient room for the tool packages. To remain within the size restraints of 48 cm in diameter, each side of the hexagon could only be 24 cm in width. This would limit the amount of tool packages that could fit on the front side of the ROV. Other tool packages would then have to be placed on the left or right portions of the bot which is not optimal.

Additionally, there were concerns with the cube design. While the idea that a pointed front could efficiently move through water with an increased speed was tempting compared to the trapezoidal design, it would come at a cost. Therefore, the team determined that it would be too difficult to attach claws onto the pyramidal-shaped front of the ROV. This would once again force tool packages onto the sides of the ROV. Hence, the team decided that the advantage of increased speed did not outweigh the importance of tool package placement.

Frame Construction

The frame was constructed out of polyvinyl chloride (PVC) pipes for a multitude of reasons. First of all, ½ inch PVC is very inexpensive, costing less than a penny per centimeter. It also provides the user a plethora of options for customization using joints such as t-joints, elbow joints, cross joints, and more. The last reason we used ½ inch PVC was due its high availability.

One of the main focuses while constructing the frame was to create the maximum amount of room possible for tool packages. To achieve this, we started off with the bottom base having dimensions of 34 cm wide, 32 cm long, and 30 cm tall. The top portion was reduced to only 20 cm wide in order to allow us to attach buoyancy equipment later (Figure 2). In the beginning, we added four PVC t-joints to the front and four more to the back of the ROV. Each pair of t-joints would provide a point of fixation for a tool package, meaning that we could effectively equip four tool packages. However, to conserve space, a replacement for the t-joints was 3D modeled and printed. These customized joints removed the gap that naturally existed between two t-joints, allowing us to continue to provide two points of fixation for each tool package while reducing the overall space needed on the frame. Furthermore, to make ensure the structural integrity and shape of the frame, various points of the frame are secured with screws.

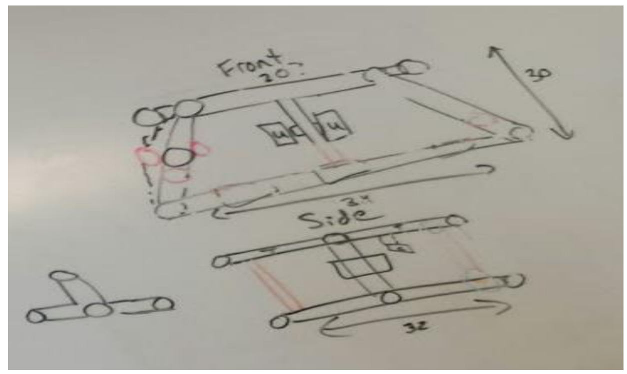


Figure 2: The original dimensions of the frame.

To improve the safety and the aesthetics of the ROV, the Lincoln Group tried to encapsulate all of the wires within the frame's body. This was achieved by drilling additional holes into the PVC frame and directing wires from the tether through the PVC to their tool package. The team also tried to make sure that all the soldered and shrink wrapped wires with silicon were inside the frame. By using a strain relief cable gland, there was sufficient tension relief on the outside of the frame to maintain the safe connections. The tension relief ensures that if the ROV were to get caught in an obstacle and the tether get snagged, that snag would not damage the soldered connections.

Camera

The Lincoln Group decided to attach three cameras onto our ROV this year. These cameras provide us with the view of both the front and back tool packages along with one camera just for the forward view (Figure 3). This decision was a result of software issues that occurred last year when using Logitech webcam cameras. These software issues severely hindered the group since they could not see where to go nor did they know what to do. To eliminate this issue, the team decided to use multiple cameras and connect them directly to the monitors. The cameras only had about 34 cm of cable, which was not enough to reach the ROV in the pool. Therefore, the team decided to purchase Masione 50 Feet Security Camera Cable to extend the tether's length.

Figure 3: The two cameras on the front of the ROV.

The cameras that the team decided to use were Uxcell ¼ inch Backup Rearview Cameras. These cameras are cost effective, at only eight dollars apiece. Additionally, these cameras were very easy to waterproof. First, they were put into a petri dish, and then encased in a one inch PVC pipe. This was then filled with epoxy and left to harden for 24 hours. The cameras were then connected to a cable around 15 meters in order to extend the range of the camera transmission. The connection between the camera's immediate cable and the extension cable was also waterproofed in a one inch PVC pipe with epoxy.

These cables led straight to the monitors which were purchased along with the cameras for $35 each. The monitors that the team decided to purchase were Buyee 7-inch Color LCD Monitors. Part of the reason that these monitors were chosen, was because they only use .34 amps. This is important because the ranger division limits the ROV to only 25 amps of power. Therefore, it is vital that we use equipment that uses low amounts of current in order to be able to include all tool packages and also remain within the limit. Also for this reason, there are only two camera monitors, resulting in one of the monitors switching between the front and back view of the tool packages. The other monitor only concentrates on the view of the environment ahead of the ROV. This setup of the cameras and monitors allows for multiple viewpoints, and ensures a reliable connection throughout the mission.

Tether

The tether's main purposes are to send power and return signals from the ROV. The tether for Half-Cut includes three camera wires, four pairs of 14-gauge speaker wires, and two CAT-5 wires (Figure 4). The camera wires send signals from the camera to the monitors, while also providing power for the cameras. The 14-gauge speaker wires send power to the thrusters on the robot. We decided to use speaker wires because it is cost effective by being inexpensive, while being able to transfer a lot of power. We decided to use 14 gauge wires because the lower the gauge, the more power they can transfer. The CAT-5 is a cable that contains four pairs of 22-gauge wire inside it. Inside each CAT-5 wire, there are blue, brown, orange, and green wires paired each paired with a white wire. Each pair of wires lead to their own corresponding tool package. The total length of the tether is around 15 meters long and is braided in order to allow flexibility.

Figure 4: Picture of the tether

Buoyancy and Ballast

Half-Cut must be neutrally buoyant in order to provide the pilot with optimal control. Neutrally buoyant means that however deep the ROV is placed underwater, it is neither trying to move up or down. To achieve this, the forces of buoyancy and ballast must be equal. Buoyancy is the tendency of an object to float up, while ballast is the tendency for the object to go down. For this reason, the buoyancy of Half-Cut was placed near the top of the frame, while the ballast was placed on the bottom (Figure 5). If this had not been done, there would have risk of the ROV flipping over. Half-Cut includes two different types of buoyancy on its frame, static and adjustable buoyancy. Static buoyancy is buoyancy that is permanent, and for this purpose the team deployed two air tanks. These were constructed using two sets of two inch PVC pipes that were 34 cm in length. These pipes were then sealed on the ends using PVC end caps and PVC cement. To construct the adjustable buoyancy, the team utilized a 20 cm long water bottle, where one could let water in and out. The adjustable buoyancy was attached to ROV using hose clamps. The ballast includes the weight of the ROV, as well as holes that were drilled into the frame, to allow water to come into the frame.

Figure 5: ROV displaying buoyancy tanks at the top.

Thrusters

Half-Cut utilizes 1,250 gallons per hour (GPH) Johnson Bilge Pumps as its thrusters (Figure 6). One reason we chose the 1,250 GPH pumps was that they produce the most thrust compared to the other Johnson pump options. Additionally, the Lincoln Group purchased the pumps while they were on sale, hence helping us save money while increasing the ROV's value. Bilge pumps are usually used on boats to pump out the excess water. However, the motors of the bilge pump can be utilized as our thruster by attaching a pre-made propeller. These thrusters are then bollard tested to see how much force each motor outputs.

Figure 6: Bilge pump motors featuring 3D printing motor shrouds.

Bollard Testing

Bollard testing plays an important role in the creation of an efficient ROV. It is done in order to measure the output force of each thruster, as each thruster has a slightly different amount of force produced. This is important because for having optimal control over the ROV, it is necessary for each of the motors going forward to produce almost the same thrust. This way, the ROV does not drift to one side or the other.

The process of bollard testing uses Logger Pro to record the output force (Figure 7). The motor is connected to a power source and a Vernier Dual Range Force Sensor, which connects to the computer (Figure 8). The Force Sensor is a device that allows for the measurement of each thruster's output force. Using the output force gathered from the motors, the team decided to put the two motors closest in force as the forwards and backwards motors, while the motors that were the most different were chosen to move the robot up and down.

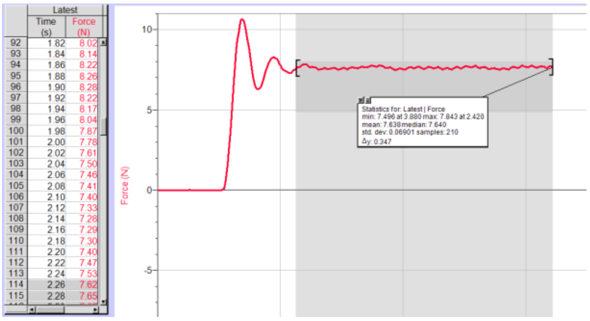


Figure 7: Example graph from Logger Pro.

Figure 8: Bollard testing setup.

Tool Packages

To complete the missions that were given to the Lincoln Group, a collection of two claws, one valve turner, and one suction apparatus were created. The claws and the valve turner are built using Legos. Each of these tool packages needed a unique design to ensure that they could perform their designated function under water. The Lincoln Group has developed a variety of methods to help bring about success.

Each of the tool packages used required a motor to operate. A high torque hobby motor is used to power the majority of these tool packages. The motor was purchased from Pitsco Education. The hobby motors have a six to twenty-four voltage direct current (VDC) and 1,300 milliamp (mA) capacity. The motor can also rotate 14,300 times per minute (rpm) when not under load. The stall torque for the high torque hobby motor is 555 grams per cm (g/cm). To waterproof the motor, a pill bottle was utilized to encase each of the hobby motors. A hole is drilled into the bottom of each so that the shaft of the motor can stick out. The hobby motors are further encased with electrical tape to prevent water from getting in. In the pill bottle, there is a small amount of Vaseline that allows the motor shaft to turn while preventing water from entering the bottle. The hobby motor is placed on top of the Vaseline in the bottle, and then the rest of the empty space is filled with hot wax, which then cools and hardens. An additional type of motor was implemented for the suction apparatus. This is a bilge pump motor, which was already waterproofed by the design of the motor.

The vertical claw is one of the tools used to complete the mission that was given to the Lincoln Group (Figure 9). It was designed to grasp and hold onto polyvinyl chloride (PVC) when it is positioned vertically. The grippers on the claw have space in between each gripping finger. The space allows each of the fingers to interlock so an almost completely closed claw can be achieved. This space also allows the claw to catch any cables in between the fingers. Pieces of pool noodles have been hot glued onto each finger to improve its gripping ability. The reason for this is because the pool noodles have a higher coefficient of friction than that of the smooth surface of Lego pieces which make up the fingers of the claw. The vertical claw has a gear ratio of 1/576.

The horizontal claw is the second gripping apparatus. This claw was designed to pick up PVC that are oriented horizontally. It functions similarly to the vertical claw and also features interlocking fingers to allow the claw to close with almost not gap in between the two sets of fingers. Pool noodles have also been added onto the horizontal claw to improve gripping ability. At the ends of the bottom set of fingers there are pointed Lego pieces which allow the claw to pick up objects on the bottom of the mission area. The horizontal claw has two moving sets of fingers rather than one that the vertical claw has, allowing it to close on objects easier. The horizontal claw has a gear ratio of 1/480.

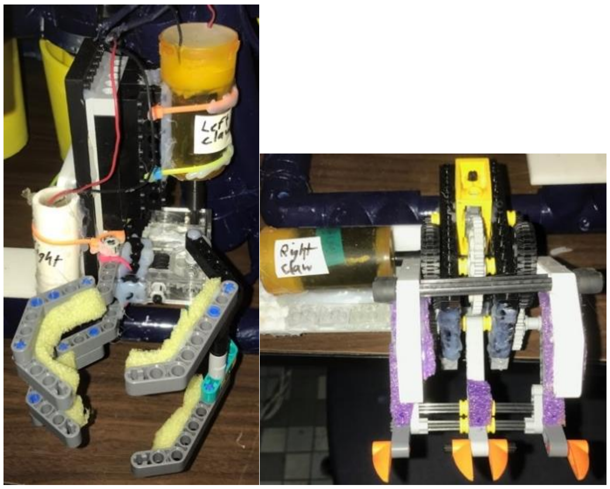


Figure 9: Vertical claw (left) and Horizontal claw (right)

The valve-turner went through a few designs, starting with a claw design on the end of an apparatus that allowed it to rotate 360 degrees (Figure 10). This design had a few problems with its size, strength, and usage. The first design was too large to be efficient. It was also not very durable. The second design is the one used with Half-Cut. This design is much simpler, requiring only one motor to turn, and is more durable. The current design takes up about half the space the first design did. A fundamental difference between the two designs is that the current design does not include a claw on the end of it, but rather uses two fingers that are mounted onto a revolving platform rotated with a hobby motor. This claw contains two gear boxes that contain one 24 tooth gear and one worm gear each gear box, bringing the gear ratio to 1/ 576.

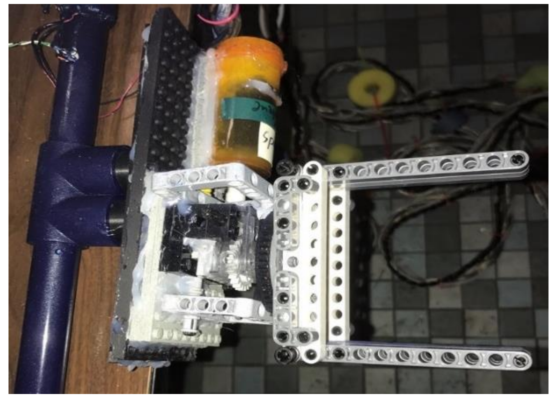


Figure 10: Valve turner

The sucker was created to retrieve the agar as a part the mission assigned to the Lincoln Group (Figure 11). We already had a sucker design from a previous year that was never used, so that was used as our starting point. The previous design was first tested for efficiency. Various lengths of the PVC were tested that changed the distance between the motor and the can, to determine how long the PVC can be before the sucker starts to lose the grip necessary to maintain suction. The Lincoln Group eventually came to the conclusion that a shorter space, as well as a slight redesign for the holes in the PVC allows better water flow, yielding more power and a greater suction. The new model contains the same can and attachment end, but a different motor and PVC pipe design. A hose clamp harness was also added so that the sucker could be easily attached to the bot.

Figure 11: Photo of the sucker.

Even though the sucker was made for use on the bot, it was decided that it would not work for this mission. There was little room on the bot that was visible for the cameras, so the addition of the sucker could not be placed conveniently in a spot where it is visible. Therefore, we concluded that taking off the sucker would result in the least possible points deducted.

The raman laser was constructed using a small piece of breadboard with two LEDs and a 10k ohm resistor (Figure 12). The breadboard was put into a piece of PVC with a piece of clear plastic on one end, and epoxy was poured in it to waterproof it.

Figure 12: Photo of the raman laser.

3D PRINTING

On our ROV we used many 3D printed parts. We used these parts for several different reasons. One of our main focuses on our bot is being cost effective and using less costly parts that do not compromise on quality. 3D printing helps to achieve this goal. By using PLA plastic, we are able to print pieces at about 2.3 cents per gram, costing us less than 12 dollars for all the pieces needed for our bot. As well as this increase in cost effectiveness, these custom parts allow customization to our needs. This allows us to fit more tool packages onto the frame of the bot while keeping a smaller size. Most importantly, 3D printing allows for full customizability. We use Autodesk Inventor to model the different parts, giving us the ability to make any part our bot might need. Doing this saves us a large amount of time that we might have been spending trying to find a solution to a problem using preexisting parts. We get the exact piece with the exact dimensions and the exact form that we want. If a part breaks we can easily reprint and replace it. These many capabilities make 3D printing a vital part of our ROV.

Design Process

When we decide to test out a new idea on the bot, we look to see what the easiest way to try it would be. Sometimes the easiest way is to use PVC or Legos, but many times 3D printing is used to get a less time consuming and more customized part. We model the part on the computer, look to see if there are any flaws, and decide if we still want to pursue the idea. If we like the part, we print them using one of our two MakerGear printers using PLA plastic. We also have two Up! Printers for slightly lower quality prints or if we need to print more than two different parts at once. Many times, there is residual plastic left on the plates of the printers. When this happens, we always wear thick work gloves to avoid the scraper slipping and injuring our hands as we scrape the plastic off. We keep all files for modeled parts regardless of if we print them or if they were successful or not. That way, we are able to reprint or make changes if needed, as well as to be able to look back at what works and what doesn't in the future. If the part printed successfully, then we put it onto the ROV to test it. If we like how it works on the bot then we look to see how we can make it even better. Once we reach a certain point of satisfaction, we move on the next piece to be modeled and printed. If the part doesn't work well, we analyze its flaws. If it is a problem with the way it printed, then we may try printing another one. If it is a problem with how it is designed, we go back to the model on the computer and alter it. If the problem stems from the concept itself, we may decide to no longer pursue the idea. This process allows us to not have to limit our ideas to what we can and cannot do with the materials we have. It opens the opportunity to let our truly innovative ideas to be tested and be turned into reality.

Parts Printed

Lego bases (Figure 13): We used 3D modeling to make our own bases to build on with Legos. We did this for two main reasons. First, we wanted a plate that fit the exact dimensions we needed. Second, to meet those dimensions with actual Lego plates would often require us to link together many different plates which would be unstable and likely to break. We measured actual Legos using calipers then printed new ones in the way we wanted, giving us the ability to build tool packages using Legos and attach them securely to our bot.

Figure 13: Lego Base

Tool package mounts (Figure 14): To attach the tool packages to the frame we used two points of fixation to make sure the tool packages did not shift while completing the mission. Horizontal and vertical mounts were both used to attach the tool packages, giving us the ability to orient our tool packages in different ways.

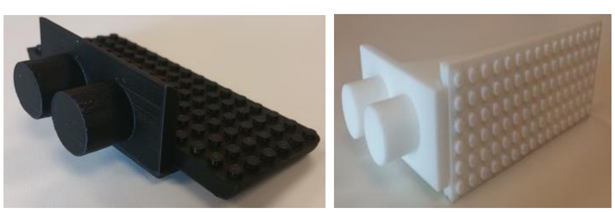


Figure 14: Tool package mounts

Double PVC tee piece (Figure 15): Our first method of achieving the two points of fixation we wanted for the tool packages was to use to regular PVC tee pieces. However, this took up too much space on the bot and we were not able to fit the tool packages we wanted and still see them with our cameras. We modeled and printed a new part to solve this issue. It combines 2 PVC holes into the same size as a normal tee piece. This frees up much more room on the frame of our bot. It also saves us money. The cost to print one of these pieces is about 58 cents. The cost for the 2 conventional tee pieces required to achieve the same goal is 1.2 dollars. While halving the size we also cut cost.

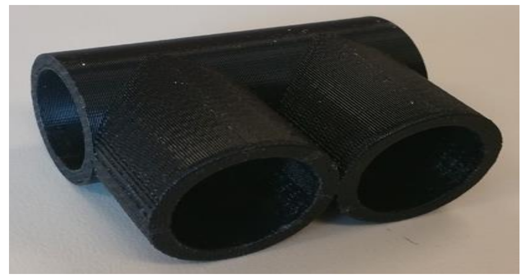


Figure 15: Double PVC tee piece

EV3 chip protectors (Figure 16): On our electronics board, we have chips that serve as an interface between our programs and our motors. These chips are just bare PCBs and very fragile. To protect them, we measured the dimensions of the chip including the size with a cable attached and printed a case to protect the chips from damage. These cases have a main shell and a lid to allow us to easily remove the chip from the case if needed.

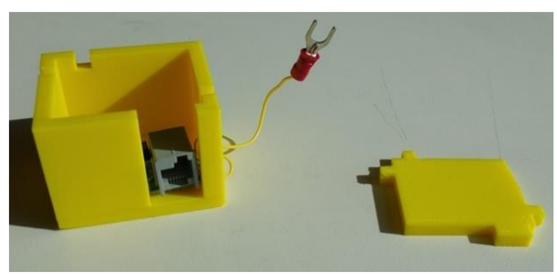


Figure 16: EV3 chip protectors

Hobby motor to Lego adapter (Figure 17): We have developed an adapter to connect hobby motors to our tool packages to power them. The adapters feature a hole for the hobby motor to attach to with a tension fit on one end and an '+' shaped hole on the other for Lego axles to fit into. With this adaptor, we are able to make complex tool packages out of Legos and then power them with simple and efficient hobby motors.

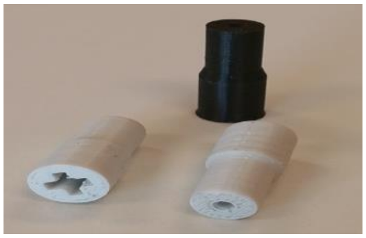


Figure 17: Hobby motor to Lego adapter

Motor shrouds are used to fix two primary problems. One is to protect the propellers and/or people from harm, such as when the ROV bumps a wall or someone carelessly grabs the motor while it is running. The other main reason the Lincoln Group uses motor shrouds is to amplify the forward and reverse thrust coming from the motors. We went through many designs of shrouds to create the best one for our bot. The problem of safety was solved by making the shrouds a conical shape that did not have any openings on the sides, which completely encases the propeller (Figure 18). In the final iteration of the shrouds, we also printed them in bright yellow plastic and embossed "CAUTION" onto multiple sides.

We conducted bollard testing with all versions of the shrouds we designed and although the versions we currently use decrease thrust, they have the least decrease compared to other versions. To get the most thrust possible, holes were strategically placed at each end. The end for forward thrust was purposely made significantly smaller than the opening for the reverse thrust to support flow. Although the shrouds ultimately decreased thrust, we decided safety for crew members and equipment was more important. One final modification was made after several iterations in which an "o-ring" was placed in the back of mounting. This modification allowed for proper motor mounting.

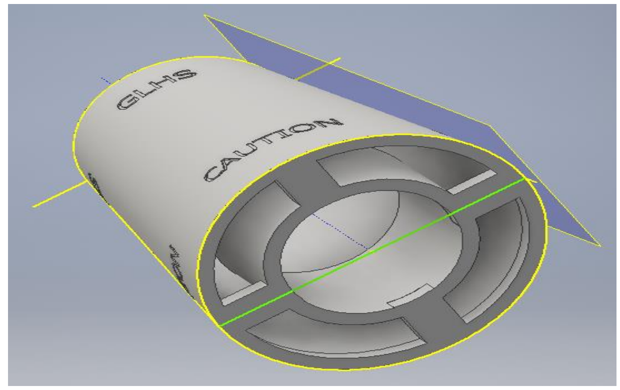


Figure 18: Inventor sketch of shroud

ELECTRONICS

Electronics Board

The electronics board contains all of the major electrical components for the ROV. Everything starts from the power supply, which sends 12 volts of power and is connected to the electronics board by two Anderson power pole connectors. A 25-amp fuse is used to protect the electronics from power surges. This particular fuse was chosen through fuse calculations (Figure 19). These calculations were created by adding the amperage of each electrical component on the ROV, coming out to a total slightly over 14 amps. This number is then multiplied by 150 percent to cover the possible times when things may put more than their normal amount of electricity. We found that the maximum electricity that Half-Cut may use is about 21 amps at any given time. The last step is to round up to the nearest common fuse for that amperage, being a 25 amp fuse for this ROV.

Half-Cut Fuse Calculations			
Item Name	**Quantity**	**Amperage/ Unit (Amps)**	**Total Amperage (Amps)**
1250 GPH Bilge Pump Thruster	4	3	12
385 Hobby Motor	3	0.33	0.99
Video Monitor	2	0.34	0.68
Camera	3	0.11	0.33
LEDs	2	0.02	0.04
TOTAL			14.04
x150% Overhead			21.06
Rounded to Standard Fuse			25

Figure 19: Fuse calculations

The source of power then leads to the electronics board (Figure 20), after this the power splits off to go to the control box, monitors, cameras, and to the MOSFETs. The control box has a positive and a negative connection that splits off to each of the switches inside. Each of the three cameras and four MOSFETs also have a positive and a negative connection. The two monitors both have a negative, a positive, and a ground connection in case there is a power surge. Each of these connections then leave the control board and connect to the ROV through the tether.

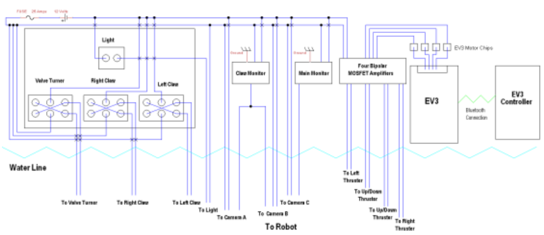


Figure 20: SID diagram (above water)

The master EV3 brick on the controller sends a signal through Bluetooth to the slave EV3 brick. The slave then sends a signal through four EV3 motor chips and then to the MOSFETs (Figure 21). The chips stop the thrusters from pulsing.

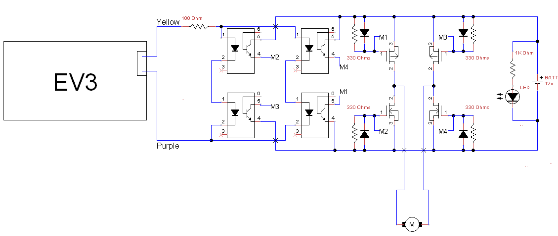


Figure 21: SID diagram of Bipolar MOSFET

The tether sends all of the signals to the ROV in the water (Figure 22). The electrical components on the ROV include four thrusters, one ramen laser, three cameras, and three hobby motors. Even after all of these components there is still enough amperage left over for the sucker, tool package that we choose to take off.

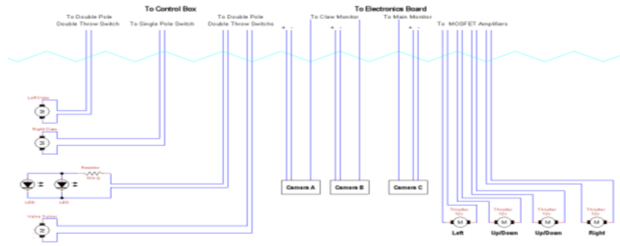


Figure 22: SID diagram (below water)

Controller

The controller was created out of Lego EV3 bricks and materials (Figure 23). One lever is separate from the main controller, which controls the up and down thrusters. The separate lever was found to be more effective for our pilots control.

Figure 23: EV3 controller

Programming

The software of our bot is coded with the Lego Mindstorm's LabView Program. Two EV3 bricks are used to transmit data, one on the electronics board, the slave EV3 brick, and in the controller, the master EV3 brick. The program on the master brick (Figure 24) sends signals to the program on the slave brick (Figure 25).

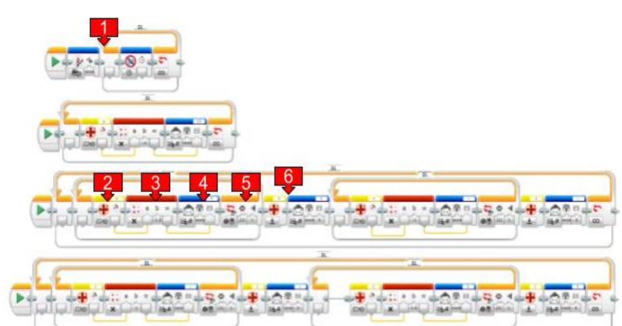


Figure 24: EV3 Master Program

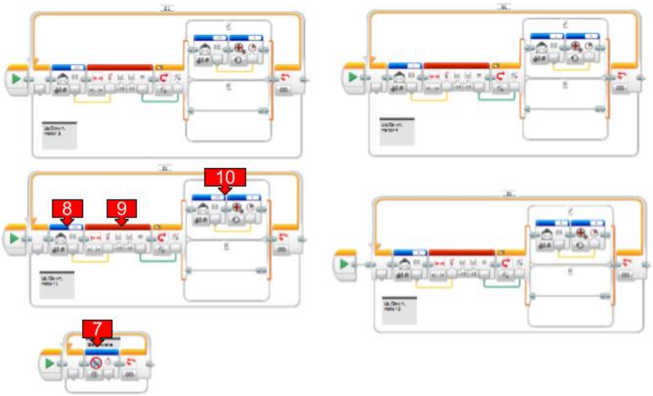


Figure 25: EV3 Slave Program

The master program first begins with the “Bluetooth connect” block that automatically connects the two bricks, then a “stay awake” block is repeated infinitely in a loop, so the program does not turn off while driving the robot (1). The main part of the program is the lever sensor. This begins by measuring the angle of the lever (2). Some motors have switched polarity and/or weaker thrust allowing these motors’ corresponding angle measurements to be calibrated accordingly. A polarized thruster is multiplied by -1, a weaker thruster is multiplied to 1.5 (3). The angle measure is then sent to the slave brick (4). This process repeats until the middle button is pressed on the controller (5), at which point the program goes into a “reverse mode”. This starts by resetting the levers’ angles, and sending a number of 0 to the slave brick so that the motors stop (6). The program enters into a new loop, which switches the left motor to control of the right lever, and the same for the right motor to the left lever. The polarities are also switched. This effect makes it easier for the pilot to move the ROV backwards and use the valve turner. Reverse Mode ends when the middle button is pressed again, causing the program to return to its original loop.

The slave program begins by receiving the master program’s angle measurements (8). It then checks to see if the measurement is between -15 and 15 (9). If it is, then the motors do not receive any signal, which allows the pilot to have a dead zone for easier stopping, while at the same time, allowing our MOSFETs to have a transition period. If the measurement is not within the dead zone, then the master program is allowed to send the measurement to the motor (10). The slave program, like the master, has a “stay awake” block in a loop to make sure it stays on during driving (7). A backup set of programs was also added in case of the main program failing, and features failsafe Bluetooth re-connectability, as well as a 2D GPS, providing the ROV a location relative to its starting point in a cartesian coordinate plane.

Switch Box

One single pole switch is used on Half-Cut which controls the light. If the suction tool is attached, it will be controlled by a single pole switch as well, as it only needs to suck in one direction. The claws and valve turner are controlled with double pole double throw (DPDT) switches (Figure 26). They are wired in an H bridge configuration; power comes in and out through the middle ports, but the direction of the switch dictates the polarity of the motor.

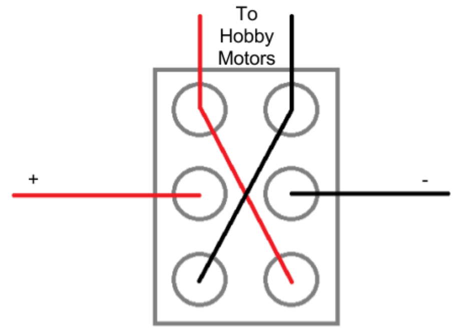


Figure 26: DPDT switch with H-bridge configuration

Bipolar MOSFETs

The Bipolar MOSFETs have three purposes: to amplify the voltage power from the EV3 slave brick to the thrusters, to regulate the speed of the thrusters by using post width modulation (PWM), and to switch the polarity of the thrusters. They have three sets of connections coming to and from them: the purple and yellow wires come from the EV3 slave brick, the red and black wires provide power from the power supply, and the green and white wires distribute power to and from the thrusters (Figure 27).

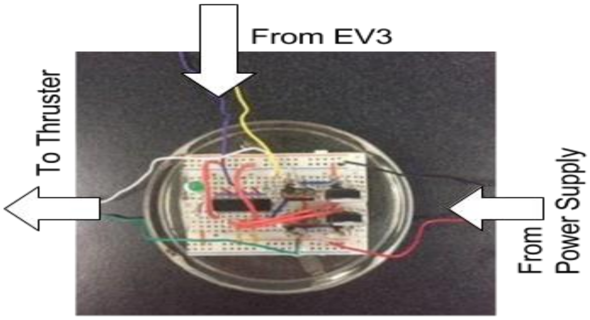


Figure 27: Bipolar MOSFET connections

The slave brick sends the thrusters five volts, but the thrusters require 12 volts to operate correctly. The MOSFETs use the five volts to open and close a switch for the 12 volts. The MOSFETS allow for variable speeds, however, are only capable of sending full power, or no power at one given time. Thrusters achieve different speeds by using post width modulation (PWM). An example of this would be that to achieve a 50% thruster speed, the MOSFETs would send 100% power 50% of the time. In order to achieve different directions, the MOSFET is wired in an H bridge configuration, just like the DPDT switches (Figure 28). One polarity from the EV3 brick turns on one route, while the other polarity turns on the other route.

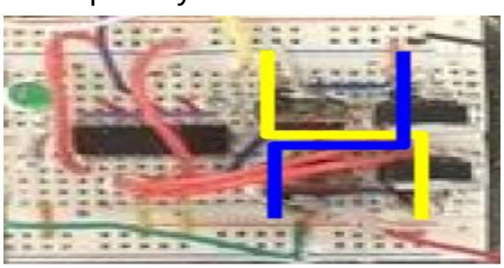


Figure 28: MOSFET H-bridge

BUDGET AND COSTS

One of the main goals of the Lincoln Group was to engineer a cost-effective ROV. Our starting budget was $1,500, however, we endeavored to minimize costs as much as possible. To accomplish this, we used a combination of inexpensive building materials and self-made components. For example, a majority of our ROV is constructed using PVC piping and LEGO bricks. Both of which were relatively inexpensive, adaptable, and readily available. As for self-made components, very few of our components are bought "ready-to-go" from a manufacturer. For example, we utilized bilge pump motors and 3D printed our own shrouds instead of buying commercial thrusters with built-in shrouds, we waterproofed our own tool package motors instead of buying waterproof motors, we built our own Bipolar MOSFET Amplifiers instead of purchasing premade electronics, and we waterproofed automotive back-up cameras instead of buying pre-made waterproof cameras. These design choices allowed us to save a substantial amount of money, money that can be passed on to the consumer.

Ultimately, we were successful in staying below our $1,500 budget with Half-Cut only costing $1,028.81. Our complete budget and cost breakdown can be found in Figures 29 and 30.

Fundraising

For the trip to internationals, we sold candy bars for a dollar a piece, with each bar gaining a profit of 50 cents. When the team finished the fundraiser, there was a total student profit of 1,269.00 dollars. After receiving a generous donation of $6,295.12 from the school district, and two more generous donations totaling to $450.00, each member's cost went from almost $1000, to below $500.

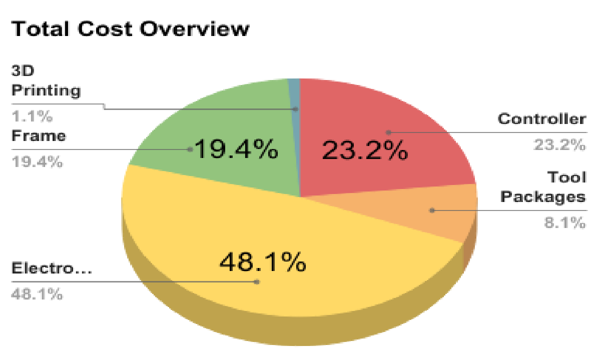


Figure 29: Cost Break-Down

Controller			
Piece name	Quantity	Price Per piece	Total cost
Technic, Bush	9	$0.04	$0.04
Technic, Liftarm 1 x 3 (Thick)	9	$0.11	$0.99
EV3 Brick	1	$150.00	$150.00
EV3 Cables (25 cm)	3	$1.99	$5.97
EV3 Large Motors	3	$18.75	$56.25
Technic, Liftarm 1 x 15 (Thick)	8	$0.56	$4.48
Technic, Liftarm 1 x 5 (Thick)	4	$0.09	$0.36
Technic, Liftarm 1 x 11 (thick)	2	$0.24	$0.48
Technic, Liftarm 1 x 9 (Thick)	1	$0.14	$0.14
Technic, Axle 9	10	$0.18	$1.80
Technic, Axle with Stop	1	$0.04	$0.04
Technic, Bush 1/2	4	$0.08	$0.32
Technic, Axle 7	1	$0.05	$0.05
Technic, Axle 2 Notched	2	$0.02	$0.04
Technic, Pin with Friction Ridges Lengthwise W	16	$0.20	$3.20
Technic, Axle Pin with Friction Ridges Lengthw	6	$0.95	$5.70
30mm Wheel with Rim	3	$0.29	$0.87
56mm Wheel with Rim	3	$2.50	$7.50
14mm Tire rim	2	$0.10	$0.20
Technic, Pin 3L with Friction Ridges Lengthwis	2	$0.07	$0.14
TOTAL COST OF CONTROLLER			$238.57

Electronics			
Electronics Board			
Part Name	Quantity	Price Per Piece	Total cost
Red Connectors	42	$0.27	$11.34
Blue Connectors	34	$0.07	$2.38
Container	1	$9.77	$9.77
16 Gauge speaker wire (cm)	310.5	$0.03	$9.32
Bridges	4	$4.41	$17.64
Chip	4	$0.70	$2.80
EV3 Cable (25 cm)	4	$1.99	$7.96
Petri Dishes	4	$0.59	$2.36
EV3 Brick	1	$150.00	$150.00
Zip Ties	13	$0.06	$0.78
Technic, Liftarm 1 x 9 (Thick)	2	$0.27	$0.54
Module Bush	4	$0.05	$0.20
330 Ohm Resistor	1	$0.06	$0.06
White LED	2	$0.02	$0.04
PVC (cm)	7.5	$0.15	$1.13
Breadboard Powerstrip	2	$5.00	$10.00
Epoxy (liters)	1.52	$20.86	$31.71
Monitor	2	$28.00	$56.00
Hose Clamps	2	$0.44	$0.88
Wood Board (per Sqaure Inch)	204	$0.01	$2.04
Cameras	3	$7.08	$21.24
Electrical Tape (roll)	1	$2.99	$2.99

Tool Packages			
Vertical Claw			
Piece Name	Quantity	Price Per Piece	Total Cost
Technic, Brick 1 x 8	2	$0.33	$0.66
Technic, Brick 2 x 8	3	$0.33	$0.99
Technic, Brick 1 x 2	1	$0.10	$0.10
Technic, Brick 2 x4	10	$0.20	$2.00
Technic, Brick 1 x 6	1	$0.27	$0.27
Technic, Brick 1 x 7	2	$0.66	$1.32
Technic, Plate 1 x 6	1	$0.13	$0.13
Technic, Plate 2 x 6	1	$0.17	$0.14
Technic, Plate 10 x 6	1	$0.80	$0.80
Doubler angular Beam 45 Degrees 3 x 7	4	$0.33	$1.32
Connector Bush With Fric. Crossale	2	$0.07	$0.14
Connector Peg	3	$0.07	$0.21
Bush for Cross Axle	10	$0.10	$1.00
Cross Axle 4m	2	$0.13	$0.26
Cross Axle 6m	2	$0.13	$0.26
Technic, Axle Connector 2L (Smooth with X ho	1	$0.08	$0.08
Technic, Gear 24 Tooth	2	$0.83	$1.66
Technic, Gear Box (2 x 4 x 3) 1/3	2	$0.73	$1.46
Technic, Gear Worm Screw (Long)	2	$0.29	$0.58
TOTAL COST OF VERTICAL CLAW			$13.38
Horizontal Claw			
Technic, Plate 6 x 10	1	$0.80	$0.80
Technic, Plate 2 x 6	2	$0.17	$0.34
Technic, Plate 2 x 4	1	$0.13	$0.13
Technic, Brick 1 x 12	6	$0.40	$2.40
Technic, Brick 1 x 6	2	$0.66	$1.32
Technic, Brick 1 x 4	2	$0.33	$0.66
Brick 1 x 4	2	$0.17	$0.34
Double Angular Beam 45 Degrees 3 x 7	5	$0.13	$0.65
1/2 Bush	10	$0.33	$3.30
Bush for Cross Axle	3	$0.07	$0.21
Cross Axle 8m	5	$0.10	$0.50
Cross Axle 6m	1	$0.13	$0.13
Cross Axle 4m	2	$0.13	$0.26
Cross Axle 3m	2	$0.13	$0.26
Cross Axle 2m (with Groove)	2	$0.07	$0.14
Technic, Gear 40 Tooth	1	$0.60	$0.60
Technic, Gear 24 Tooth (New Style)	4	$0.07	$0.28
Technic, Gear 36 Tooth	2	$0.61	$1.22
Technic, Gear Worm Screw (Long)	2	$0.04	$0.08
Technic Gear Box (2 x 4 x 3) 1/3	2	$0.34	$0.68
Technic, Axle Connector Double Flexible (Rubb	2	$0.03	$0.06
Bionicle 1/3 Tooth with Axle Hole	4	$0.01	$0.04
Inno-wave Assorted Pool Noodle	1	$1.98	$1.98
TOTAL COST OF HORIZONTAL CLAW			$16.38

3 cm screws	4	$0.09	$0.36
Small Gauge Wire (ft)	9.16	$0.04	$0.37
TOTAL COST OF ELECTRONICS BOARD			**$341.89**
Tether			
Speaker Wire (ft)	200	$0.10	$20.00
Cat5e Cable (ft)	100	$0.50	$50.00
Camera Cable (ft)	150	$0.27	$40.50
Hot Glue (stick)	1	$0.20	$0.20
Zip Ties	50	$0.06	$3.00
Pool Noodle (cm)	3	$0.02	$0.06
TOTAL COST OF TETHER			**$113.76**
Controll Box			
22 Gauge Black Wire (cm)	168	$0.01	$1.68
22 Gauge Red Wire (cm)	118	$0.01	$1.18
22 Gauge White Wire (cm)	30	$0.01	$0.30
22 Gauge Green Wire (cm)	10	$0.01	$0.10
22 Gauge Brown Wire (cm)	10	$0.01	$0.10
22 Gauge Wire (cm)	10	$0.01	$0.10
22 Gauge Blue Wire (cm)	10	$0.01	$0.10
Gray Wire Nut	6	$0.03	$0.18
Yellow Wire Nut	2	$0.03	$0.06
22-18 AWG Female Disconnect	22	$0.10	$2.20
DPDT Switch	3	$8.26	$24.78
Regular Switch	2	$2.47	$4.94
Zip Tie	2	$0.02	$0.04
Box	1	$3.50	$3.50
TOTAL COST OF CONTROL BOX			**$39.26**
TOTAL COST OF ELECTRONICS			**$494.91**
Frame			
Part Name	**Quantity**	**Price Per Piece**	**Total Cost**
1" PVC (cm)	48	$0.02	$0.96
1" PVC End Caps	3	$0.28	$0.84
90 Degree PVC Elbows	8	$0.34	$2.72
4-Way PVC Piece	1	$0.87	$0.87
.5" to 1" Adapter	4	$3.25	$13.00
1" Couplers	4	$1.00	$4.00
Tension Relief	1	$5.00	$5.00
Hose Clamps	4	$0.44	$1.76
T Piece	16	$0.51	$8.16
Bilge Pump Motors	4	$40.00	$160.00
.5" PVC (cm)	255	$0.01	$2.55
TOTAL COST OF FRAME			**$199.86**

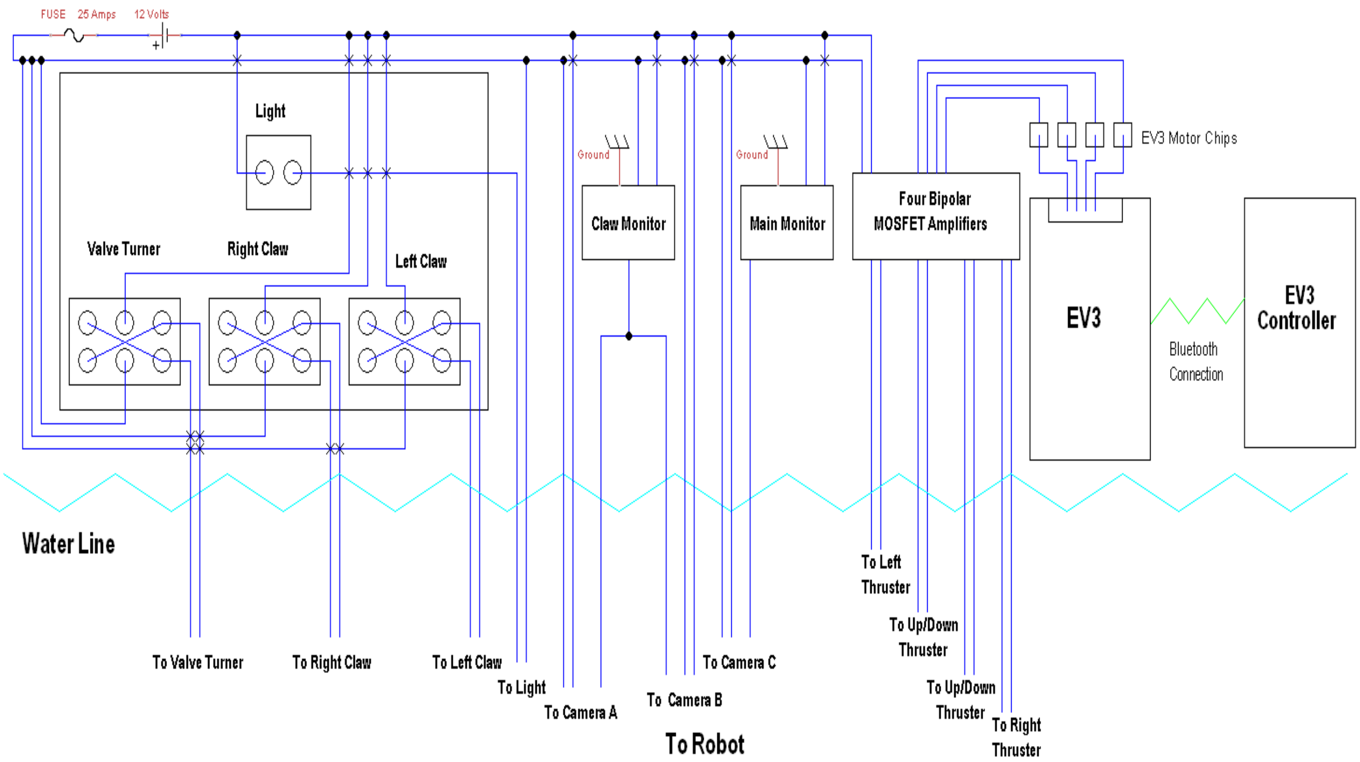
TOTAL COST OVERVIEW	
Controller	**$238.57**
Tool Packages	**$83.70**
Electronics	**$494.91**
Frame	**$199.86**
3D Printing	**$11.77**
TOTAL COST OF ROV	**$1,028.81**

Claw Motors (2 total)			
Empty Perscription Bottles	2	$0.11	$0.22
Solder (99.3% Tin)(Inch)	3.5	$3.74	$13.09
Vaseline (oz)	4	$0.73	$2.92
Hobby Motor	2	$11.00	$22.00
Hot Glue (1 4inch Stick)	1	$0.20	$0.20
Gulf Wax (oz)	6	$0.19	$1.14
TOTAL COST OF CLAW MOTORS			**$39.57**
Valve Turner			
Plate 6 x 10	2	$0.80	$1.60
Plate 2 x 10	4	$0.03	$0.12
Plate 1 x 10	2	$0.03	$0.06
Plate 2 x 6	1	$0.17	$0.17
Plate 2 x 4	4	$0.13	$0.52
Brick 2 x 4	2	$0.20	$0.40
Technic, Brick 1 x 2 with Holes	2	$0.01	$0.02
Technic, Gear Box (2 x 4 x 3) 1/3	2	$1.03	$2.06
Technic, Gear 24 tooth	3	$0.17	$0.51
Technic, Gear Worm Scew (Long)	2	$0.21	$0.42
LEGO Upper Part for Turntable Z60	1	$0.63	$0.63
LEGO Baseplate for Turntable Z60	1	$2.05	$2.05
Technic, Liftarm 1 x 11 Thick	8	$0.24	$1.92
Technic, Liftarm 2 x 4 L-Shape Thick	4	$0.02	$0.08
Technic, Liftarm 5 x 7 Open Center Frame Thic	2	$0.53	$1.06
Technic, Liftarm 5 x 11 Open Center Frame Thi	1	$0.57	$0.57
Technic, Pin 3L with Friction Ridges Lengthwis	10	$0.03	$0.30
Technic, Pin with Friction Ridges Lengthwise w	18	$0.05	$0.90
Technic, Pin 3L with friction Ridges Lengthwise	4	$0.05	$0.20
Technic Pin Connector Perpendicular 3L with 4	1	$0.02	$0.02
Bush for Cross Axle	4	$0.03	$0.12
1/2 Bush	4	$0.03	$0.12
Cross Axle 6m	2	$0.13	$0.26
Cross Axle 10m	2	$0.13	$0.26
TOTAL COST FOR VALVE-TURNER			**$14.37**
TOTAL COST OF TOOL PACKAGES			**$83.70**
3D Printing			
Piece	**Quantity**	**Grams of Plastic**	**Cost**
EV3 Protectors	4	19	$1.75
Vertical Adapters	1	86	$1.98
Horizontal Adapters	1	57	$1.31
Double T PVC Connectors	3	25	$1.73
Motor to LEGO Adapter	3	1.33	$0.09
22 x 8 LEGO Base	1	16.17	$0.37
Motor Shroud	4	49.3	$4.54
TOTAL PRICE OF 3D PRINTED PARTS		**$11.77**	

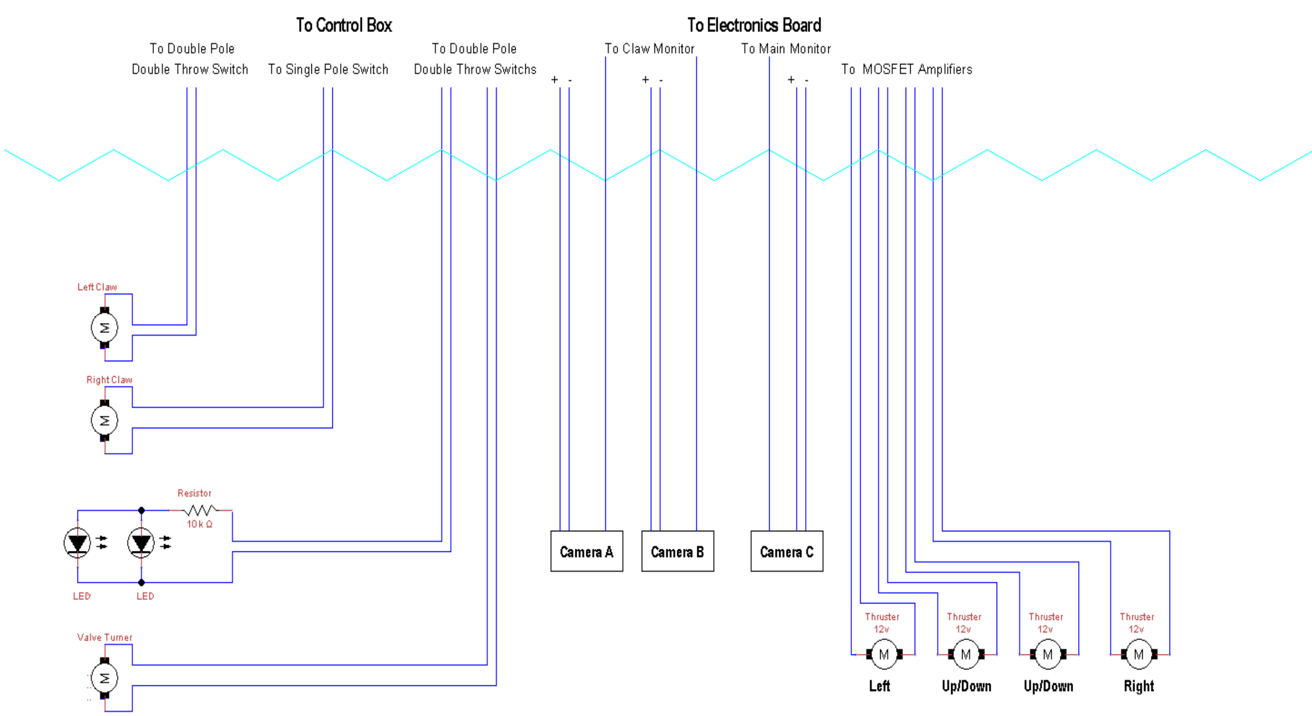
Figure 30: Complete budget for the ROV

ENLARGED DIAGRAMS

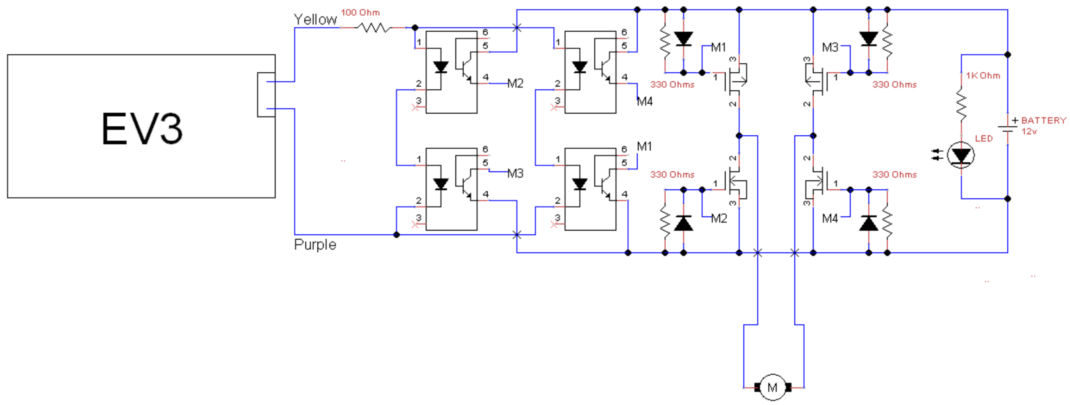
Top Side SID and Fuse Calculations



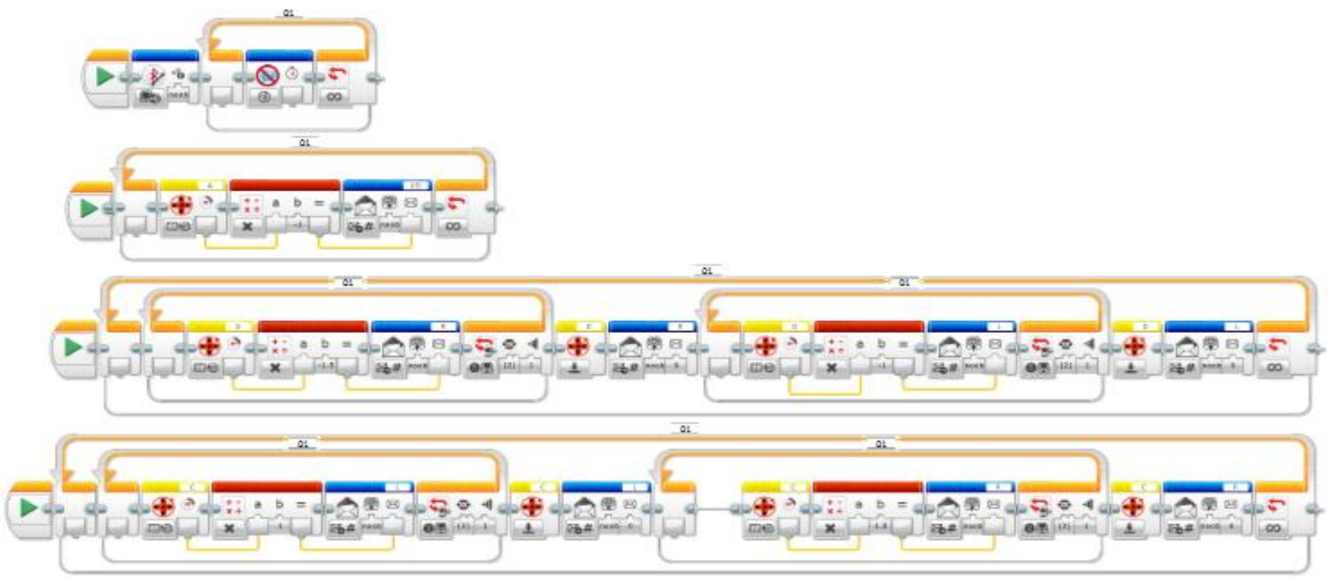
Water Side SID



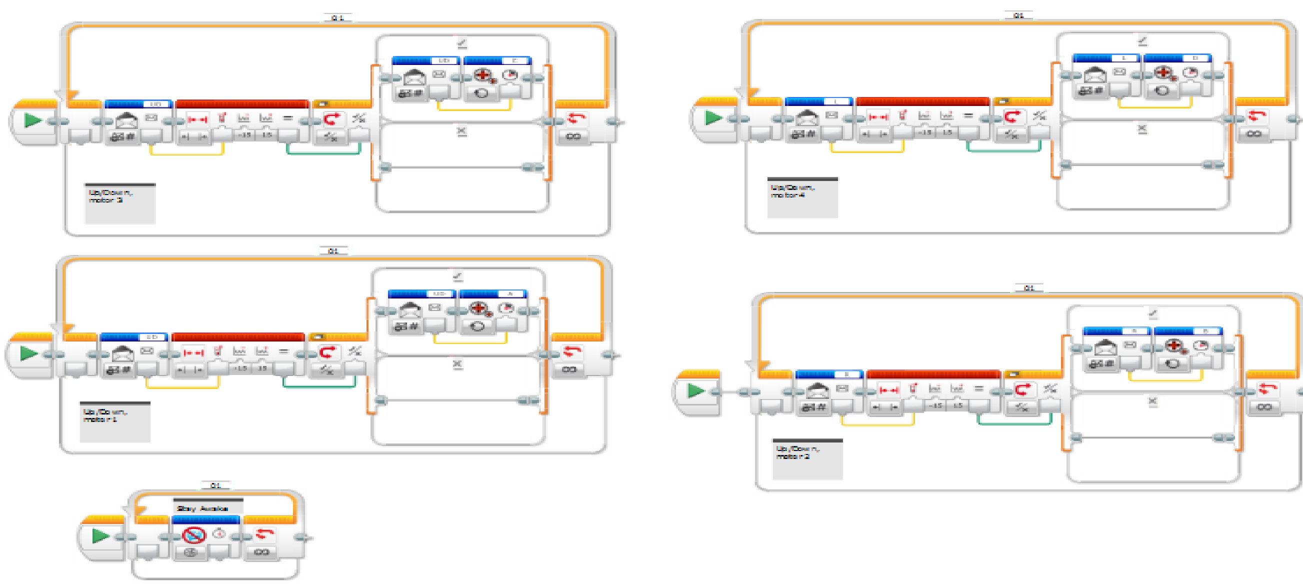
Bipolar MOSFET Amplifier SID



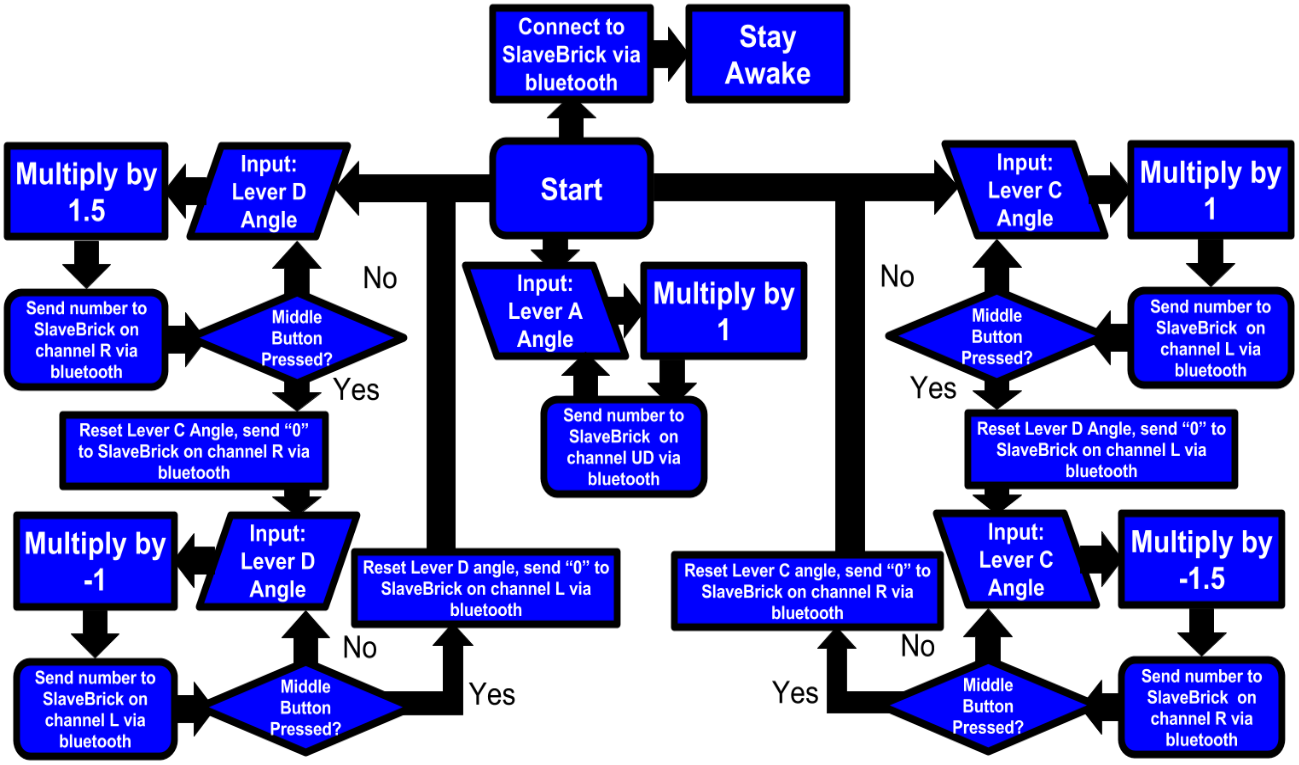
EV3 Master Program



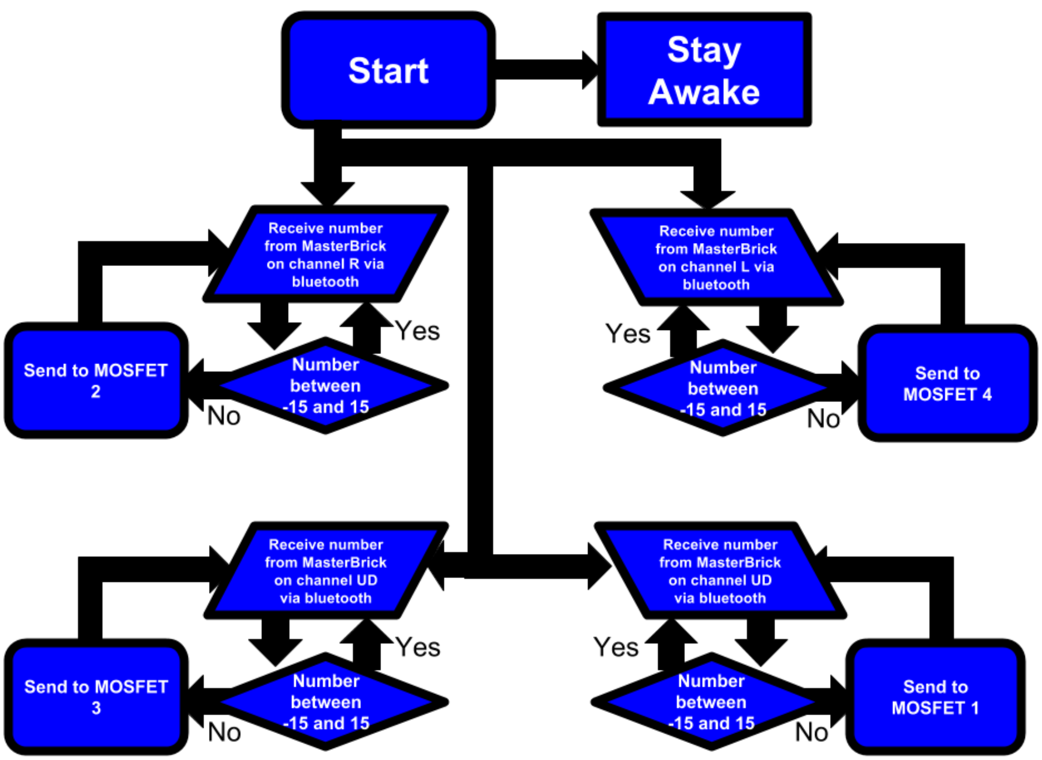
EV3 Slave Program



EV3 Master Block Chart



EV3 Slave Block Chart



REFLECTION

CHALLENGES

Tool package problems

Both claws are comprised mostly of Lego pieces. Since Lego cannot give the solid connection that we need, hot glue and zip ties were used to help keep the Legos together in areas that needed more structural security. Another problem that occurred was the design of the first valve turner. The original design was bulky, fragile, and overly complicated. We then decided to scrap the original and build a new valve turner that worked much better. The last problem that the tool packages team experienced was the construction and application of the suction apparatus. The original suction apparatus' size did not fit with the ROV requirements. The suction apparatus was then shrunk as much as possible to the best of the clubs abilities.

3D Printing Issues

Although the bases of the 3D printers are heated, when our team printed longer pieces the plastic would start to peel up near the edges causing the piece to be warped. To overcome this, we placed the printers under a table and made walls of cardboard hanging down from the top of the table. This trapped in heat from the printers and helped to improve the quality of the prints. A space heater was added to further improve quality to a point that was acceptable for the ROV. This was a cost effective and easy way to fix the issue while getting high quality prints.

Frame Issues

The main issue that the frame team encountered was the ROV's ability to have a suction apparatus on the frame in conjunction with one of the other tool packages. The original design placed the vertical claw next to the valve turner, however during testing the team realized that the claw becomes an obstacle when trying to turn the valve. Due to this, our CEO did a cost analysis and we determined that the suction apparatus was worth the least amount of points. As a result, the suction apparatus was removed from the bot.

Electronic Issues

The Bipolar MOSFET amplifiers are fragile and components can easily come loose. To avoid this, epoxy is poured over them to harden and secure all of the parts. Also, when using EV3s in combination with bipolar MOSFET amplifiers, the thrusters pulse in one direction. This is overcome by stripping regulator chips from EV3 motors and putting them between the slave brick and the MOSFETs. These chips solve the issue; however, they are quite fragile. Our 3D printing team created small boxes to encase them, so they would be less likely to break. Furthermore, the wires of the MOSFETs tend to be messy, since there are 24 of them in total. We cleaned up the board by putting these wires underneath, so that the wires do not cover any heat producing components.

FUTURE IMPROVEMENTS

Tool packages

The current Lego claws have proved to be more fragile than we intended. In the future, vex claws would be used instead of the Lego ones.

Electronics

We will use an existing PowerPoint to create MOSFETS instead of copying old ones. Lengthening the wires on the

MOSFETs will also allow for better organization. Creating a way to unplug the board from the tether would also be more convenient.

Frame Team

During the regional competition, a couple of problems were noted. One being that Half-Cut was not as fast as other ROVs in movement. To fix this, the team could explore using more powerful motors at the cost of the budget, or we could improve the shroud design to increase thrust. Secondly, there was a major problem with controlling the buoyancy and ballast of the ROV. In the future, we could investigate different methods that would allow the tether person to easily adjust the buoyancy and ballast of the ROV.

ACKNOWLEDGEMENTS

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