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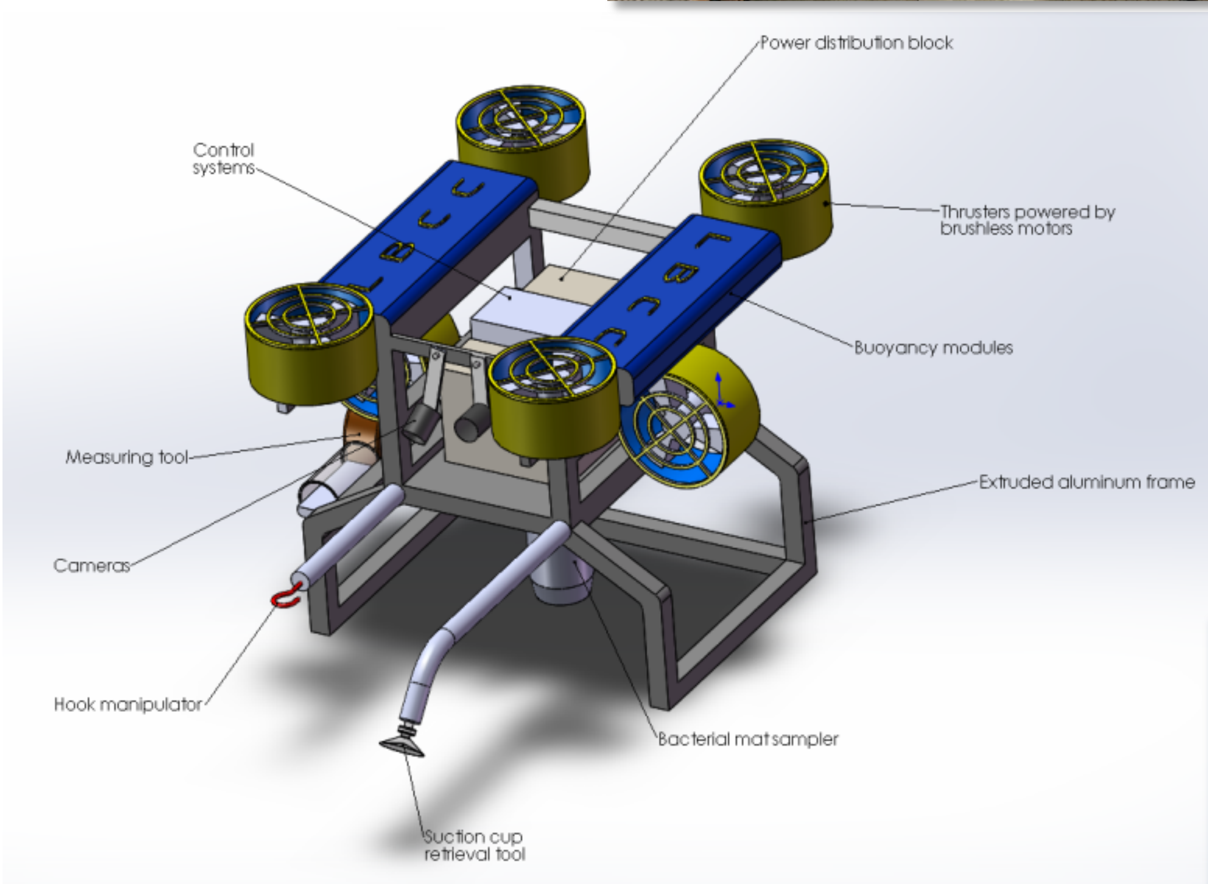

Linn-Benton Community College
ROV Technical Report
Albany, OR

Contents

Abstract

The Linn-Benton Community College (LBCC) Remotely Operated Vehicle (ROV) team is a returning company that is no stranger to the MATE competition. It is composed of new and returning members with a variety of backgrounds united by the goal of building an ROV, designed to excel at performing specific underwater tasks. The experience of building a specialty underwater ROV posed a variety of challenges that built teamwork and exercised important teamwork skills. Coupling the knowledge and experience of returning ROV team members with the excitement of new members, this year's ROV team was set to tackle any difficult challenge with novel ideas.

The resulting ROV was designed with efficiency, simplicity and affordability in mind. It has an aluminum frame, a powerful propulsion system including in-house 3D printed propellers and ducts, low-profile analog cameras, limbs for manipulating surroundings, and powerful thrusters for maximum maneuverability. It is controlled by an Arduino Mega, a short Python program, and a common USB videogame controller. Electrical components are potted in epoxy to render them waterproof, and the vehicle is powered from the surface by a 48V surface power supply.

The Mission

Linn Benton Community College ROV brings together a diverse group of students to develop technical and teamwork skills through the process of designing and building a Remote Operated Vehicle. Capitalizing on the various strengths of individual group members, the team aims to produce a robust product capable of surpassing the client's expectations.

Requested Mission Tasks

When approaching the ROV design process, the team had to keep the missions at hand in mind. There were multiple tasks to consider as well as the narrow time frame in which to complete them. The client has suggested

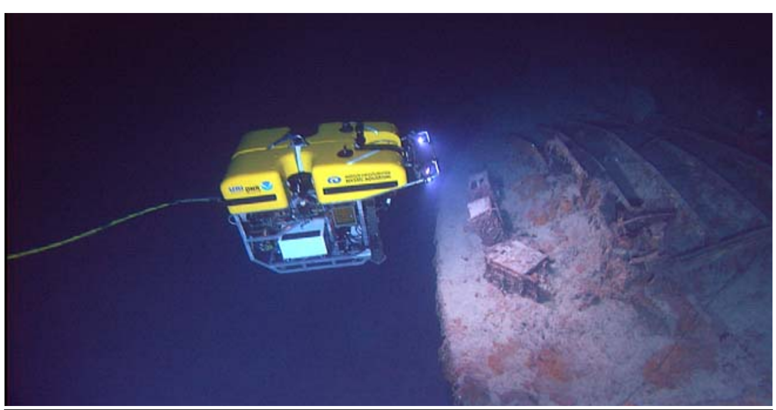

Figure 1: An ROV explores a shipwreck

there will be a window of approximately fifteen minutes of work time per dive. During this time window, the client has requested assistance in identifying and analyzing a recently-discovered shipwreck and the surrounding area.

A first step in analyzing the shipwreck will be to obtain the dimensions of the wreck. A servo-powered measuring tape tool will be attached to a point on the corner of the wreck. The ROV will move to extend the tape to the correct distance, and cameras mounted on the measurement device will take the reading. This process will be repeated to determine the length, width and height of the shipwreck.
In addition to determining the dimensions of the shipwreck, the team will take detailed scans along the length of the ship, utilizing a grid frame for reference. Images will be captured of each individual section of the grid, then stitched together into a single image depicting the side of the ship.

The client has identified a 75 x 75 cm entry hole on the wreck. This entry point is blocked by a winding of rope. The rope will be moved by the hook manipulator, and the vehicle will proceed inside the ship. The ROV has been designed with dimensions significantly smaller than this entry hole, for ease of entry and to conserve the integrity of the shipwreck.

The team has categorized four features by which they will identify the shipwreck: external features, type of cargo, build date, and home port. Each of these categories will be addressed as follows.

External details of the shipwreck will identify the type of ship. A wooden sailing schooner will have a mast head, a steam-driven paddlewheel ship will have an octagonal paddlewheel, and a propeller-driven bulk freighter will have a propeller.

The home port of the ship in question should be printed on the ship's china. The ROV will search the inside of the wreck for any such items which may display this information. The vehicle has been outfitted with a suction cup retrieval tool designed to provide excellent suction to glazed-ceramic surfaces.

The client has indicated remains of the ship's cargo are present around the shipwreck. The ROV will search these materials to identify what type of cargo the ship was carrying.

Many ships carry plaques commemorating their build date or christening. Once inside the shipwreck, the vehicle will use its cameras to scan for this information. The ROV has been outfitted with ten watt LEDs, in the event of a low-light situation.

Shipwrecks introduce a new variable into the seafloor ecosystem. In order to quantify the changes this causes, the client has requested several scientific tasks be performed.
A bacterial mat has been growing in and around the shipwreck to be explored. The ROV will use its coring tool to return a sample of the mat material to the surface. The coring tool is mounted on the underside of the vehicle. Using targeting cameras, the ROV will position itself over a suitable area, and use its thrusters to push the coring tool down into the bacterial mat. A one-way valve will create backpressure in the coring tool once the mat material is pushed inside. Once the ROV has returned to the surface, the valve will be depressed, releasing the sample core.

Seafloor vents often have a different salinity than the water around them. Vents in the area of the shipwreck will be tested for salinity. The ROV will insert a seven-inch probe into the vent opening. This probe has two gold-plated contacts, by which the operator will be able to measure the conductivity of the vent water. This conductivity reading will be used to determine the salinity of the water.

Zebra mussels are an invasive species in the area in which the wreck is located. The team will estimate the quantity of zebra mussels on the shipwreck. The ROV will set a 50x50 cm^2 quadrat on an area where the muscles are located. The team will use the number of mussels contained within the quadrat, and the dimensions of the ship to estimate how many mussels are on the ship.

In order to collect scientific data about the shipwreck and surrounding ecosystem, sensor strings have been deployed in the immediate area. The strings must be switched out periodically to retrieve the collected data. The ROV will use its hook manipulator to retrieve the sensor string and return it to the surface. A new sensor string will be placed in the location of the original sensor.

While the ROV is investigating the shipwreck, it will retrieve any refuse located on the seafloor. Common items are bottles and cans, and marine waste. Any such items will be placed into the ROV lift basket, then returned to the surface via lift bag. The client has specifically requested the removal of a Danforth anchor and attached anchor chain. This task requires a significant amount of lifting force, and thus was considered during the vehicle design process. The team came up with a system which utilizes a separate, non-powered basket to be lowered into the water, filled with items, and brought to the surface by air pumped into an attached lift bag. The anchor will be placed in or attached to the lift basket, and the heavy lifting will be done by the buoyant force of air in the lift bag.

Budget and Expenses

Workgroup	Requested (Estimated)	Actual (as of 5/29/14)	Notes
Power	$1,000.00	*$928.97*	
Control Systems	$400.00	*$387.89*	
Frame	$300.00	*$517.30*	Includes large purchase of optically clear epoxy to replenish supply; large piece of sheet vinyl donated by LinnGear (~$60) for box lid
Propulsion	$1,000.00	*$578.25*	Not yet billed for some 3D printing
Arm/Manipulator	$250.00	*$376.01*	
Sonar	$0.00	*$0.00*	appx. $100 worth of sonar components donated, in exchange for underwater performance information
Connectors	$100.00	*$20.00*	
Cameras - Digital	$100.00	*$90.86*	
Cameras - Analog	$100.00	*$83.40*	
Science Team	$50.00	*$2.27*	
Props	$50.00	*$9.99*	
Food	$1,250.00	*$183.49*	Includes estimate of anticipated food costs for international competition
Miscellaneous	$150.00	*$100.00*	MATE Registration fee
Travel	$12,000.00	*$0.00*	Estimate of anticipated travel costs for international competition
Total:	**$16,750.00**	***$3278.43***	

Design Rationale

The LBCC ROV was designed with simplicity in mind to deliver the best portability, functionality, power, and efficiency at an affordable price point. Emphasis was made to keep systems as simple as possible to avoid unnecessary complications.

Analog Camera System

CFO Krissy Kellogg is head of research and functionality for the analog cameras for the ROV. The cameras are required to provide a clear image for navigation and analysis, while being unobtrusive to the design. The chosen solution was analog vehicle backup cameras with 640x480 resolution, low-light capability and a 170° viewing angle. These commercially available cameras were chosen for their extremely low cost, cast metal housing and small size. The internal silicone packing was removed and replaced with epoxy. A circle of acrylic was epoxied around the front to ensure the lens was waterproofed. COO Amos Parmenter assisted in developing the waterproofing method.

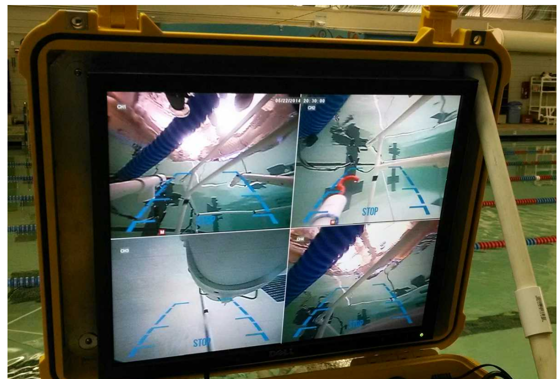

Figure 2: Images from analog cameras onboard the ROV

Three cameras are mounted to the front of the ROV, one forward-facing, one showing the suction cup retrieval tool, and one providing a view of the hook manipulator. One camera is mounted on the underside of the vehicle, used for guiding the coring tool. One camera is attached to the measurement tool, allowing the operator to quickly take measurements. Four available camera views are shown in Figure 2. More cameras can be added for increased visibility as needed.

The cameras include rangefinder lines, and an original intention was to use the rangefinder lines to measure the dimensions of the wreck in a low-impact manner. However, the client informed the team the shipwreck is not located on a flat surface. Without sensors for matching the ROV's angle of tilt with that of the ship, the possibility for error in measurement proved too great. Thus, the rangefinder idea was abandoned in favor of a simpler, more accurate measurement technique.

Arm and Manipulator

In the interest of better serving the client, the LBCC ROV team is currently developing an arm and dynamic manipulator to accomplish the requested tasks more efficiently. The proposed system utilizes both stepper and servo motors to perform a range of precise and heavy jobs. The stepper motors carry out robust operation requirements and produce the necessary torque for payload and structural system support. The original design utilized only stepper motors, but they were switched for servos after the team discovered each stepper would require an individual gearbox. Stepper motors are still employed for manipulation and control of the gripper because they operate more rapidly and accurately.

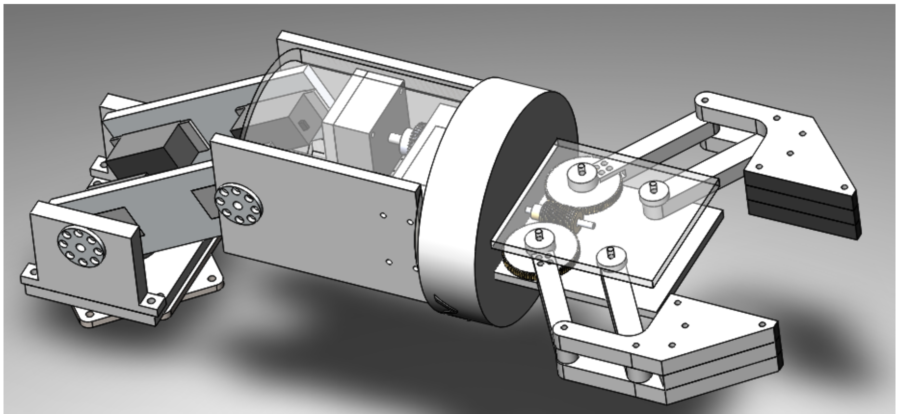

Figure 3: Current arm design

One goal of the arm design is continuous 360° rotation of the gripper. The initial design produced a fundamental flaw and required several revisions to accomplish the proposed strategy. The stepper motors were repositioned behind the wrist, and the gear boxes positioned to prevent the wires fed down the arm from over twisting and breaking. The wrist was 3D printed with two slots to connect the shaft to the motors and gearboxes controlling the open and close function of the gripper and then enabling desired rotation of the wrist. This redesign accomplishes the goal of 360° rotation.

Waterproof Brainbox Enclosure

Amos Parmenter is head of construction and materials procurement for the brain box. Parts consist of aluminum, a nylon lid, and o-ring cord material. The main housing of the box is 10”x16”x8” and is constructed out of aluminum. Sam Parmenter welded the box using an arc welder. The top nylon plate was sent out to a custom machine shop to be cut and drilled precisely. The top and housing come together using two rubber o-rings that will hold water out around the remaining seam. Wires from the box pass horizontally through holes in the nylon top plate and are be sealed using epoxy.

The Odroid XU, along with the rest of the rest of the control, sensor and power systems, was to be housed in this aluminum brain box. Unfortunately, the box leaked. Without much time to explore alternatives, the decision was made to epoxy pot all the vulnerable electronic components. Rather than epoxy pot the Odroid, a mothballed Arduino Mega was epoxy potted to become the ROV brain for the regional MATE competition.

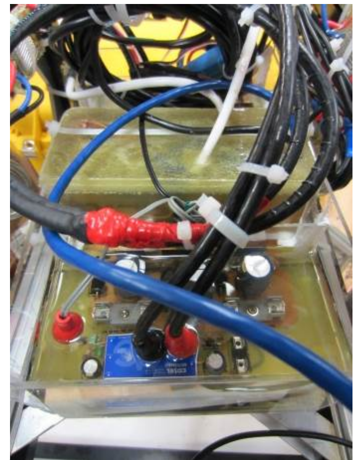

Figure 4: Epoxy-potted Arduino Mega (translucent block at top of image)

Control System

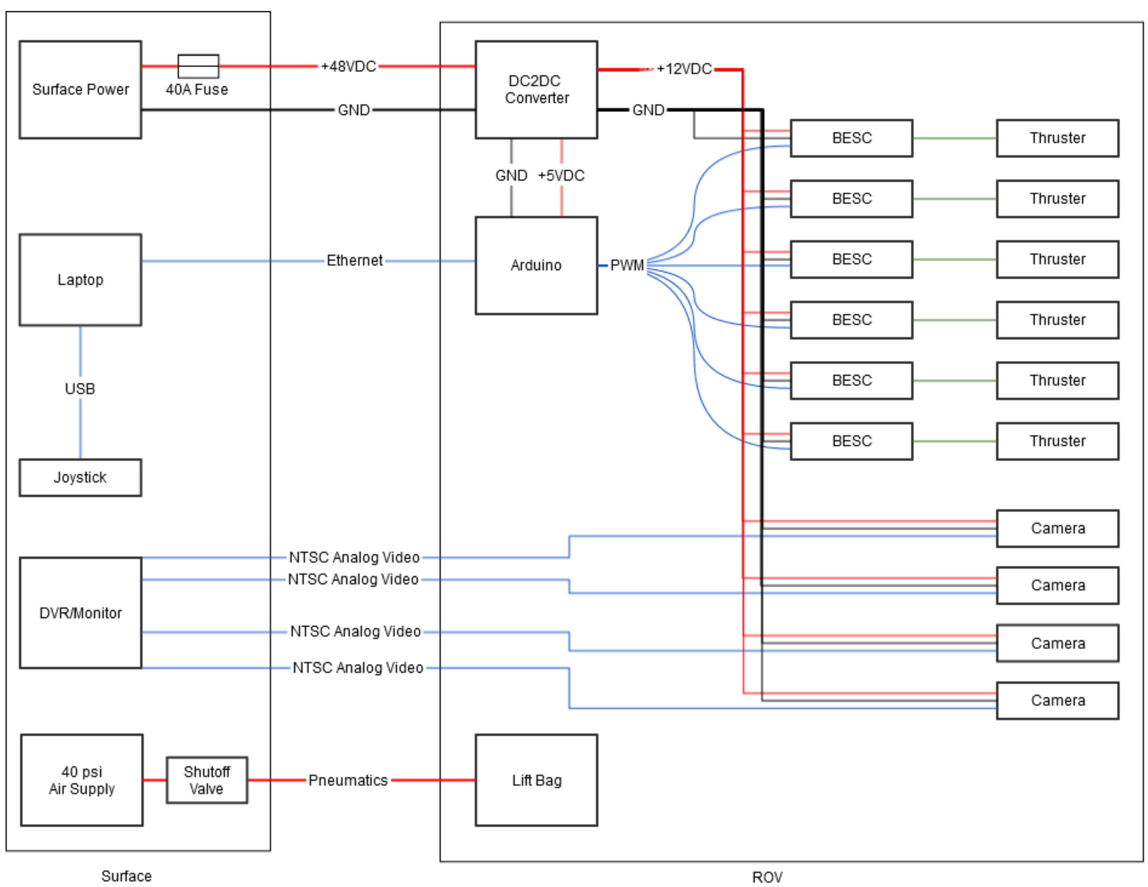

Figure 5: Systems Interaction Diagram (SID)

The onboard brain of the LBCC ROV was an Odroid-XU manufactured by hardkernal.com. This was a new approach for the team as previous LBCC ROVs have used Arduino based robotic controls. The increased computational capacity provided by the Odroid offered the opportunity to move more data processing and operational control to the ROV CPU, which is one more step on the path to a remotely guided autonomous robot.

Last year's ROV used Arduino PWM output pins wired to H-bridges to provide power and control for expensive sealed brush DC motors thrusters. The new thruster design utilizes inexpensive brushless DC motors embedded in a 3D printed custom designed propeller assembly created by team member Steven Gibbel. The Odroid-XU controlled all eight custom thrusters through commands transmitted out its serial port to a custom serial to line protocol board designed and fabricated by team member Devon Goode. The line feeds an Adafruit to PWM converter based on the NXP PCA9685 chip. Six of the PWM outputs from the Adafruit board drive individual motor controllers for the six thrusters, depicted in Figure 5. Team member Steven Gibbel modified the open source firmware to provide a more symmetric forward/reverse response which provides a more effective position control of the ROV.

Additionally, the ROV Odroid-XU received and processed video and other sensor data. The Odroid-XU also would have controlled the servos which articulate the ROV arm and claw.

Figure 6: Laptop, controller, tether and ROV

However, due to complications, the team was forced to switch to an Arduino Mega. Programming from the Odroid -XU was hastily ported and modified for the Arduino using its native $\mathrm{I}^2\mathrm{C}$ output to drive the AdaFruit PWM breakout board. The controller consists of two analog joysticks and triggers and is a modern gaming system controller. The decision to use a commercially available controller was made to due to time and budget constraints. The controller used is inexpensive, easily accessible, and easily operable. It is wired directly into the ROV. The controls will be set to only use part of the 20 Newton capability for safety, and because the maximum amount of thrust is not necessary to perform the requested tasks.

Surface control of the ROV is managed on a laptop running a Python program managing video. Data communication with the ROV Arduino brain is handled over Ethernet using a UDP packet based communications library. Additionally, the ROV Odroid-XU receives and processes video and other sensor data. The Odroid-XU also controls the servos which articulate the ROV arm and claw.

Frame

The ROV frame was inspired by the Wood's Hole Oceanographic Institute's hybrid ROV, called the Nereus, shown in Figure 7. The Nereus, named after a Greek titan of the sea, reached Challenger Deep in the Mariana Trench, the deepest surveyed point in the ocean. Sadly, the Nereus was recently lost at a depth of 9.97 km during a research trip the Kermadec Trench northeast of New Zealand. (Lee) It is suspected there was a rapid pressure change causing component failure and implosion. However, despite this turn of events, LBCC's ROV design easily meets the requirements for the client's requested tasks. Additionally, the design is visually appealing, which excited team members.

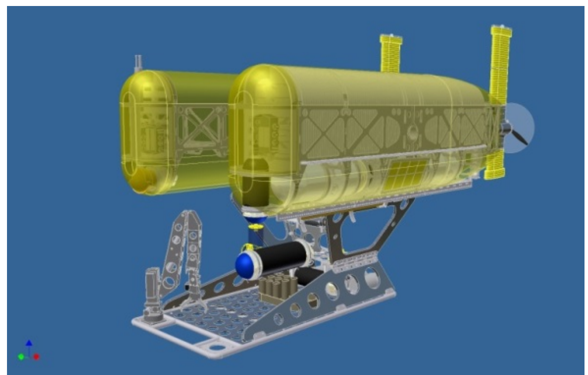

Figure 7: Rendering of WHOI's Nereus hybrid ROV

Aluminum was chosen as the frame material as it is strong and light. This allows for smaller frame components, necessary in light of the 75X75 cm^2 entry to the shipwreck. Foam is used as ballast material to make it less susceptible to changes in water temperature. The frame runs inside the foam to support it. The frame can be separated into different parts and easily reassembled for transportation purposes.

Figure 8: Prototype buoyancy module

Propulsion

This year, a new propulsion system was developed utilizing inexpensive Hobby King NTM2830-750 brushless DC motors. In order to enable this switch to inexpensive motors, team member Stephen Gibbel created 3D designs for matching propellers and housings which mate with the Hobby King motors. The propellers were produced by the by the 3D printer at Linn Benton Community College. These LBCC 3D printed components went through several iterations of fabrication, testing and redesign. The first iteration had six blades at a fixed 45° pitch. This was followed by versions with fewer blades, to reduce drag, and reduced pitch. Each iteration improved thrust.

Figure 9: Propellers with 3D printing support material attached

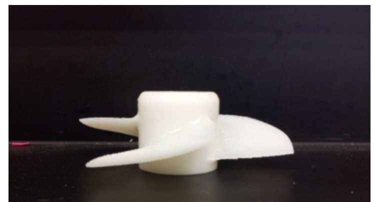

Figure 10: Propeller, side view

The current version of impeller, shown in Figure 10, has three blades with a reduced variable pitch and produces 40 Newtons of force at full throttle. The matching Hobby King motor controller, shown in Figure 11, was reflashed with open source firmware modified by Stephen Gibbel. The original open source firmware for the Hobby King F-30A motor controllers purposefully provides asymmetric forward/reverse motor behavior. It was modified to provide a more symmetric forward/reverse response which provides more effective position control of the ROV. The F-30A motor controller in Figure 11, epoxy potted and in place on the ROV, has a scaled down version of the same microcontroller used in the Arduino Mega.

Figure 11: Epoxy-potted speed controller

Power Supply

The ROV power supply system was designed to provide safe, clean, efficient DC power for all ROV subsystems. Team member Devon Goode designed and fabricated a two sided 6” by 9” circuit board providing a single rail 12.5 V DC source for motors and servos, along with a single rail 5V DC source for

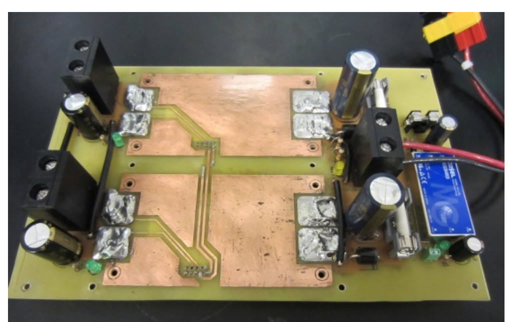

Figure 12: Power supply board, top view

logic and signal systems. This custom-made circuit board also provides reverse polarity and TVS diode transient over voltage protection along with fuses for the 48 Volt DC input. Although these fuse holders had to be shunted when the unexpected waterproof brainbox failure required the epoxy potting of all electronic components, inline fuses at the surface end of the tether provides alternate protection.

The 12.5V DC rail for motors and servos is powered by two Cosel CDS6004812 48 volt to 12.5-volt DC to DC power modules wired for parallel operation providing up to a maximum of 100.8 amperes (90% of twice the 56 ampere capacity of a single module). At a 100.8 ampere load, the corresponding load on the 48V DC circuit board input would be less than the 32.8 amperes. This is implied by the 89% full load efficiency of the Cosel modules

Figure 13: Power supply board, bottom view

The 5V DC power rail for logic and sensors is provided by one Cosel MGS304805 DC to DC module which provides up to 6 amperes of DC current for the 5V DC rail. It draws less than 0.7 amperes from a 48V DC source at full output.

All three of the Cosel modules provide overvoltage protection on their inputs and overcurrent protection for their outputs. Originally the heat dissipating surfaces of the three Cosel modules of the primary power system circuit board were intended to mate with the aluminum plate bottom of a planned and constructed welded aluminum brain box. Unfortunately, leaks in the welded seams led to a change in plans resulting in the epoxy potting of all electronic components including the power board. The heat dissipating surfaces of the Cosel modules are now exposed directly to the water.

A second smaller circuit board was also fabricated by Devon to provide a separate 12V DC power rail for sensor device electronics. The 12V power rail supplied by this circuit board is powered by a Tyco QW050B1 module scrounged from the ROV lab junk box. Similar to the Cosel modules, this Tyco module also provides overvoltage and overcurrent protection, but has a slightly lower 85% power conversion efficiency. Thus its current draw from the external 48V DC source when at full load is less than 1.25 amperes.

The total current draw from a 48V DC source when the ROV operates at a hypothetical full load on all of its power supply systems has been calculated to be less than 34.75 amperes. The 8 gauge wire used in the 100 foot ROV tether would then result in a voltage drop across the tether of 4.6 volts at the hypothetical full load. This leaves a voltage of 43.4 volts being presented to the ROV power supply modules. This is well above the 36 volt minimum required by the DC to DC power modules for proper operation. Furthermore, the tether voltage drop would cause the total current draw to increase to 36.5 amps, which is still well under the 40 Ampere external surface power source limit.

Gauge wire	100 feet Ω	100 foot tether Ω	Voltage loss in Tether at full load	Current at full load with 100 foot Tether (in Amperes)
8	0.063	0.126	4.6	36.5
10	0.1	0.2	8.4	42.15
12	0.159	0.318	17.2	54

Table 1: Effects of different gauges of wire used for DC power in the ROV tether

From the table, 10 gauge power wires in the tether would cause the inline fuses to blow if the ROV operated at full power. Twelve gauge wires would cause the input voltage to the ROV power modules to drop below their 36 volt minimum.

Measurement System

Originally, the team explored the idea to use sonar as a measuring device. The XL-MaxSonar is an active sonar unit that emits a wave at 42kHz. The equipment itself is made to be used in air rather than water, so the team took steps to waterproof it. The edges of the transducer were coated with silicone after covering the device with a ¾" PVC elbow to protect the electrical connections. These connections allowed communication between an Ardunio Uno and the MaxSonar device.

Being supplied with five volts from the Arduino, the 4.9 mv/cm is used as the scaling factor to get the two devices speaking the same language. The final readout is a voltage reading as commanded in the microchip coding. The voltage is sent from the device to the Arduino and is later divided by the scaling factor by the chip’s analog-to-digital convertor. This produces the final readout.

Testing the device in air proved successful, but a 20 cm dead zone right in front of the device was found. The dead zone existed because it was too short of a distance for the ping to dissipate before the reflected wave was received by the transducer. With a minimum range of 20 cm to a maximum of 545 cm maximum, the device read very well in the air. When placed in the water, the device only read roughly 3.78 volts when placed anywhere in the pool, indicating that the transducer was not capable of sending out a strong enough ping underwater. The team was unable to alter the frequency of the transducer. This system was abandoned in favor of a simpler, tape-based measurement device. A servo-powered measuring tape tool will attach to a point on the corner of the wreck. The ROV will move to extend the tape to the correct distance, and cameras mounted on the measurement device will take the reading.

Tether

The tether cable is the method of communication between the operator and the ROV. The tether used for the competition is 15 meters long, neutrally buoyant in fresh water, and contains a coated steel cable to reduce strain on the wiring. Power is supplied to the ROV by a pair of 10 gauge wires that carry 48VDC from the surface power supply. The tether power lines connect to the power distribution block on the ROV.

In addition, the tether contains one pneumatic line for pumping air into the lift bag. This line is controlled from the surface. There are two CAT5 cables for cameras and thruster control. At the surface, the tether is attached to the MATE power supply through a switch box, a half meter 10 AWG extension, and a 75 Amp Anderson Power-pole connection. The switch box provides additional safety fusing, bleed down resistors, and controls voltage to the ROV. It also adds a layer of safety with an additional fuse breaker, and switched on-off control. The data lines are connected to a one meter CAT5 Ethernet extension with an RJ45 connector at the end, allowing the ROV to be attached to the control station via Ethernet ports.

Waterproof Connectors

A special challenge in building a submersible vehicle is making sure electrical connectors stay dry. Often times the simplest solution is the best. The team came up with a simple solution: a flexible sleeve custom-made to stretch around existing connectors. The connector sleeves are

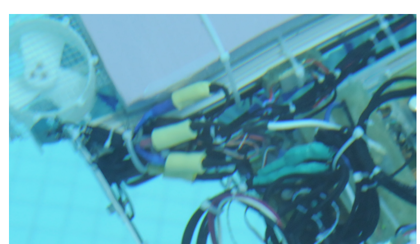

Figure 14: Connector sleeves in action (yellow objects)

fabricated from a product called Amazing Mold Putty. This product is intended for making molds of objects.

The inner diameter of the connector sleeves is significantly smaller than the connector it is designed to fit over. This keeps the connectors dry by making a tight seal around the connector. The soft silicone material compresses as the water pressure increases, forming a tighter seal at higher pressures. The low price of the connector sleeves helped keep cost down, as commercially available waterproof connectors are pricey. They also improve ease of use.

Safety

Safety is of the utmost concern to the team, and many precautions were taken during the construction process. Team members wore safety glasses while working on the ROV, and ear protection while working with loud power tools. To prevent accidents, all tools were reviewed and authorized prior to use, and members were trained on the safe use of tools. In addition, team members worked in groups of at least three to ensure a quick response in the event of an accident. First aid kits were always onsite, and an appointed safety officer ensured that team members adhered to safety guidelines.

During ROV pool testing, the safety officer and a lifeguard were always present. The ROV itself is equipped with safety features such as propeller blade guards, fuses on the power distribution system, and an external fuse line running to the surface. Anytime the batteries are connected or the ROV is receiving power, team members vocally repeat commands and responses to ensure everyone is aware of the state of the system.

Challenges

The biggest challenge in developing this ROV was team communication. Communication is of the utmost importance and was the most difficult thing to achieve. It was more of a challenge this year than last due to a large contingency of new team members. Differences in age, personalities, and schedules made it difficult for the group to work cohesively. As the team started meeting and working together more regularly, working relationships were formed which helped to ameliorate the problem. As the team is composed of students, time constraints are a constant challenge.

The team has learned to communicate electronically about the status of certain projects, allowing members to work when they are available.

A lack of communication between sub-teams caused a lack of cohesion when trying to combine the sub-systems to complete the ROV. Tools and parts were sometimes lost in the transfer. The lack of communication caused a general lack of organization during the construction and testing of the ROV, which did not allow the team and ROV to meet its full potential in some respects. As the team has grown together, there have been improvements in communication and teamwork.

The greatest technical challenge posed by the ROV and mission tasks was waterproofing. The original designs of the enclosure for the power brick and operating systems often leaked. Early tests using an Otter Box leaked as well. Surrounding the components in epoxy solved the water leakage problem, but limited access to the components. The team is currently testing new and improved pressure vessel designs, in hopes of developing a waterproof solution that also allows access to components.

Waterproofing connections has been a problem for the team in the past. The team investigated some injection molding ideas, but found they leaked too. In attempting to recreate the injection molded parts with a different material, team member Krissy Thorsen had the idea to enclose the existing non-waterproof connectors in a sleeve made of stretchy silicone rubber. This idea was tested vigorously at depth and found not to leak. This provided the team with an inexpensive, customizable method for waterproofing connections.

Lessons Learned

One of the recurring difficulties that the LBCC ROV team has had to overcome is that of communication. Most of the members of the ROV team are highly intelligent and extremely independent. This is both a positive and negative thing for the ROV team. Individual members made progress, but the team did not make as much progress it potentially could have because of the lack of communication. This was resolved by holding regular team meetings in a convenient location, and persistent one-on-one meetings between leadership and individual project leaders. The team found having regular weekly pool tests really helped keep the project on-track. Seeing the ROV working in the water encouraged team members and brought them to a common location where they could discuss the work together.

Future Improvements

LBCC ROV hopes to improve the sonar prototype for future use on the ROV. Time and effort were put into producing a precise underwater sonar system, but it has not been achieved to date. Adding sonar to the ROV would add ease of execution to performing mission tasks.

Another improvement is adding more cameras, so the pilot has more angles of view from which to operate. This improvement is currently under development. A small new power distribution board is being fabricated to provide clean, regulated power for all the cameras.

A future goal for the tether is to encase the wires in a woven sheath to protect the person handling the tether. Currently, the cables are bundled together with zip ties, which can have sharp ends.

A very important improvement is in teamwork and communication. Effective communication and organization will help both the team and the ROV progress. The team has been working on improving this aspect for several months now. As the ROV has come together, increased hours spent working together in the lab have helped build camaraderie and commitment. The team hopes to continue this trend as it prepares for international competition.

Reflections

The team agrees communication was the major challenge, but learned new strategies to overcome that challenge. It is important to put as much effort into being a team as is put into being brilliant engineers.

A common regret amongst the group is the lack documentation of the process. More pictures, notes and videos should have been taken for troubleshooting purposes, and for future improvements.

Building an ROV is a great learning experience. Team members have been exposed to many new kinds of technology. They have been stretched intellectually and interpersonally.

They have learned to balance schoolwork with an outside project. Some have learned valuable skills like soldering, circuit design, and tool use. They have learned from each other and the team's mentors, and have become better engineers as a result.

References

Amazing Mold Putty Material Safety Data Sheet.
http://www.alumilite.com/MSDS/Amazing%20Mold%20Putty.pdf

Cosel CDS40048 DC-DC Converter Datasheet.
http://datasheet.octopart.com/CDS6004812-Cosel-datasheet-20886274.pdf. Accessed 5/28/2014.

Lee, Jane J. "Deep-Sea Vehicle Nereus Lost 6 Miles Down."
http://news.nationalgeographic.com/news/2014/05/140512-nereus-deep-sea-vehicle-lost-ocean-technology-science/. Accessed 5/27/2014.

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