2015 MATE International Competition

LBCC ROV: Technical Report

Linn Benton Community College
Albany OR, USA

Albany, Oregon is 5265km from the 2015 international MATE competition in St. John's, Newfoundland and Labrador, Canada.
LBCC ROV has been participating in the MATE competition each year since 2008.

Top row left to right: Josh Carle (Frame Team Leader), Lucas Markert (CTO), Jason Klindthworth (Algae Collection Team Leader), Jacob Archer (Anode Team Leader), Jacob Gould (Manipulator Team Leader).
Middle row left to right: Kyle Prouty (HR Leader), Will Rogers (Laser Team Leader), Greg Mulder (Team Mentor), Jasmine Brown (Tether Leader).
Bottom row left to right: Melanie Woodard (CEO), Sam Wiard (CFO), Austin Aguilera (COO), Rob MacDonald (Programming Team Leader), Eli Yazzolino (Power Team Leader), Nikolai Danilchik (Lift Line Team Leader).

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Our Mission Statement

Explore Remote Operated Vehicle technology by learning, building, and designing, together.

Abstract

The LBCC ROV team was founded at Linn-Benton Community College in 2008. We design and build remotely operated vehicles that are customized for specific applications, yet are adaptable enough to excel in a wide variety of environments. Our cost-effective vehicles are designed to be modular, maneuverable, and durable. The diversity of our team allows us to provide increasingly effective products.

LBCC ROV's current design, The Water Bear, is optimized for arctic conditions, applications in pipeline inspection and maintenance including the survey of the local ecosystem. It can be equipped with up to eight cameras, one manipulator arm, a laser-based rangefinder and measurement system, an anode tester, an algae collector, a detachable flow sensor, and a detachable lift line for removing damaged or corroded sections of pipe. Our adjustable buoyancy system allows for balanced, slightly positive buoyancy with any configuration of tools, reducing environmental impact by mitigating sediment disturbance. Eight thrusters which utilize vector thrust allow for precise maneuverability and damaged or inoperable thrusters are automatically compensated for by the software. Our design is compact and lightweight, easing storage and transportation, while still allowing for maximum efficiency.

The Water Bear

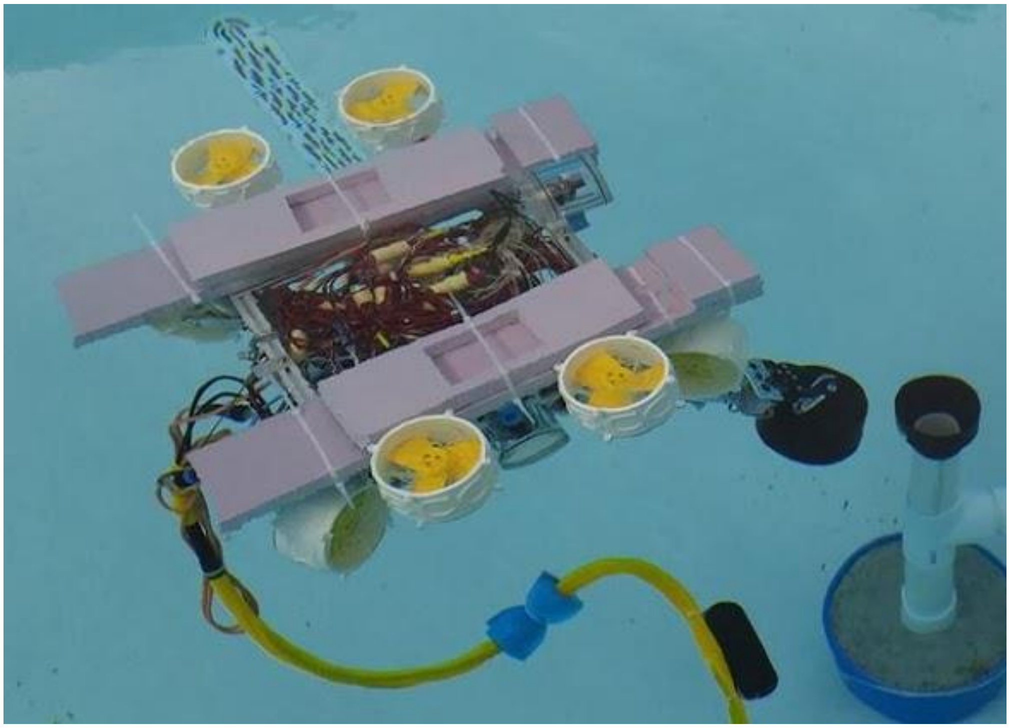

Fig. 1 The Water Bear in a testing pool prior to the Oregon regional competition.

Engineering Timeline

With 30 active team members, one of our first priorities was to create an engineering timeline. Our early planning allowed the team to recover from technical setbacks experienced during the build process.

Task Name	Start Date	End Date
Mission Goals and Design Philosophy	10/22/14	11/21/14
First Meeting/Mission Goals	10/22/14	10/22/14
Initial Planning and Design	10/23/14	11/21/14
Thruster	10/23/14	04/24/15
Design	10/23/14	11/21/14
Build	11/22/14	02/15/15
Test	02/16/15	04/24/15
Cameras	10/23/14	04/24/15
Design	10/23/14	11/21/14
Build	11/22/14	02/24/15
Test	02/25/15	04/24/15
Brain	11/22/14	04/24/15
Design	11/22/14	03/21/15
Build	11/22/14	03/21/15
Test	03/22/15	04/24/15
Power	01/24/15	04/24/15
Design	01/24/15	03/18/15
Build	03/19/15	04/06/15
Test	04/07/15	04/24/15
Lift Line	04/07/15	05/28/15
Design	04/07/15	05/12/15
Build	05/09/15	05/13/15
Test	05/10/15	05/28/15
Algae Sampler	03/18/15	04/28/15
Design	03/18/15	03/30/15
Build	03/29/15	04/27/15
Test	03/31/15	04/28/15
Frame	01/27/15	04/24/15
Design	01/27/15	03/11/15
Build	02/02/15	03/22/15
Test	04/16/15	04/24/15
Tether	03/22/15	05/28/15
Design	03/22/15	03/22/15
Build	03/22/15	03/22/15
Test	03/28/15	05/28/15
Manipulator	01/21/15	05/28/15
Design	01/21/15	04/22/15
Build	02/03/15	05/25/15
Test	02/20/15	05/28/15
Lasers	12/01/14	05/28/15
Design	12/01/14	04/15/15
Build	12/11/14	05/05/15
Test	12/18/14	05/28/15
Anode Tester	04/25/15	05/28/15
Design	04/25/15	05/20/15
Build	04/30/15	05/20/15
Test	05/19/15	05/28/15
Flow Sensor	03/22/15	05/28/15
Design	03/22/15	05/28/15
Build	05/19/15	05/28/15
Test		
Water Mover	03/22/15	05/28/15
Design	03/22/15	05/28/15
Build		
Test		

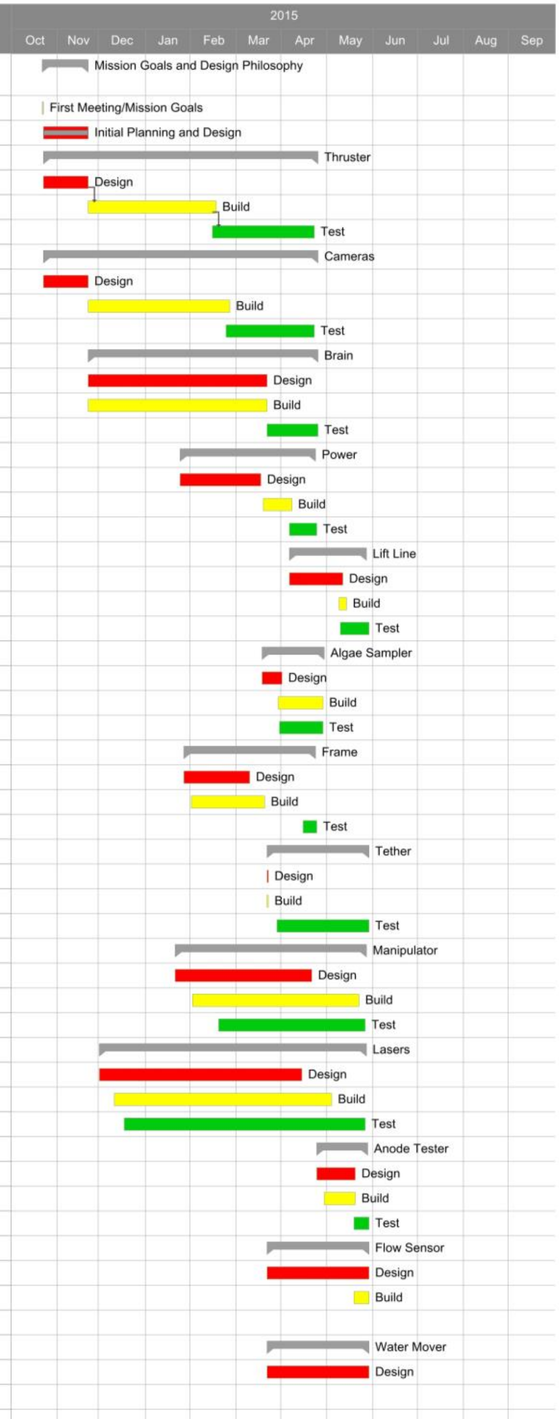

Fig. 2 This Gantt chart helped our team stay on track during the design, build, and test process.

Project Costing Summary

Subsystem:	Donated	Expenses	Total cost
Power System Team Totals	$216.34	$326.81	$543.15
Brain Team Totals	$8.00	$114.50	$122.50
Thruster Team Totals	$0.00	$790.40	$790.40
Camera Team Totals	$249.34	$334.97	$584.31
Laser Team Totals	$34.98	$118.23	$153.21
Frame and Buoyancy Team Totals	$159.00	$91.19	$250.19
Manipulator Team Totals	$0.00	$272.83	$272.83
Payload Tools Team Totals	$30.20	$0.00	$30.00
Cost of Manufacturing the Water Bear R.O.V:	$697.86	$2,048.93	$2,746.79

Table 1 Building all Water Bear subsystems in house allowed us to keep costs down, and build an ROV to make us proud.

System Interconnection Diagram

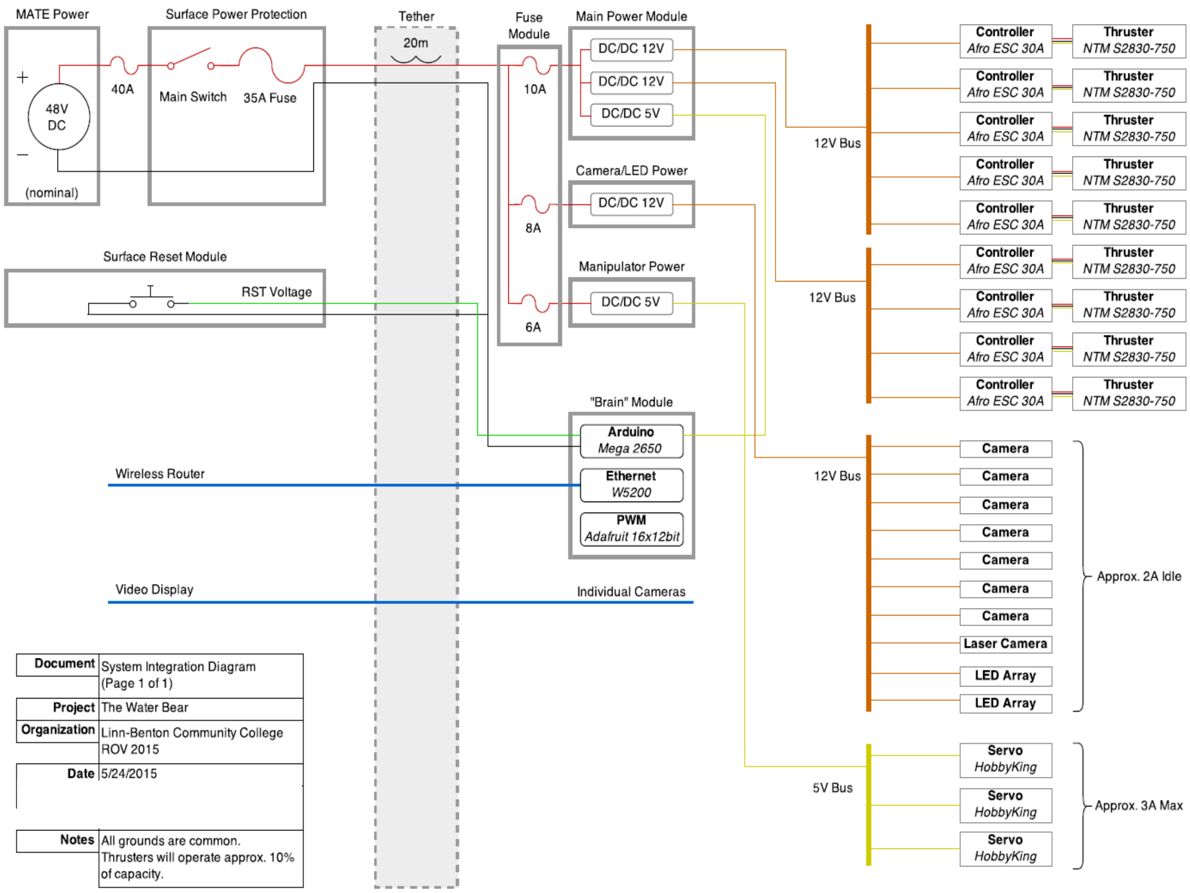

Fig. 3 The Water Bear's design reduces the number of cables needed in the tether while providing a variety of possible voltage outputs.

Software and Programming

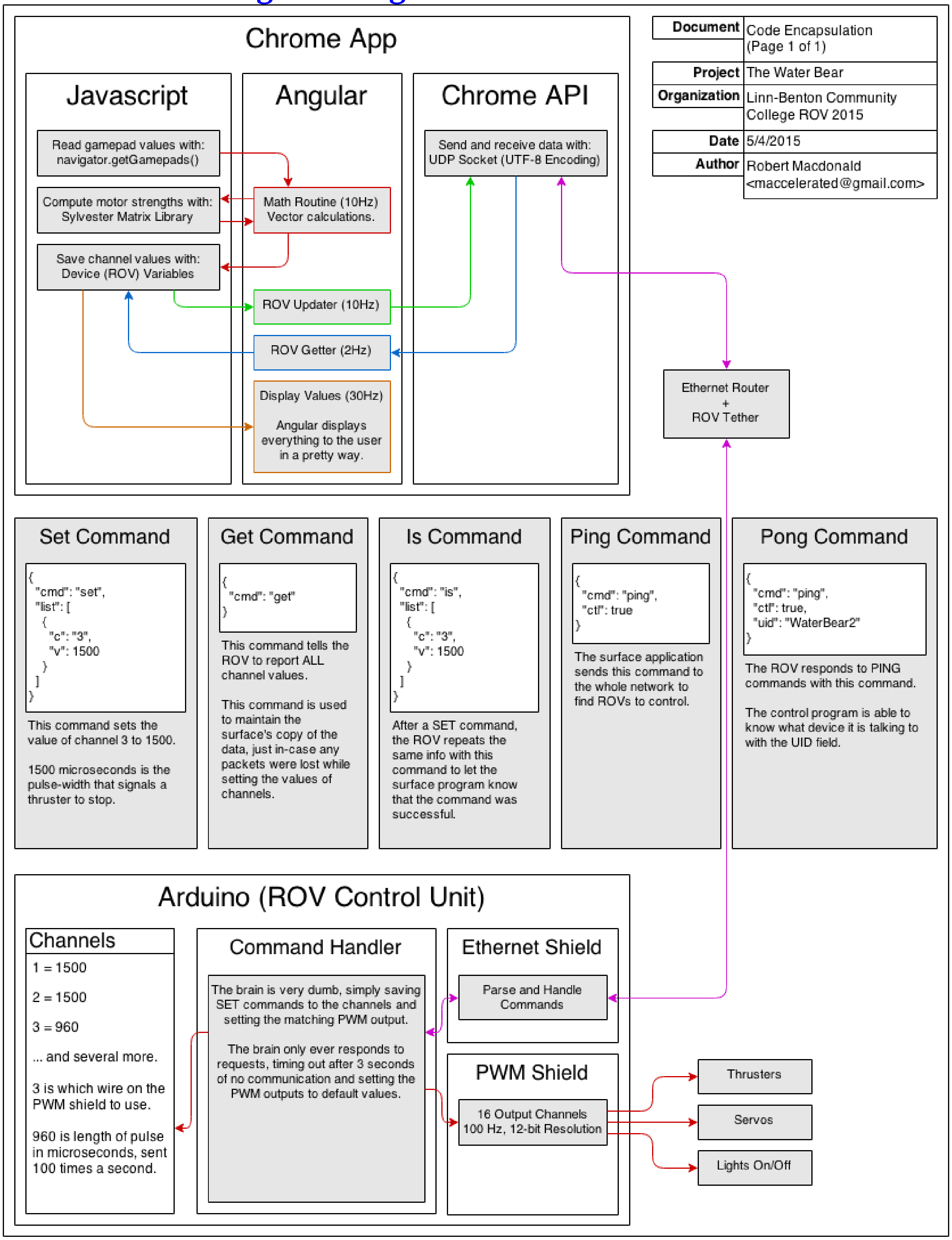

Fig. 4 The easy to use Chrome App's graphical interface belies the sophisticated matrix algebra that allows the Water Bear superior maneuverability in the water.

Design Rational

During our first team meeting, we decided to design and build all subsystems in house both in order to reduce cost and put to use the skills and knowledge we've gained in all of our classes. As a result, we gained skills such as acid etching circuit boards from scratch, how to hold companies to their technical specification sheets, communicating sophisticated technical information between sub-teams, and utilizing linear algebra and vector calculus to create an ROV that moves through the water like a graceful tardigrade gliding from spot to spot on mossy vistas.

When designing each component of the Water Bear we evaluated the primary task of that sub-system.

Frame

Fig. 5 Example of the extruded aluminum used on the Water Bear.

Task:

Construct a compact frame that provides attachment points for other components.

Design:

To construct the Water Bear's frame, LBCC ROV chose to use 80-20 extruded aluminum. Being aluminum, the frame is both robust enough to support the weight of the Water Bear on land, and still has a low enough mass to not impede its underwater movement. The channels on each side allow for easy mounting, adjusting, or replacement of components as the need arises, with minimal time and effort.

Brain

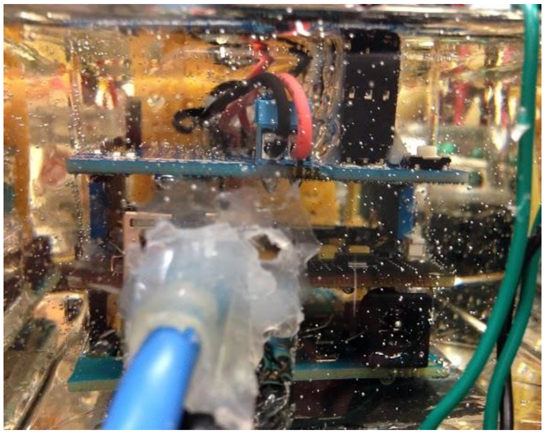

Fig. 6 Arduino Mega, Ethernet Shield, and PWM Shield encased in clear epoxy.

Task:

Provide a centralized hub for processing and distributing inputs from the surface to the Water Bear's core systems.

Design:

While the array of available microcontrollers for this sort of application is quite vast, there are a few distinct advantages to using an Arduino. The community support for open source libraries for both components and algorithms is virtually unmatched among other hobbyist microcontrollers. Another distinct advantage stems from the openness of the Arduino platform. While a commercial product, the Arduino remains an open hardware platform which has other models which allows code portability to more powerful or specific models.

LBCC ROV's choice of the Arduino Mega 2560 was dictated by the need for a high number of IO (Input/ Output) for our robust design, the community support for open development, and the large onboard data storage of the model. Based on an Atmel AVR CPU, the Mega 2560 gives access to 14 PWM (Pulse Width Modulation) channels, an additional 40 digital IO pins, and 16 analog pins. This multitude of input output negates the use of multiplexing through external circuits which is a benefit for reducing the complexity of the overall clarity system.

Fig. 7 USB Logitech game controller used for maneuvering the Water Bear.

Clever usage of linear algebra and vector calculus allows the Water Bear to have three degrees of translational freedom and three degrees of rotational freedom. This allows for unparalleled maneuverability and exceptionally fluid motion.

Power

Task:

Convert the MATE supplied 48VDC to multiple other voltages to power various parts of the Water Bear.

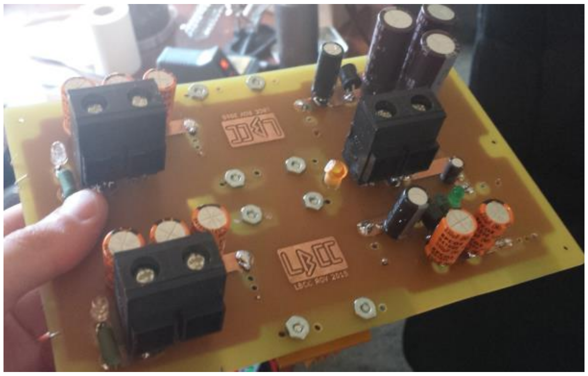

Fig. 8 Main power board before epoxy.

Design:

LBCC ROV is using a 48VDC/5VDC converter to step down power for the Arduino Mega. Two 48VDC/12VDC converters are used to power the thrusters. This main power board and its components are incased in transparent epoxy for waterproofing.

Fig. 9 Arm and camera power boards before epoxy.

Additionally there are two other smaller power boards on the Water Bear. The first contains a 48VDC/5VDC converter to power the Water Bear's manipulator arm. The second is a 48VDC/12VDC converter that powers the lights and cameras. Each of these boards is encased in clear epoxy for waterproofing as well.

Each of the three PCB's were custom made by LBCC ROV using a method known as toner transfer etching. The reverse sides of the power boards have heat sinks attached that are exposed to the water to prevent overheating. To improve the safety of the Water Bear's electrical systems, each power board is equipped with both an LED that lights up when that board is powered up, and an inline fuse to prevent electrical shorts.

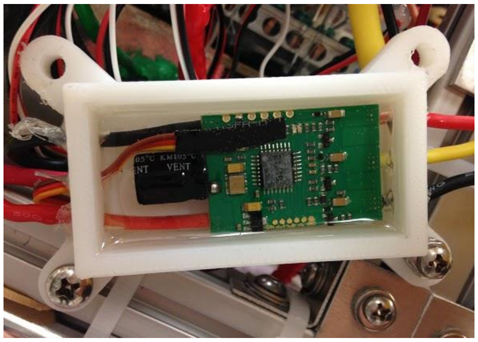

Fig. 10 One of eight ESCs held in a custom 3D printed housing and waterproofed with LBCC's signature epoxy process.

Propulsion

Task:

Provide the Water Bear with the essential aspects of motion; the ability to make pinpoint maneuvers and the power to get from task to task in a timely fashion.

Design:

The Water Bear's motion is from eight NTM-750 Brushless Outrunner S2830 motors. Each motor is equipped with a 3D printed propeller, custom designed by LBCC ROV to provide more thrust than any previously used store bought model. A 30 Amp Afro electronic speed controller is wired to each motor. This combination of motor, propeller, and ESC is capable of providing so much thrust that in order to remain within safe amperage and speed limits, each thruster is digitally limited to 10% of its maximum speed.

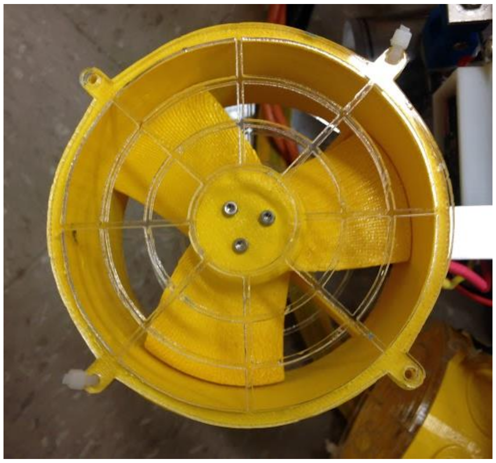

Fig. 11 LBCC ROV proprietary 3D printed propellers with empirically tested blade pitch to maximize thrust.

Fig. 12 Custom 3D printed thruster shrouds for enhanced safety.

Cameras

Task:

Provide the pilot with 720 degrees of visibility with the option to focus on specific payload tools.

Design:

Each camera on the Water Bear is a CCTV Home Surveillance Outdoor Security Camera. They are housed in clear acrylic with swivel mounts attached that allow multi-angled adjustment of the camera's point of focus. The camera signal travels through the Ethernet cables in the tether and displayed in real-time on an LCD display for the pilot. Baluns on both ends prevent signal interference when running multiple cameras.

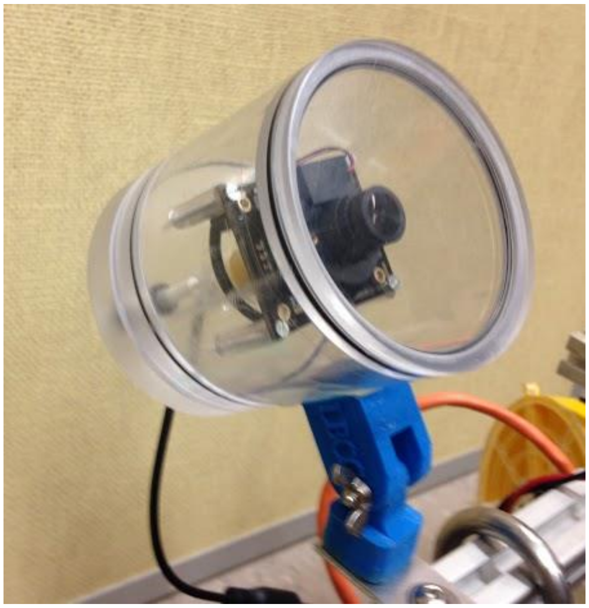

Fig. 13 One of the Water Bear's cameras including its housing and mount.

Tether

Task:

Build a neutrally buoyant, simple tether capable of connecting the Water Bear to the surface.

Design:

The Water Bear's tether is 20 meters long and wrapped in a high visibility, flexible mesh tubing. There are four Ethernet cables, two 12 gauge power lines, and one braided metal cable in the tether. Two Ethernet cables are used for video, one for control, and one for an emergency reset line. Shorting the reset line allows us to quickly reset the Arduino Mega 2560. The 12 gauge power lines are the send and return of all power. Each line has specialized connectors, depending on the purpose of the line. The braided metal cable is used to remove stress on the wiring. Neutral buoyancy is achieved by attaching small buoys approximately every 75 centimeters with zip ties.

Fig. 14 Section of the Water Bear's tether including a floatation buoy

Manipulator

Task:

Design a manipulator arm capable of grabbing, lifting, rotating, and releasing objects smoothly.

Design:

The manipulator is a vertical lift with an outstretched arm on the front of the Water Bear. The arm has a rotating joint at the end with a closable claw. The manipulator is made of 3 primary components, a vertical lift linear servo, an arm with an attached servo for rotation of claw, and a claw. The lift allows the arm to move in a vertical direction. The arm allows an offset of 20 centimeters from the frame so that the Water Bear will not impede the manipulator from performing tasks. The rotator is run by a servo held in a servo block that is set up inside the arm. The rotator allows the claw to rotate 180 degrees in both directions from center. The use of this manipulator alongside the Water Bear's smooth maneuverability allows the retrieval and placement of nearly any small, graspable object. The manipulator is modular and can be removed when not needed.

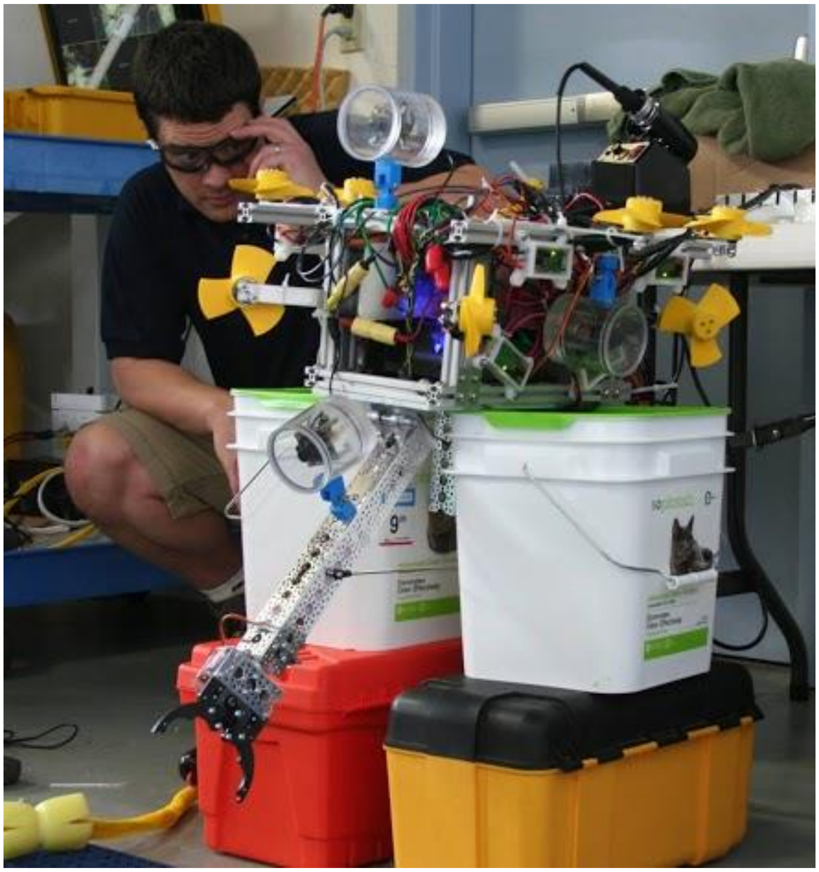

Fig. 15 Early testing of the manipulator showed that it could perform multiple missions reducing the need for extra parts.

Lasers

Task:

Perform measurements on submerged sections of an iceberg and an exposed well head.

Design:

Three low power lasers are equipped to the Water Bear in a waterproof housing. Two of the lasers are set parallel to each other and the other one is at a set angle from the ones that are parallel. To measure the iceberg, the Water Bear maneuvers into position so that the arms of the iceberg are in view of the camera and the two parallel lasers are projected on one of the arms. Next a screenshot of this image is taken. Using the two parallel lasers as a scale, and using basic geometry, the volume can be calculated. The offset laser provides a point to find the distance from the Water Bear to the arm of the iceberg.

Laser lights have an inherent danger to them; to mitigate this LBCC ROV is using lasers that operate at a wavelength of 650nm and less than a milliWatt of power. Additionally, there is a cover for the laser housing that is only removed as the Water Bear is launched.

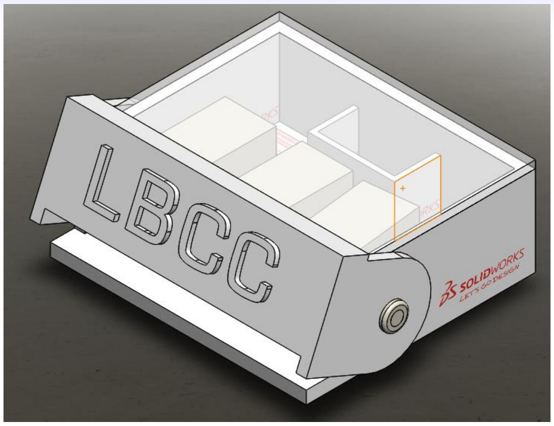

Fig. 16 The measurement lasers housing includes a safety swivel gate.

Algae Sampler

Task:

Collect ping pong balls from the underside of the ice sheet.

Design:

The box for ping pong balls is made of aluminum. The bands stretching across the open top are made of elastic. They are spaced apart by a distance slightly narrower than the balls' diameter, so with application of force they can slip through, but won't come back out.

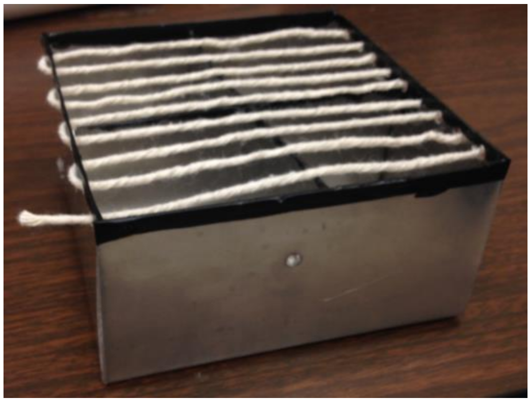

Fig. 17 The simulated algae is easily collected in one of four chambers and held in place by elastic bands.

Lift line

Task:

A bracket used to attach a lift line to the section of pipe to be removed.

Design:

A bracket made of a 30cm long section of PVC pipe, 2" in diameter, has a gap in one side just smaller than the 1.5" pipe to be retrieved. The bracket is attached to the lift line for retrieval, and also to the underside of the Water Bear by way of a detachable connection. With the application of downward force by the thrusters, the bracket is snapped onto the pipe, and a hair trigger mechanism pulls the pin out, releasing the bracket from the Water Bear. The pipe is then pulled up manually. Strips of insulating foam on the inner surface of the bracket pipe keep the retrieved pipe from slipping out.

Anode Tester

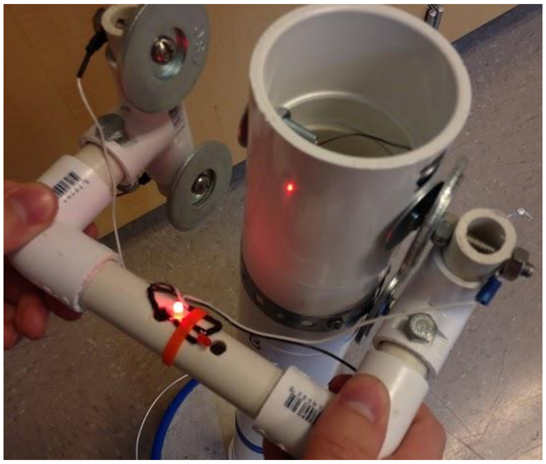
Fig. 18 The Anode tester separated from the manipulator.

Task:

Be able to detect a current across a ‘hot’ and ‘cold’ anode.

Design:

Affixed to the manipulator of the Water Bear is a PVC pipe with two washers on either end. Connected to the washers are a small resister and an LED. When the washers come in contact with the anodes, the LED will light up if a current is present.

This cost effective design was chosen for its simplicity.

Water mover

Task:

Create a non-electrical method of pushing water through a pipeline to be observed on the surface.

Design:

A cone shaped attachment at the end of a hose is connected to the Water Bear’s frame. The hose runs up the tether to a modified bike pump on the surface. After the cone is inserted into the pipe, a LBCC ROV technician pumps water through the hose and into the pipeline.

Flow Sensor


Fig. 19 Flow sensor used by LBCC ROV.

Task:

To design a simple system that aligns a flow sensor with the direction of the current.

Design:

The flow sensor is suspended between a weight and a buoyant foam ball. The foam ball is attached to the flow sensor via a 10 centimeter string. The weight is attached to the flow sensor via a 20 centimeter string. The flow sensor will automatically align with the current of the water due to metal fins attached to its sides. The Water Bear grabs the weighted flow sensor and drops it at the bottom of the pool to collect data. This whole system is attached to a lift line which will be used to retrieve the flow sensor after data collection.

Operational Safety Checklist

Pre-Powering / Operating Water Bear

Personal Protective Equipment

1.1: All personnel are wearing proper personal protective equipment.

- Safety Glasses
- Closed toed shoes/slick resistant shoes
- Team uniform

Additional personal protective equipment is only allowed to be worn after the safety office has inspected the additional protective gear.

Pre-Setup Equipment Check

2.1 All necessary equipment is accounted for.

- Power supply
- Fuse Box
- Tether
- Camera System
- Laptop

2.2 Check that Tri-Clop's lid is down.

2.3 Visual check of all involved equipment before any connections are made.

2.4 Power supply, fuse box, and air tank have been safely put into position and nothing has been set on top or leaned against these components.

2.5 The manipulator is raised off of ground and in neutral position.

Staging-Systems Check

3.1 All equipment is out of splash zone of the water excluding the tether and Water Bear.

3.2 Camera system is placed on top of cart with data laptop.

3.3 Power is run from external A/C power to the cameras and laptop then secured to the ground. (Reduce tripping hazard.)

3.4 Power supply is in the OFF position before energized.

3.5 Power supply is energized.

3.6 Fuse box is in the OFF position.

3.7 Fuse box is connected to power supply by the Safety person.

3.8 Adequate space between power supply and fuse box.

3.9 All connections are double checked by an additional person.

Connection Check.

4.1 All connections on the power brick, the brain, H-bridges, air lines, and cameras have been made.

- The Brain
- Power Brick
- H-Bridges
- Cameras
- Lasers

- Manipulator

4.2 Any empty connections are plugged and sealed.
4.3 All mounts are securely fastened to the frame.
4.4 The buoyancy foam is properly mounted to the frame.
4.5 Tether is secured to the hook on the tail.

Finish Staging

5.1 All final connections are made.
5.2 All personal are one step away from the Water Bear.
5.3 Verbal check from the team to the safety person.
5.4 The Water Bear is turned on by the safety person for systems check before launching.
5.5 Motors systems check.
5.6 Final camera adjustments made.
5.7 Approval from pilot to tether manager to place the Water Bear in the water.
5.8 Water Bear is placed into water by tether managers.
5.9 Safety personal is prepared to turn off power if needed.

Challenges Overcome

Interpersonal Communication and Teamwork:

Working and communication as a team quickly became one of the most challenging and interesting obstacles to overcome. Many skilled groups of people would produce great designs and ideas, but out team often had difficulty bringing these ideas together in harmony with other sub-systems.

Compartmentalizing sub-system work sometimes created a gap in understanding of certain systems. As tensions began to rise over this issue, the team decided to seek help. Luckily, we were able to overcome our communications issues with the help of LBCC Communications Professor Dana Emerson. Professor Emerson walked us through some key interpersonal communication techniques that greatly improved the team functionality. Effective technical communication learned this year will carry through to every team member’s lives.

Bad Spec. Sheets

We experienced two examples of companies sending us materials and equipment that did not match their spec sheets.

We purchased a set of cameras from an overseas company based upon the spec sheets the company posted online. Based upon what was advertised we modified these cameras so that they would integrate into our system. To our surprise and chagrin the cameras did not work as we predicted. Thinking the fault was in our wiring or thinking we spent several days trying to troubleshoot the problem. Eventually we completely dismantled one of the camera all the way down to its individual components and discovered that the CCD chip in the camera was not the chip advertised. We called the company from which we purchased the cameras and told them of our discovery – they kindly reimbursed us for all of the cameras.

We experienced a similar problem with the optically transparent epoxy that our team has used for the past several years. LBCC ROV has developed a technique to safely encapsulate electronics in epoxy as a waterproofing measure. In February, at a critical juncture in our building process, our technique stopped working. After several days of troubleshooting we became convinced that the problem was with the epoxy. We called the manufacturer and discovered that without warning or notice they had changed their epoxy formula. The company kindly refunded our team for the epoxy and sent us a large amount of the original formula.

As an added benefit to our community, two local marine technology company have been using our epoxy process. We were able to alert them to the formula change potentially saving them thousands of dollars and much lost time.

In both of these cases, we resorted to our original Gantt Chart to figure out how to save time and get back on schedule.

Electrical Components:

We immersed our electrical components in epoxy to ensure they would remain waterproof and operational in adverse conditions. Due to a lack of time, some of our components, such as the power boards, were epoxy potted before they had been stress tested. Our current board does not provide enough amperage to drive our thrusters at maximum capacity – we thus had to install special fusing for safety and use software current limiting to remain under our current limit. Future models will have a larger more robust power distribution block that can handle the draw from the thrusters.

Components that have been epoxy potted are very difficult, if not impossible, to fix. Due to an unexpected increase in load from one of our cameras, our wires were unable to handle the current. We were able to make a temporary repair by drilling into the epoxy, but the board had to be replaced. Using epoxy can be an easy and efficient way of waterproofing components, but we learned to thoroughly test our components before epoxy potting them.

Access to Resources:

Throughout the design timeline, we often did not have access to a pool. This limited the amount of testing and troubleshooting that could be done. We were able to perform basic waterproofing and proof of concept tests in a fountain, but it was not large enough to more than basic sub-systems tests. Several indoor pools would let us in based upon their limited ability and we learned to be flexible in order to match their schedule. Once the weather warmed up we eventually were able to use the Lindenwood apartment complex that graciously allowed us to test in their facility.

Assumption of Specifications:

We encountered a few issues with materials not being within our expected tolerance range. Our propellers and shrouds, as well as our laser housing, were designed in-house and 3D-printed. Upon completion, several of our components were repeatedly misshapen or scaled down from our designs, beyond the stated tolerance of the printing equipment. This delayed the production and testing of a few of our systems. Again, our early scheduling process helped us to figure out how to get back on track.

Our laser-based range-finding and measurement system requires that we have two parallel lasers, accurate up to several meters away. This became more of an issue than anticipated, as the lasers were not emitted in line with the modules; they emerged at angles that varied from module to module. We solved this by having separate, adjustable housings for each module within the main housing.

Future Improvements

Our systems this year will allow for expedited testing and development in subsequent years. The programming is adaptable, and allows for vector thrusting with any configuration of motors. An improved power board will allow us to achieve a high degree of mobility and efficiency. If future mission specifications allow for a larger frame, we will be able to make our components more accessible and achieve a cleaner design.

We used optically clear epoxy on our components, which is expensive and has a long curing time. We found that clear resin may be a viable alternative; it is a lot cheaper and cures in a fraction of the time. However, the resin expands as it cures, rather than contracts as the epoxy does. Our tests indicated that this did not have a detrimental effect on the printed circuit boards and their components, but this will require more testing.

We plan on setting stricter deadlines than we did this year, especially for paperwork. We learned about the difficulties of getting information from people, and we will be more prepared to handle it. We will also set a higher standard for rationale documentation, including photos of components. Additionally, we learned that not procrastinating is very important when writing a technical document, specifically that one week is not enough time to do justice to the months of effort and time that each member contributed.

Reflections

While working on this project, we learned and improved on a variety of skills. We came from a wide array of backgrounds, from engineering and computer science to horticulture. We learned about communication and teamwork, and about ourselves: our strengths and weaknesses. Many engineering, programming, and electronics skills were used and tested, and we all learned a great deal. The lessons, skills, and relationships gained from this experience will follow us throughout our lives.

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Travel Expenses

Travel Expenses	
Budget: $17000 Total Cost: $17712	
Airline Tickets	$13,212.00
Van Rental	$600.00
Housing	$1,900.00
Food	$2,000.00
Total	$17,712.00
Donations (as of 28.May.2015)	
Oregon Marine Technology	$1,000.00
Donation to LBCC Foundation	$1,000.00
GoFundMe Site	$1,100.00
Klindworth Roofing	$3,000.00
OSU Physics Dept.	$1,000.00
LBCC Computer Science Dept.	$1,000.00
LBCC Student Activity Committee	$3,500.00
Student Government	$3,000.00
Individual Student	$2,400.00
Total	$17,000.00
Difference to be raised by 20.June.2015	-$712.00