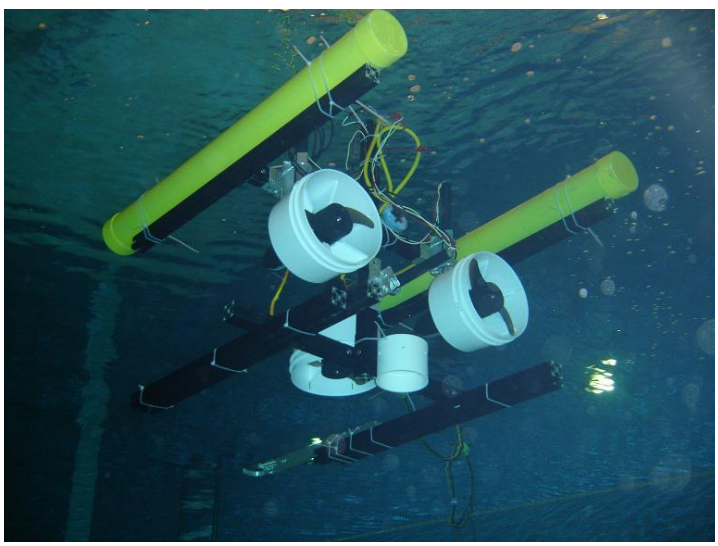
TECHNICAL REPORT

Linn-Benton Community College
Underwater ROV Robotics team

2009 MATE International ROV competition

Explorer class



Team Members

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Carrie Rebhuhn, Matt Seidlitz, Louann Van Beek, Rachel Waite

Mentors

Greg Mulder, Professor of Physical Science

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ABSTRACT

This technical report explains ROV “$\epsilon\delta_0$ (Epsilon Delta Not)”, built by Linn Benton Community College underwater ROV robotics team to compete in the 2009 MATE International ROC competition. Building the ROV and traveling to the 2009 MATE competition in Boston, Massachusetts, cost was approximately $6123.00, which includes the value of donated materials. The ROV frame was built using aluminum fractional extrusion. The propulsion consists of three 12 volt thrusters that are attached to the frame using aluminum clamps. For manipulating objects we have a robotic arm that is capable of reaching .7 meters in any direction from where it is mounted. The onboard electronics run the thrusters and is connected to the surface using our custom built tether. The topside electronics consist of a handheld controller and the control electronics. Also, to control the robotic arm we have a duplicate arm controller that is physically manipulated to move the ROV arm. To be able to see underwater we have two cameras, one mounted on the arm and another mounted on the ROV frame. The two cameras are attached to a video converter and connected to a laptop computer to display the video from both cameras.

To build the ROV the team learned many new skills. A few skills learned are circuit board construction and design, learning how to use pulse width modulation, becoming more efficient with our time management skills, and importantly scheduling realistic timelines and keeping to them to provide smooth forward progress. In the design of “$\epsilon\delta_0$”, most of our focus was on easy adjustability and having plenty of maneuverability.

Figure 1 LBCC Underwater Robotics Team

Left to right

Front row: Michael Goldtrap, Caleb Doner, Leigh Killingbeck, Raven Dorr, Joel Lonbeck Jesse Lowther,
Back row: Justin McLeod, Carrie Rebhuhn, Greg Mulder, Louann Van Beek, Samuel Driver, Jeremy Burris

1. BUDGET AND FINANCIAL STATEMENT

Item	Donations	Purchases
3 X Minn Kota Endura 30 Motors		$360.00
Submarine Prop Construction		$65.00
Traxxas 2075 Waterproof Servo		$24.00
MG995 11KG Metal Gear Servo		$22.00
15 X EasyDriver v3 Stepper Motor Driver		$214.00
20 X Mosfet High Speed Motor		$75.00
10 X Stepper Motors		$365.00
Misc Tools / Epoxy		$111.00
Deep Cycle Battery		$80.00
Electronics Components		$177.00
Anodized Aluminum	$400.00	
2 X Waterproof Camera's	$400.00	
Misc. Wiring		$80.00
Robotic Arm Material	$50.00	
Frame Components	$400.00	
PVC (Bouyancy Tubes)		$100.00
Tether		$200.00
Airtravel / Lodging	$1,000.00	$2,000.00
Totals	$2,250.00	$3,873.00
	Overall Total:	$6,123.00

2. DESIGN RATIONAL

2.1 ROV Frame

Figure 2 Frame attached together by flathead socket cap screws, ball bearing T-nuts and 90 degree aluminum angle pieces.

Last year there was an issue concerning the amount of time and effort needed to dismantle and reassemble the ROV. This year we emphasized quick and easy adjustment along with dismantling and reassembling the ROV much faster. To build the frame we used TS15-15L extruded aluminum bars and to attach the extrusion together we used flathead socket cap screws, ball bearing T-nuts and 90 degree aluminum angle pieces, refer to Figure 2. By using the aluminum extrusion instead of PVC pipe, the ROV components can be adjusted easily with only a hex key wrench and it is also easy to attach things to the extrusion. Our ROV is fairly large compared to most. We made the frame large because the thrusters take up lots of space; also having plenty of room makes it significantly easier to work on.

2.2 Propulsion

Figure 4 ROV Thruster

The $\epsilon\delta_0$ propulsion system consists of three Minn Kota Endura 30, 12 volt DC trolling motors. We chose to use trolling motors because they cost far less and produce plenty of thrust compared to traditional ROV thrusters. At 15 amps the motors produce about 25 Newtons of force per motor. The downside to using tolling motors would be their overall size, weighing in at 3.4 Kilograms per motor. Due to safety concerns we have attached a shroud to each motor made out of a plastic bucket and polyurethane plastic molding, refer to Figure 3. For protection against the spinning propeller, wire mesh was added to the end of the shroud. To waterproof the shaft, epoxy was used to plug the hole and secure the wires. Attaching the thrusters to the frame we designed and built three aluminum brackets, refer to Figure 4. During the design process the ability to make quick and easy adjustments was stressed. This was accomplished by using socket head cap screws to attach the brackets to the aluminum extrusion frame. On the clamping side of the brackets, u-bolts along with angled aluminum are used to properly distribute the clamping pressure on the thruster shaft. We decided that the best placement of the thruster would be along the center of mass. One on each side and one in the middle for depth control. The reason for this was to have the thruster's propellers rotate in opposite directions and have the ROV rotate in one spot without wandering.

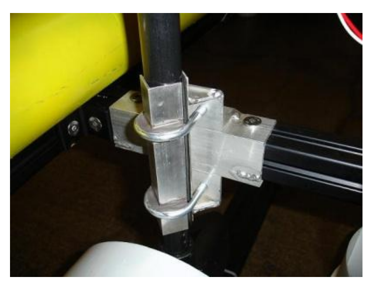

Figure 3 ROV Thruster Clamp

2.3 Robotic Arm

The robotic arm has three joints and a claw at the end, refer to Figure 5. The arm is capable of moving in any direction with a reach of about .7m. Originally servos were going to be used to move the arm but there was an issue of waterproofing. The problem basically came down to water entering the servo through the output shaft. Another drawback from using servos was their limit on speed and torque. The base of the arm demanded more torque to move than the servos could output so a stepper motors were used instead. Because stepper motors are being use then an enclosure was built around it for waterproofing. Each section of the arm has a common motor enclosure. Inside each enclosure are two stepper motors that rotate and swivel the arm. The enclosures are made out of white polypropylene plastic with a clear plastic top. Sandwiched in between the clear plastic and the polypropylene is a rubber gasket to make the enclosure water tight. Since there are two motors inside each enclosure there are two output shafts that are made with 303 stainless steel. Each output shaft has its own spring loaded seal to prevent water from leaking in.

The only drawback using stepper motors are the amount of torque they produce relative to weight and size. The motors are heavy and they don't produce very much torque. To solve this problem the enclosures were designed with a transmission inside. To achieve the mechanical advantage needed, specific gear ratios were used to increase torque at the output shaft. After the redesign of the new arm all of the previous design flaws have been corrected.

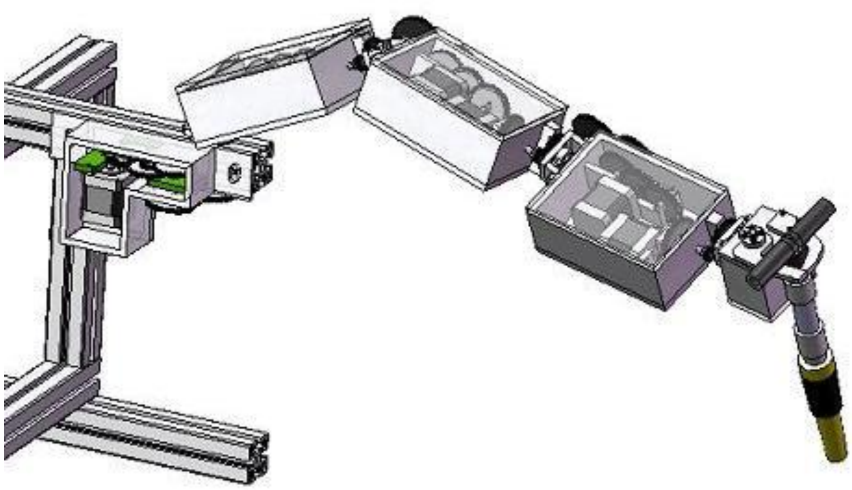

Figure 5 ROV Robotic Arm

2.4 Tether

The $\epsilon\delta_0$'s tether is 60m long and composed of two different types of wire. We used three 12 gauge wires for power to the motors and three 12 gauge wires for ground connections. The size was chosen due to the amount of current our propulsion motors draw and was cross referenced with AWG (American Wire Gauge) and NEC (National Electrical Code) sizing guidelines. For data communication, twisted pair wire was chosen. Our tether uses IP68 rated electrical connectors for both power and data lines. All of our tether equipment is rated for underwater use and the connecters are rated to stay waterproof for up to 2 weeks continuously underwater at 10m.

2.5 Control System Electronics

Last year's ROV used only light switches for directional movement control so this year we decided to use microcontrollers. With microcontrollers we can switch the motors on and off at rapid speeds. Doing this will "average down" the amount of volts and amps used to control the motors and reduce the amount of energy lost and heat gained by a huge margin. Another big advantage of using microcontrollers is that the amount of wires required will be reduced greatly which means that the tether size will be smaller. In choosing a good microcontroller we wanted one that was simple, easy to use, and one that has lots of information and tutorials available on the internet. After a long search we chose to use the "Microchip PIC 16F877A" microcontroller.

To control the thrusters a wired RC radio controller is used. The two analog sticks on the controller are two dimensional potentiometers with the middle as a center position. The position of the sticks on the controller outputs a voltage from zero to five volts. When the stick is pushed forward the thrusters will also move forward at increasing speeds depending on how far you push the stick. Full throttle forward is five volts and full throttle backwards is zero volts with center position, no movement, at 2.5 volts. The microcontroller interprets these voltages and then sends signals to the appropriate H-bridge circuit card that provides the PWM, pulse width modulation, signal to the thrusters. The PWM signals controls the speed of the thrusters by sending them a square wave where the width of the pulse is modulated to make it wider or smaller. The wider the pulse width the faster the thruster spins and vice versa.

The robotic arm is controlled by a second scaled down arm that is at the surface. When an operator physically moves the controller arm the ROV arm will mimic the movements. Using this style of controller will eliminate the use of a conventional and complicated type of controller. Using a conventional controller there would have been too many dials and switches to effectively control the arm accurately. The controller arm uses potentiometers at the joints to limit voltage as the arm is moved. The robotic arm uses stepper motors to control its movement. The stepper motors receive these signals and rotates to match the same voltage that the control arm sent it. Because there is a transmission in each section of the arm, for every degree the potentiometer moves on the control arm, the stepper motor will rotate a certain number of revolutions to achieve the equivalent angle that the control arm was moved.

2.6 Programming

We chose to use the "PICkit 2 Debug Express" (from Microchip.com) to program our microchips because it allows us to program the chip while in the circuit and offers in circuit debugging. After we compile our code and generate a .hex file we open up PICKit and choose the .hex file to program the chip with. We made sure that our custom circuit boards would interface with the programmer so we don't have to swap out our microchips every time we update the code.

We encountered some issues with changing hardware while programming for our propulsion. Our first version was programmed to use bridge drivers that took two inputs, one each for forward and reverse. Each input requires a PWM signal, which is interchangeably turned on as we controlled the direction and speed of the motor. However those bridge drivers couldn't take the voltages required to run our motors so we had to upgrade.

The code for our propulsion now implements the use of the A3941 bridge drivers from Allegro MicroSystems. This required a little reprogramming because instead of taking in two PWM signals, the bridge drivers have an input to specify direction (high is forward and low is reverse) and one for PWM.

3. CHALLENGES

There are many challenges that the team has run into this year, but as the <u>Little Engine That Could</u> made it over the hill, our little commuter school has also triumphed over our challenges. We have a good sized ROV team, full of talent and great ideas; however we soon realized there where often too many good ideas and it was a challenge to come to a group consensus at meetings. This led to much frustration and stalled progress. To alleviate this we broke into subgroups, allowing individuals to choose their area of focus. Each subgroup was then able to delegate a leader. That leader was able to make final decisions, attend specialized leadership meetings, and keep their group on track. This made a huge improvement in the decision making process.

Being a commuter school, many of our members are employed outside of school, have families, or have to travel a good distance for school, which can all prove problematic when trying to work as a group. This led to communication problems within and between groups. For instance, when one group decided to change the design of a major component and failed to tell the other groups, this created inconsistencies within the ROV design, wasted time, and halted forward progress. An example of this was when the electronics team found out from the team leader that the power supply at the competition was 48 volts. The electronics were designed for 12 volts; this meant everything had to be redesigned in order to compensate for the new voltage. This wasted lots of time because new parts had to be ordered and this caused some frustration within the team. Once this issue was fixed we were able to continue our forward progress in building our ROV.

To avoid these lapses in communication, we decided to build a website for the team. This way the site could be continually updated by each facet of the team as progress was made. This enabled each member to actually *see* the other groups' progress through pictures, descriptions, and videos. If one member was unable to make a meeting, they are now not left behind. We invite you to visit our site at http://www.lbccrov.com/. This web site has proven very valuable, and we are excited to carry it forward to next year's team.

4. TROUBLESHOOTING TECHNIQUES

Building our ROV required several different types of trouble shooting techniques. Certain components required a very logical and strategic approach, while other components called for trial and error. The learning curve comes in knowing which strategy to apply first to avoid wasted time.

The programming required a very logical step by step process. The programmers created the code, and then ran simulation tests. In this, they were able to step through the code piece by piece. While tracking the code, comparing the expected values to actual values finds differences. When a discrepancy is found, this may or may not be where it originated from, but at this point we can work backwards to find the original error and fix it. This may lead to rewriting a whole section of code, or simply a modification.

Solving for buoyancy was a different strategy all together. With all the different components added together, we could really only get rough estimates. It took actually getting the ROV in the water to see where we were at and then make the proper adjustments.

5. FUTURE IMPROVEMENTS

Our small school has somehow managed to build one of the largest ROVs in the competition not once, but twice now. For future improvements we would like to scale our ROV down quite a bit. A smaller ROV would be easier to transport and set up. The smaller version would also be able to maneuver more quickly and put less strain on our battery, thus allowing for longer dives.

We would also like to improve our tether. The umbilical cord is currently made up of eight wires. With so many, this increases our chance for something to go wrong. We would like to bring this down to two higher quality connectors. We would also like to develop a launch, recovery, and storage system for our Tether. A slip ring system would enable us to store the cord on a spool and could protect the individual wires during launch or recovery.

Lastly, we would like to improve the controlling interface. The system in place now is very effective, but could be improved upon. We would like to see key stroke control, similar to a gaming system. This would give us very precise movements and allow us to take advantage of exact locating devices, such as "GPS".

6. LESSONS LEARNED/SKILLS GAINED

In the broad sense, this is a brand new team. Although Linn Benton Community College competed last year, our 2009 team had only one returning member. This has given us the opportunity to learn many lessons and new skills as a group~~.~~ We were lucky enough to have at least one member of each subgroup with significant hands on experience in their discipline. This led to a mentoring relationship, where the experienced students were able to teach the students with less experience.

By far, our biggest lesson learned was in the area of communication. We learned that a little extra effort up front pays off exponentially in the long run. There were many hours put in to set up the web site initially, and it takes a continual focus to ensure the site's upkeep, but it is worth it. Communication can definitely make or break a team, and we found a way to make it!

7. REFLECTIONS ON THE EXPERIENCE

"My experience with LBCC's ROV club has been a beneficial time commitment. I have been exposed to new concepts, like the importance of electrical fundamentals or the difficulties of waterproofing just about anything. Being a team member has also helped me to develop skills associated with any group project. It was fulfilling to research propulsion, debate the pro's and con's, and then see that how my thoughts were incorporated into the ROV's final design. I count my club activities as one of the most productive actions of this year." – Samuel Driver

"I am used to doing things my way all the time. When I joined the LBCC ROV team, I had to learn how to adjust to other people's ideas. It has been a challenge for me to find the delicate balance of providing design ideas and being willing to work with other people's design ideas. Learning to work in a diverse team to come up with a unified solution has definitely been a great experience for me." – Caleb Doner

"Since being on the ROV team I have learned to effectively manage a team of students to help carry out specific tasks. I have also learned how to teach others some of my skills from industry such as the Solidworks class I taught during fall term. I think I improved my design skills overall, and also applying engineering principles from statics and dynamics through designing the ROV's arm." – Leigh Killingbeck

"I have always, always, always, wanted to build a robot or be on a robotics team, but I've only been able to do little things. Being a member of this team has allowed me to grow and develop the skills necessary to complete a larger, more complex project. I look forward to building my own ROV in the months to come." - Joel Longbeck

8. DESCRIPTION OF A SUBMARINE RESCUE SYSTEM

On September 17, 2008, the US Navy tested their new Submarine Rescue Diving and Recompression System, SRDRS, by mating with a Chilean submarine[1]. The international test was a great success and proved just how valuable the new rescue system will be. The SRDRS, as seen in Figure 6, combines state of the art engineering with the latest technology to make it an asset to not only the United States, but an asset to the world.[2]

Figure 6 Pressurized Rescue Module

This unique new system is comprised of four major components. The US Navy brought the first component of the system into use in 2006. This is the Atmospheric Drive System 2000, ADS 2000. The ADS2000 is a manned dive suit, designed for one person to be able to dive down to a maximum 2000 ft, and perform an assessment of the situation. This component of the system is capable to quickly deploy to the disabled submarine, locate and assess the situation, clear debris away from the escape hatch, and bring ELSS (Emergency Life Support Stores) to the sub. The suit is capable of maintaining one atmospheric pressure inside the suit; this makes decompression unnecessary for the operator.[3]

Once the situation is assessed, the next component is set in motion. The second component of this system is the Pressurized Rescue Module (PRM). The Navy's PRM, shown in Figure 6, is named Falcon. Falcon is a remote controlled rescue vehicle that is capable of carrying up to 16 passengers to safety. Falcon has the ability to make several trips down to the disabled submarine, making the total rescue capability 155 passengers. It is controlled and powered through a tethered line to the main controls aboard the vessel of opportunity. The PRM is manned by two operators who can assist in transferring the sailors aboard, and offer medical

[1] Mohl, Michael, NavSource Online: Submarine Photo Archive, "Submarine Rescue Diving and Recompression System SRDS," http://www.navsource.org/archives/08/08494.htm (accessed May 13, 2009).

[2] Specialist 2nd Class (SW) Alexia M. Photo # N-7029R115 by Mass Communication. (Image). *NavSource Online: Submarine Photo Archive.* < http://www.navsource.org/archives/08/08494.htm> (accessed May 20, 2009)

[3] Global Security.org, "Submarine Rescue Diving and Recompression System SRDRS," http://www.globalsecurity.org/military/systems/ship/systems/srdrs.htm (accessed May 13, 2009).

assistance where needed[4]. Falcon “uses a conventional hydraulic system for thruster power and control. Hydraulic systems are also used for skirt de-watering and position controls.”[5]

The third component of this system is the Launch and Recovery System, LARS. The LAR System is made up of the Cursor, the Umbilical Handling System, the Structural Interface Template Sets (SITS), and the Deck Cradle. The Cursor is the mechanism, the jaws if you will, that holds on to the PRM as it is lowered in or raised out of the water. The Umbilical Handling System is comprised of a winch and load alleviator to manage and store the chord. The SITS are basically a structural template, designed for quick installation of this recovery system to any vessel of opportunity. The Deck Cradle is designed to hold and protect the PRM while it is aboard the ship.[3]

The last component of the submarine rescue system is the Submarine Decompression System, SDS. Two submarine hyperbaric decompression chambers, each with the capability of accommodating 32 sailors, are located aboard the vessel. The rescued sailors can be transferred from the PRM into the awaiting chambers via a pressurized passageway. Thus keeping the rescued sailors under pressure the entire time to avoid decompression illness, which can be fatal.[4]

In any successful rescue mission, time and conditions are always a factor. This SRDRS is designed to be mobilized and carried via air or ground to any location in the world within 72 hours to first rescue[6]. Once on location the SRDRS can, according to NavSource Online, “conduct rescue operations to a depth of 2,000 feet, can mate to a disabled submarine at a list and trim of up to 45 degrees, and can transfer up to 16 personnel at a time… [and] because SRDRS-RCS [Falcon and its support units] receive their power from a VOO [vessel of opportunity] via an umbilical, it can operate around the clock without pause”[5]. The PRM can handle a large temperature variance, and is prepared to operate in water temperatures of 28°F up to 85°F.[7] All in all, this new rescue system is designed to save lives just about anywhere, anytime, and in any conditions possible.

This is a huge improvement over the Navy’s last PRM, Mystic. According to Ocean Works International Corporation, who led the team in designing the SRDRS, they wanted to make several future improvements from the Mystic design for this new Submarine Rescue Diving and

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[3] Roy Thomas, Andrew DeSpirito, Roy Bleiberg,The Society of Naval Architects and Marine Engineering, “The Application of Classification to the US Navy Submarine Rescue System,” http://www.sname.org/AM2008/papers/088.pdf (accessed May 14).

[5] Global

[6] Mohl

[7] Gibson, J. and J. English, OceanWorks, “Pressurized Rescue Module System”, http://www.oceanworks.cc/cms/pdfs/OW2002_Pressurized%20Rescue%20Module.pdf (accessed May 13, 2009).

Recompression System including but not limited to propulsion, navigation and control systems, depth capability, and the ability for a quick deployment and setup.[8] These parallel with our future improvements. It doesn't matter how technically advanced your rescue system is, the basics are still the basics, and there is always room for improvement.

9. FUTURE MISSIONS

Newberry Caldera

Following up with Linn-Benton's previous ROV, the Allen Throop, The LBCC $\epsilon\delta_0$ will be going to the Newberry Caldera to do field research. Newberry Caldera was created in a volcanic eruption that drained the magma chamber below. The volcano collapsed in on itself to create the caldera, and over time rain filled the caldera to create two lakes: East Lake and Paulina Lake as shown in Figure 7.[9] Paulina Lake holds a geological mystery; a 50 meter tall spire near the center called Dante's Peak. The top of the spire is 20 meters below the surface, and has been explored by SCUBA divers. Reports from the SCUBA teams have indicated there is evidence of wave action on top of the spire, which suggests that the top of the spire may once have been at the top of the lake and sank downwards. The bottom of the spire, 70 meters down, has never been explored. Due to implosion of the ballast tanks on the Throop during the summer of 2008, samples from lower than 20 meters were not collected, and the sediment from the top of the spire was stirred up too much for reliable video footage to be collected.

Figure 7 Paulina Lake (Left), East Lake (Right)

Learning from some of our mistakes last year, $\epsilon\delta_0$ has been designed with close to neutral buoyancy in an effort to keep down the amount of sediment kicked up from maneuvering near the spire. Improvements will also be made to $\epsilon\delta_0$ after the competition, which include metal buoyancy tanks, a neutrally buoyant tether, and high-pressure thrusters.

$\epsilon\delta_0$'s missions will be to:

- Collect video data from the spire
- Collect rock samples from at least three different depths
- Take temperature readings (if volcanic activity is observed)

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[8] Gibson

[9] Torrid. Interlude: Images of Central Oregon. (image). *LOADED ORYGUN.* <http://loadedorygun.blogspot.com/2006/12/interlude-images-of-central-oregon.html> (accessed May 20, 2009)

The LBCC $\epsilon\delta_0$ is also part of an ROV workshop for high school student which will be held over the summer at Paulina Lake. The workshop is designed such that each student will make their own miniature ROV with which to explore the lake. Three of the students will accompany the LBCC ROV Team to the competition in Massachusetts, and all of the students will observe and operate $\epsilon\delta_0$ in Paulina Lake. The students will also assist with design and learn more in-depth about the mechanical functions and operation of the ROV.

10. ACKNOWLEDGEMENTS

We would like to offer our sincere gratitude to our sponsors, without whom this project would not be possible:

AudioFiles
Neutrino Graphics
Salbasgeon Suites
Osborn Aquatic Center
Bottom Dwellers Inc.
SolidWorks
SOSI
Light, Camera, Action
ATS
CPM Precision Machine
Student Life and Leadership
The LBCC Foundation
WET Labs
Portland State University
MATE Center

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Cressey Merrill, Diving Instructor
John Sweet, Engineering Transfer
David Kidd, Civil Engineering
Dana Emerson, Speech
Sandy March, Drafting & Engineering Graphics Aid
Dowless, Dean, Welding
Ketler, Dave, Welding
Schmitke, Dave, Welding
Stuewe, Fred, Welding Technology
Mack, Dave, Mechatronics
Karelia StetzWaters, English/Writing

We saved the best for last. We would like to offer a sincere appreciation to our mentor for all his guidance and support.

Greg Mulder, Physical Science

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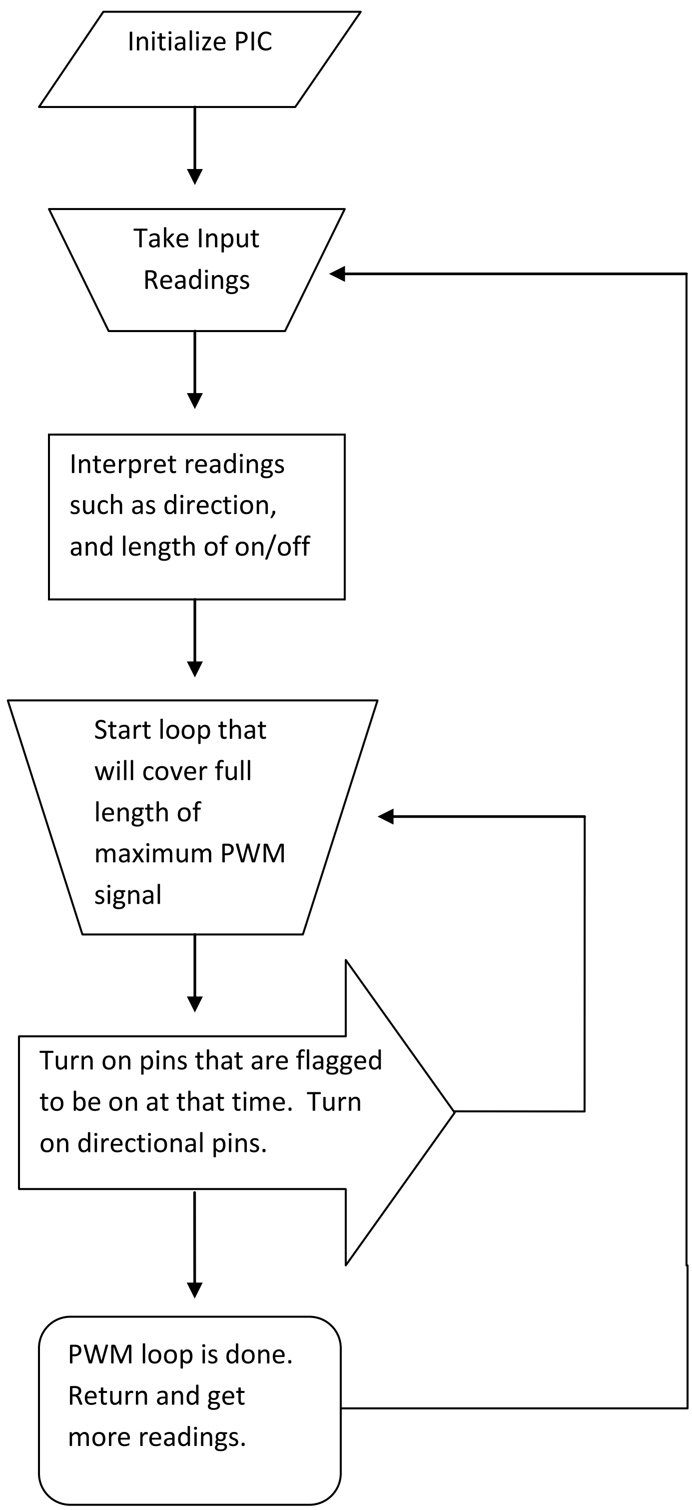
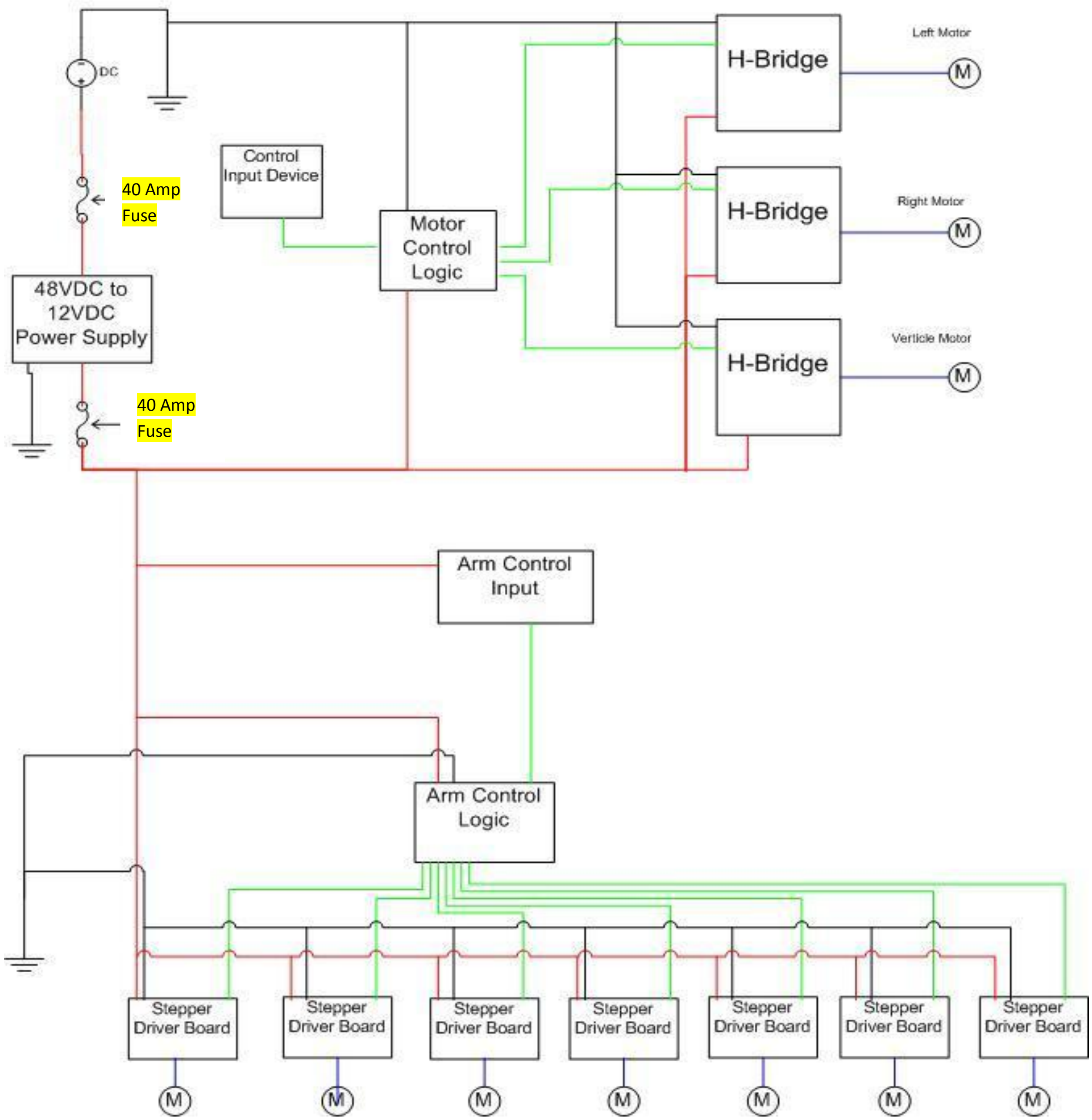
Torrid. Interlude: Images of Central Oregon. (image). *LOADED ORYGUN.* <http://loadedorygun.blogspot.com/2006/12/interlude-images-of-central-oregon.html> (accessed May 20, 2009)

APPENDIX A - PROGRAM FLOW CHART

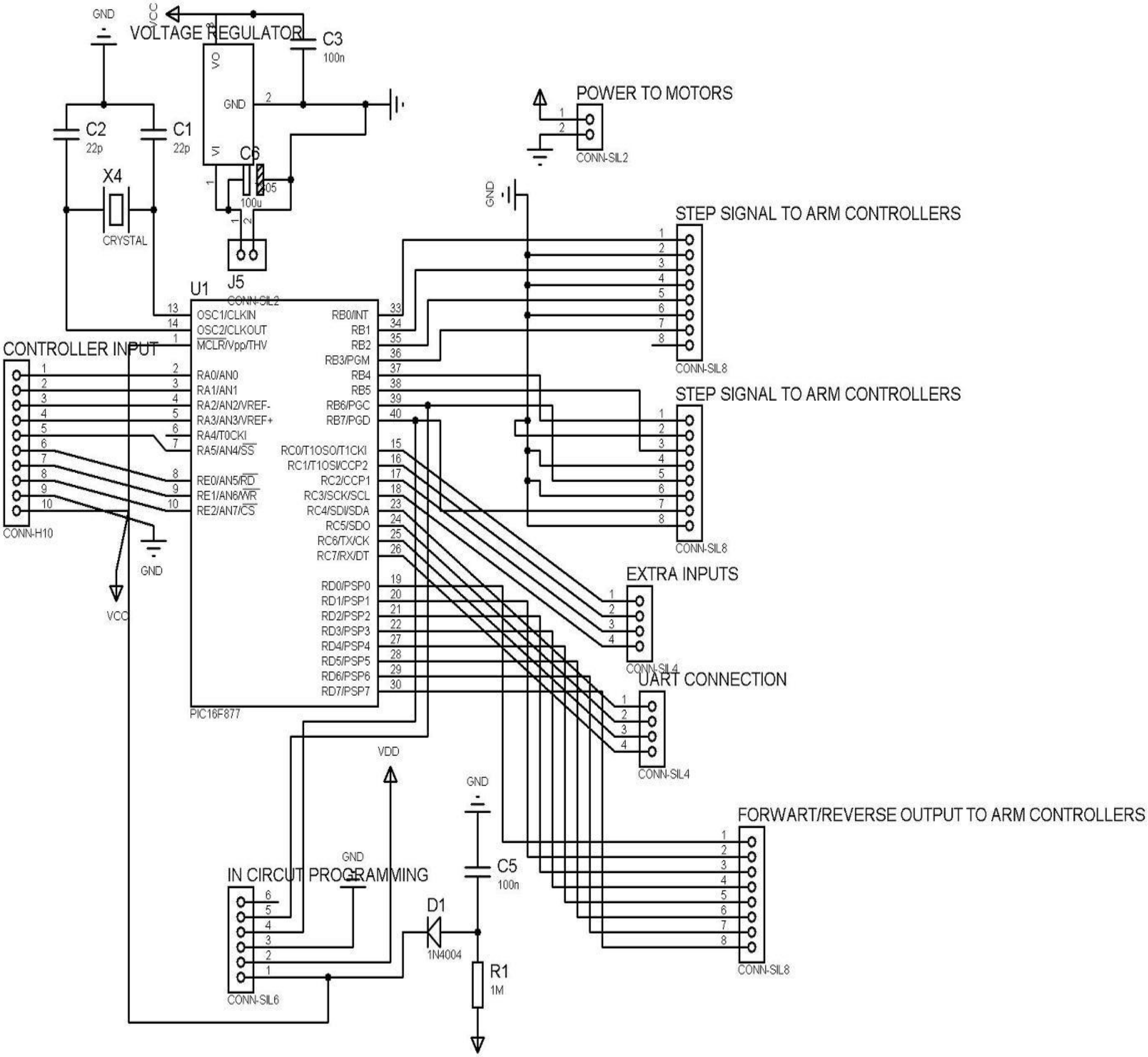


APPENDIX B - ELECTRICAL SCHEMATICS

ROV System Diagram



ROV Robotic Arm Control Circuit



ROV Thruster Control Circuit