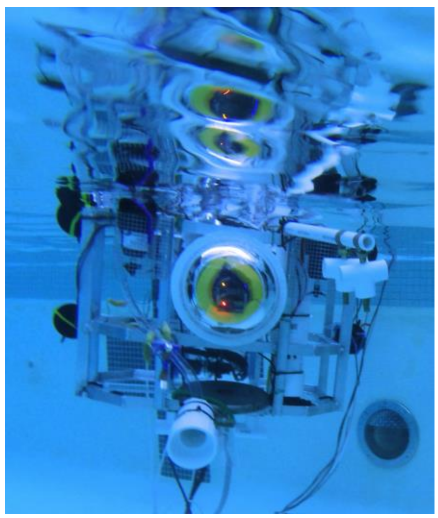
SeaDawgs Robotics

Mississippi State University, Mississippi State, MS 39759, USA



Team Members

Amelia Hebert – Team Leader
Bradley Calhoun – Lead Design Engineer & Pilot
Anna Purser – CFO
Hunter Rawson – CMO

Team Advisors

Mrs. Jane Moorhead

Abstract

SeaDawgs Robotics was founded in August 2014 at Mississippi State University (MSU). It is comprised of four senior students from the Electrical and Computer Engineering Department in the James Worth Bagley College of Engineering. The company was started to fulfill a senior design project requirement which was to design and build an ROV capable of completing the EXPLORER class tasks of the MATE 2015 International ROV Competition. As a student design team, the company was operating on a $1500 hardware budget for the project. Because of this, SeaDawgs Robotics has designed an extremely cost effective product that is capable of performing the same functions as competing products, but at a much better price for the consumer.

The flagship product from SeaDawgs Robotics is The LUB. This ROV is specially designed to perform various tasks commonly completed in Arctic environments and in and around oil platforms. The LUB features a lightweight aluminum frame, three wide angle cameras, an adjustable ballast system, and customizable, removable manipulators.

SeaDawgs Robotics is a first year competitor at the MATE International Competition and has already learned many things from the competition experience. The SeaDawgs are excited to showcase their product, which is described in detail on the following pages.

Table of Content

1. ROV Overview

The SeaDawgs Robotics' ROV, The LUB, is comprised of an aluminum frame with a 6" PVC tube inside the frame. The tube is the main electronics enclosure and has a mechanical plug on the back to seal out water and has an acrylic dome on the front for the camera to look out of. The ROV has eight bilge pump motors - four horizontal that control propulsion and rotation and four vertical motors that control altitude. It is equipped with four cameras. One camera is located in the main enclosure right inside the acrylic dome and the other three cameras are in separately sealed enclosures and attached to the frame in strategic places so that the pilot can see all of the prop manipulating apparatus. Figures 1 and 2 show The LUB.

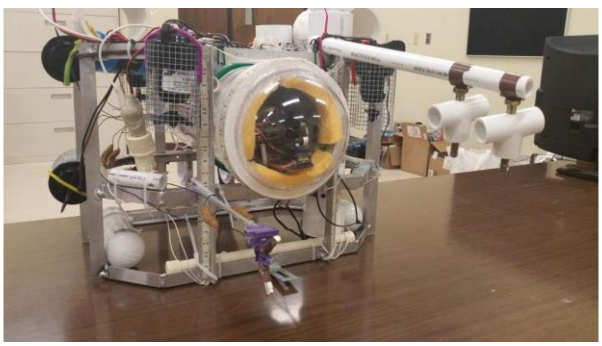


Figure 1. Front of the ROV

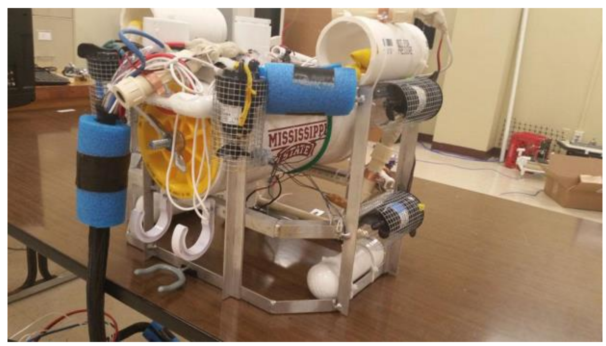


Figure 2. Back of the ROV

2. Budget

Table 1 shows SeaDawgs Robotics' starting budget.

Table 1. Budget

Expense	Quantity	Single Price	Total Price
BeagleBone Black	1	$62.89	$62.89
PCB Board	1	$100.00	$100.00
Voltage Regulator	2	$0.95	$1.90
Continuous Servo	4	$13.95	$55.80
Silicone	1	$4.58	$4.58

Starting off, SeaDawgs was planning on salvaging many of the spare parts that were just lying around the lab in order to minimize the cost of the ROV. Unfortunately, it became clear that the parts were not sufficient enough to use, and the team would have to invest in better materials.

3. System Interconnection Diagram (SID)

Figure 3 shows SeaDawgs Robotics' System Interconnection Diagram (SID). The 48VDC, 40A power supplied by the competition is sent down the tether to the ROV where it is fed into two DC-DC converters. One of them takes the 48VDC and converts it 12VDC for all the motors while the other DC-DC converter provides 12VDC to the cameras. The cameras each have their own cable that runs in the tether back to the base station where the camera feeds are fed into a video box that allows all four video feeds to be displayed on one monitor. An Xbox controller is connected to a laptop running Linux Ubuntu. The signals from the controller are sent to the BeagleBone Black using a Cat5 cable that is included in the tether. The BeagleBone Black then sends PWM data to the motor driver boards and the servos to control them.

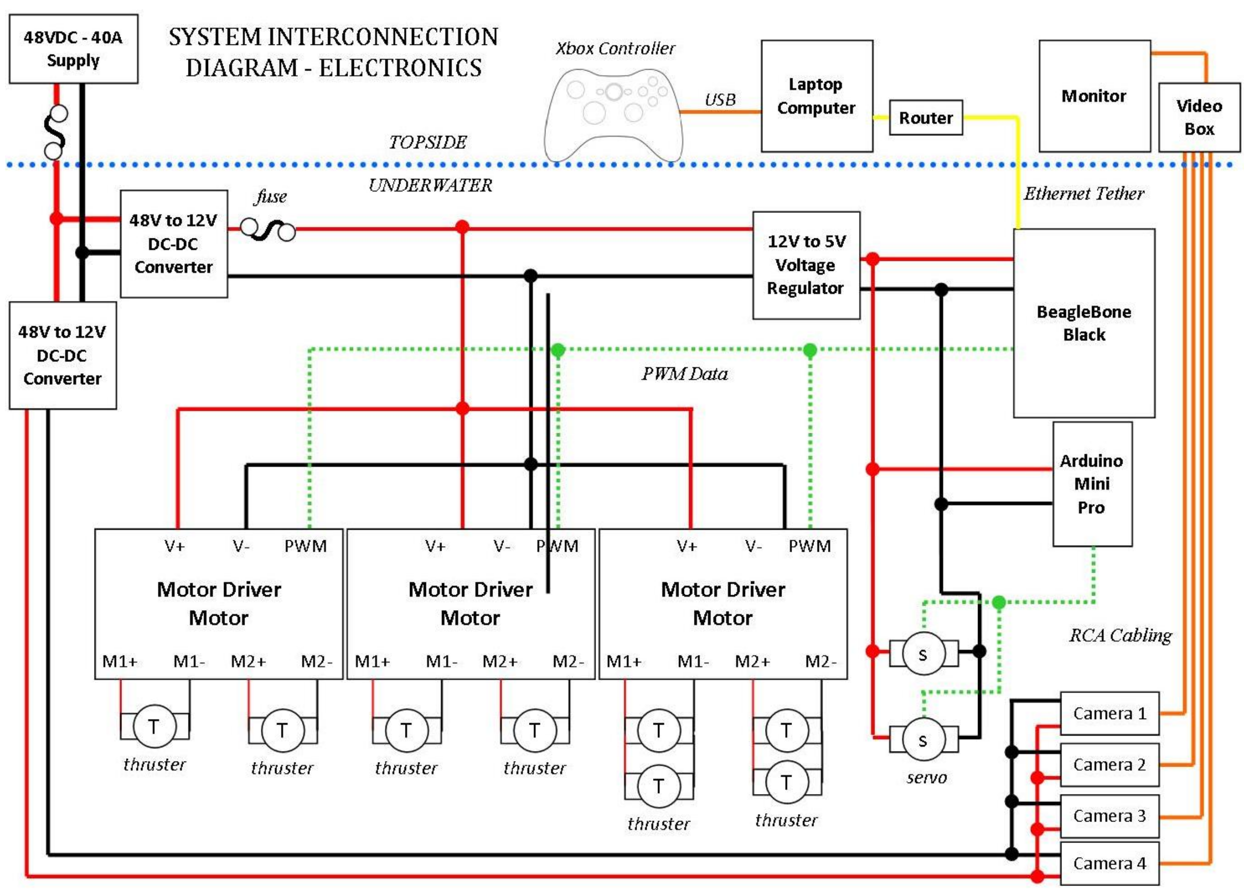


Figure 3. System Interconnection Diagram

4. Software Block Diagram

For their software, SeaDawgs Robotics has decided to use ROS (Robot Operating System) for their main control system. ROS is a meta operating system that runs on top of a linux operating system and can either be programed in Python or C++. The advantage of using ROS is that software that is written on two separate devices can communicate easily with each other over an internet connection. Since the SeaDawgs have two software devices (base station laptop and the BeagleBone Black), two separate software diagrams are provided.

Figure 4 shows the flowchart of the base station software. Whenever the base station receives Xbox controller data, it divides it up into motor control data and servo control data and sends them as separate packages. If the data is motor control data, then the laptop adds a software delay to it and sends it to the BeagleBone Black. If the data is servo control data, it is sent to the BeagleBone Black with no alterations. While waiting for Xbox controller data, the base station is also waiting on sensor data from the Beaglebone Black. Anytime the base station receives sensor data, it displays it to the pilot.

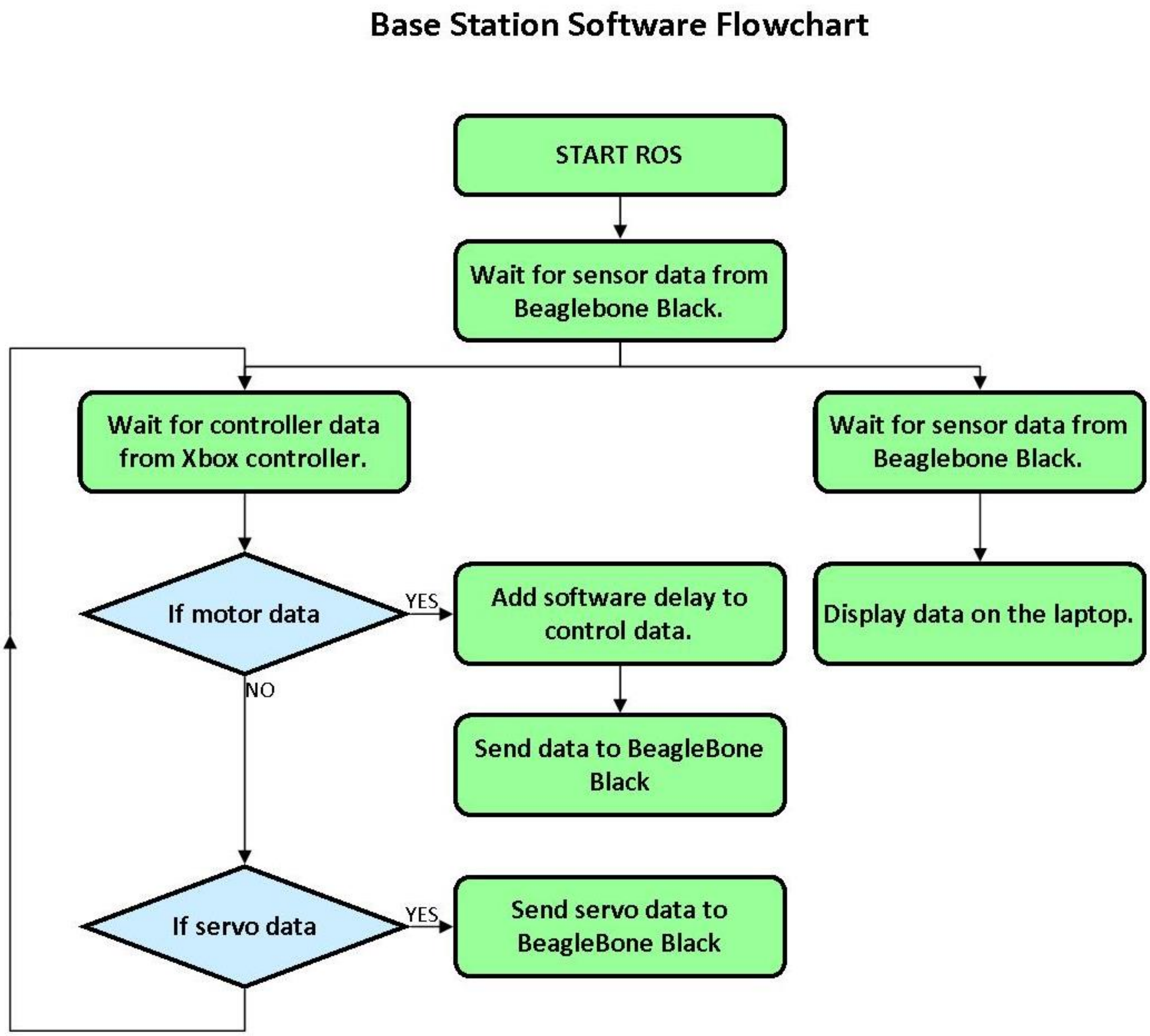


Figure 4. Base Station Software Flowchart

Figure 5 shows the BeagleBone Black's software flowchart. The BeagleBone Black waits for controller data to be received and sends PWM data to the proper devices. While waiting, the BeagleBone Black is constantly sending sensor data back to the base station.

BeagleBone Black Software Flowchart

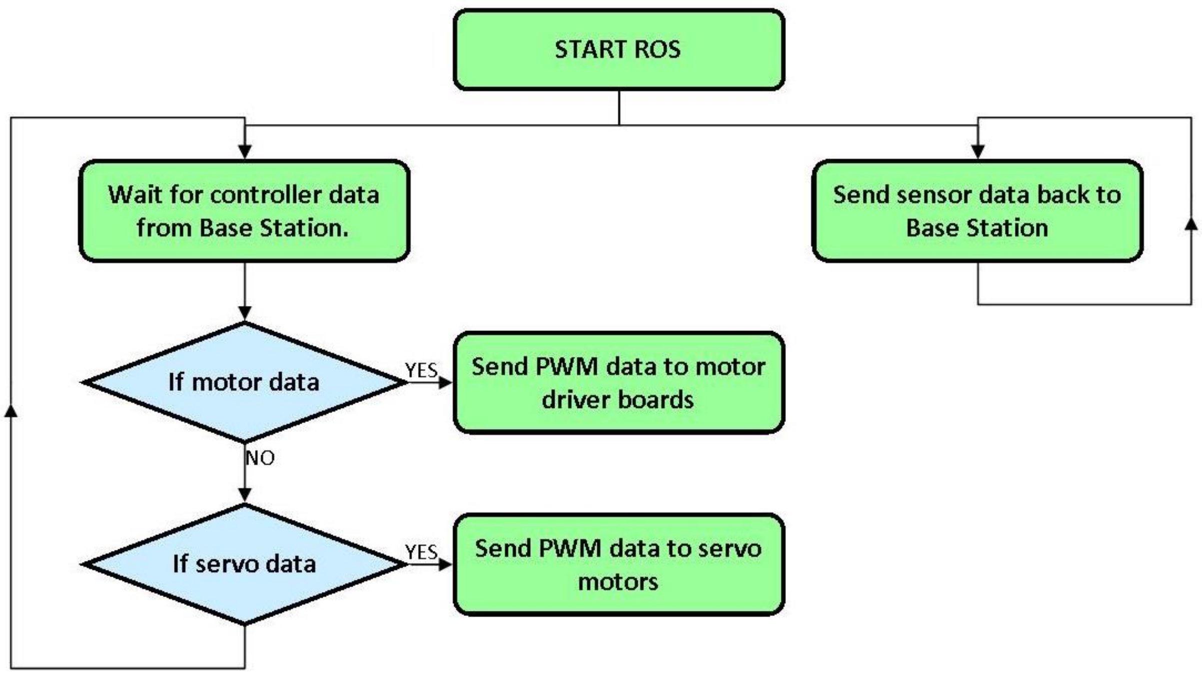


Figure 5. BeagleBone Black Software Flowchart

5. Design Rationale

The SeaDawgs ROV team is tasked with constructing an underwater ROV to complete a specific set of tasks provided by the MATE ROV competition manual. The ROV has been built to complete all the given tasks of the competition. This section will explain these mechanisms that will give the ROV its capabilities.

Frame

The frame of the ROV is constructed out of aluminum L-channel which is to ensure strong, structural integrity of the ROV, to give the ROV a cleaner look, and to be a lightweight frame. The size of the ROV cannot be larger than 75 cm by 75 cm and was constructed by welding the aluminum into an octagonal, three tier formation shown in Figure 6. The SeaDawgs chose this shape for the frame so that it could fit within the size constraints but have a large area inside the frame if needed. The electronic enclosure consists of a six inch PVC tube that is placed between the top and middle tier of the aluminum frame. One side of the PVC tube has an acrylic dome sealed to it, and the other side has a mechanical plug that can be resealed.

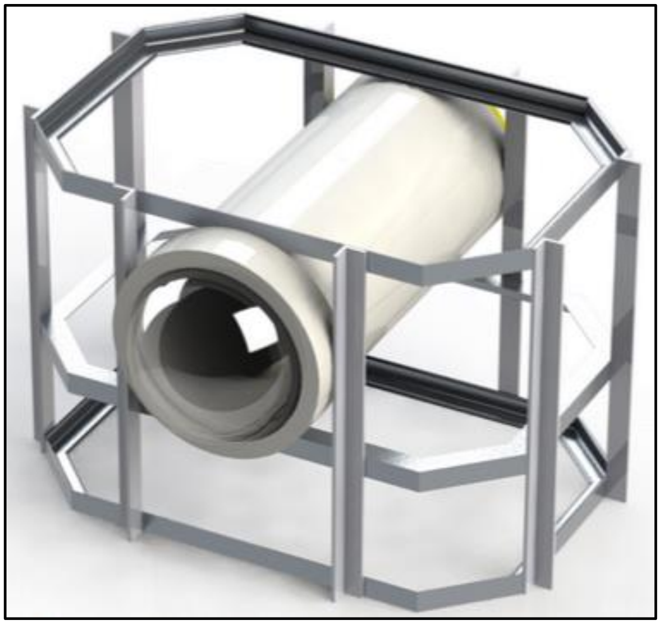


Figure 6. Aluminum Frame and Enclosure

Base Station and Controller

The base station is the system used on the surface to control the ROV during the competition. It will consist of an Xbox controller connected to a laptop. The laptop be connected to a router via an ethernet cable and the ROV will also be connected to the same router via an ethernet cable in the tether. The connections to the router will allow the laptop and the ROV to communicate with one another over a TCP/IP connection. This allows the team to have multiple types of data transferred over a single cable.

ROV System

The ROV system is comprised of electrical components onboard that are used to control the ROV and relay data back to the base station. The SeaDawgs Robotics team has decided to use a Linux based system to control the ROV. The systems considered by the SeaDawgs are listed in Table 2.

Table 2. Linux System Comparison

NAME	MODEL	PROCESSOR SPEED	ONBOARD STORGE	GPIO	USB Hosts(s)	COST
BeagleBone Black	Rev C	1 GHz	4 GB eMMC	65	1	$55.00
Raspberry Pi	B+	700 MHz	none	40	4	$39.99

The team chose to use the BeagleBone Black board for the Linux control system. While the Raspberry Pi has more USB hosts and is cheaper, the BeagleBone Black has more processing power as well as an abundance of GPIO ports. The BeagleBone Black microprocessor is shown in Figure 7.

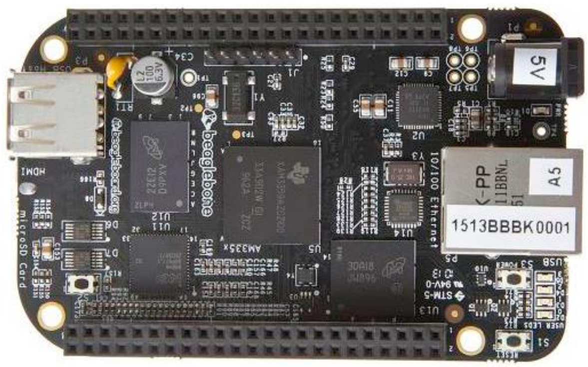


Figure 7. BeagleBone Black [2]

Peripherals

The peripherals are the electronic components that give the ROV its capabilities. These peripherals and their purposes are listed in Table 3.

Table 3. Peripherals and their Purpose

PERIPHERAL	PURPOSE
Cameras	Provide video feedback to the user
Manipulating Arm	Collect and manipulate competition props
Skim Pump	Collect ping-pong balls
Voltage Probe	Measure voltage across an anode and cathode
Thrusters	Give the ROV propulsion and directional control
IMU	Measure acceleration and orientation of the ROV
LEDs	Emit light to dark areas for the cameras

Cameras

The pilot controlling the ROV will not be allowed to see the ROV during missions. This rule makes cameras necessary to complete all the competition tasks. It is possible for the ROV to be equipped with only one camera and still complete the given tasks. However, it is more practical to have multiple camera feeds to provide multiple perspectives. The LUB utilizes four cameras. One is placed on a gimbal inside the main enclosure to allow for pan and tilt capability. The other three cameras are fixed to the frame in their own sealed enclosures. Each camera has it’s own RCA extension cable that runs in the tether back to the base station.

Manipulating Arm

Several tasks of the competition require the manipulation or collection of objects. Some items will be picked up by the manipulating arm and stored in a chamber inside the ROV. Others must be interacted with in the following ways:

- Collect objects from the tank floor
- Deploy objects to the tank floor
- Remove u-bolts from a pipe
- Remove a cap from a pipe
- Place objects in specified areas

SeaDawgs Robotics decided to use a series of different types of hooks and other various apparatus to manipulate all the props to complete the tasks above. For example, a single hook is on the front of the ROV and two hooks are in the back. The single front hook is used to collect objects from the tank floor, remove u-bolts and the cap from a pipe, and place objects in specified areas. The back two hooks are used for carrying objects to deploy that the ROV is provided before the mission starts and also to insert objects into certain openings.

Skim Pump

The purpose of the skim pump is to collect the ping-pong ball from the surface of the water. The skim pump is made out of 2” PVC pipe and is illustrated in Figure 8.

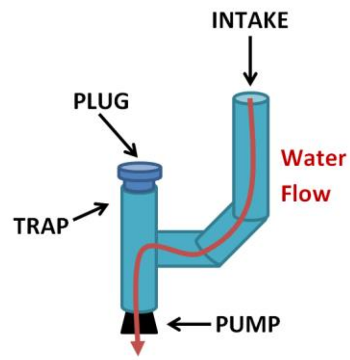


Figure 8. Skim pump

When the pump is turned on, it forces water out of the bottom of the pipe which forces water in from the top. The intake nozzle acts as a vacuum, and when close enough, it sucks the ping-pong ball into the tube and down to the pump. When the pump is cut off, the flow of water stops, and the ping-pong ball floats up to the trap where it remains until the ROV returns to the base station.

Voltage Probe

The purpose of the ROV's voltage probe attachment is to measure voltage across an anode and cathode. The probe design is shown in Figure 9. Both wires run back to the BeagleBone Black. The input wire goes to one of the ADC pins, and the gnd pin goes the ground pin. The design allows for the two contacts to be pressed against the anode/cathode. During this time, the BeagleBone Black can measure the voltage across the anode/cathode using the onboard analog to digital converter.

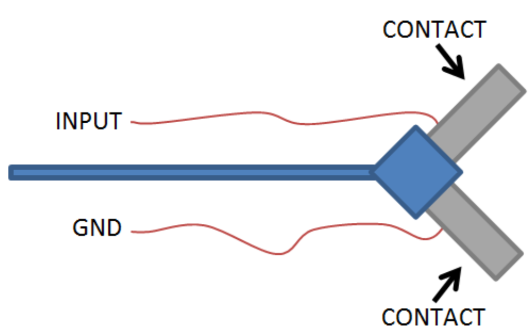


Figure 9. Magnet probe

Thrusters

SeaDawgs Robotics is the third group at MSU to prepare for the MATE competition, so there is hardware from the previous teams that can be reused. The thrusters are one set of components that is being reused. These thrusters are bilge pump motors that have been modified to have propellers in place of impellers. Bilge pump motors are intended for underwater use and are already waterproofed. The alternative to using these bilge pump motors would be brushless DC motors, which would have to be waterproofed. Past MSU teams have not had great success in waterproofing motors, so the bilge pump motors are used.

An issue with the bilge pump motors is counter-electromotive force, common with most brushless motors. According to [3], "The counter-electromotive force also known as back electromotive force is the voltage, or electromotive force, that pushes against the current which induces it." This excess current, illustrated in Figure 10, exceeds the DC-DC converter's current limit which is 30 A. SeaDawgs Robotics handles this by using software to increase the current slowly over time instead of allowing the full amount of current to reach the motor instantly.

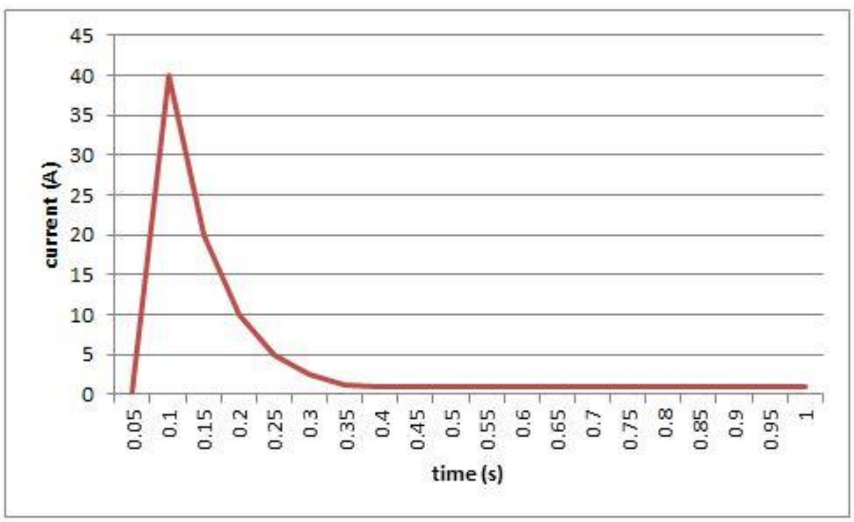


Figure 10. Counter-Electromotive Force

The desired effect is illustrated in Figure 11. As the rate of the PWM duty cycle increases, the current draw from the motors rolls instead of spikes. This will keep the current low enough for the DC-DC converter to handle.

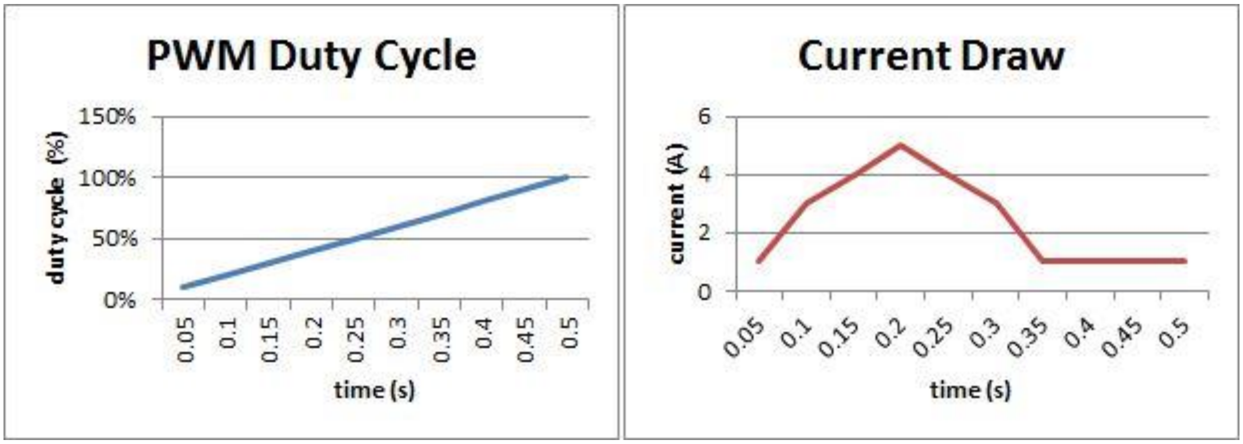


Figure 11. Current padding effects

Inertial Measurement Unit (IMU)

One of the sensors that is onboard the ROV is an IMU. The data from the IMU will be used to calculate the position of the ROV. The measurements taken by the IMU will be sent back to the base station where they will be fed into a program to graph the ROV's position in the water. SeaDawgs Robotics is using the Adafruit 10-DOF IMU. Since this sensor has ten degrees of freedom it will provide the most accurate data for the pilot.

Table 4. IMU Comparison

NAME	AXIS	DEGREES OF FREEDOM	INTERFACE	PRICE
Accelerometer	3	3	SPI / I2C	$17.95
Gyro Sensor	3	3	Analog	$29.95
Accelerometer & Gyro Sensor	3	6	SPI / I2C	$39.95
Adafruit 10-DOF IMU	3	10	I2C	$29.95

Flow Rate Sensor

The competition rules require teams to design and build a passive flow rate sensor. This sensor will need to be deployed by the ROV to a specified location during the competition. After being deployed, the sensor needs to begin collecting data. The data will then be transmitted back to the base station to be processed. The competition requires that the average flow rate of the water over a five minute period be displayed after the data has been collected. SeaDawgs

Robotics has built a flow rate sensor with a grab point similar to the acoustic sensor competition prop so that the ROV can pick it up easily. The flow rate sensor contains a reed switch that sends data back every time a pinwheel spins around. We use this data to calculate the average flow rate in the tank.

Measurement Solution

Multiple competition tasks require the ROV to measure the length or height of a pipe in the water. SeaDawgs Robotics' solution to these tasks is to measure the pipes using a software package called ImageJ. The ROV takes a picture with its dome camera and sends it back to the base station where it is processed on the surface laptop. To process the image, we open the image in ImageJ and use the outer diameter of the PVC pipe as our known dimension. We know this dimension because the competition specifies what size pipe is used to build each prop and the outer diameter of various sizes of schedule 40 PVC pipe can be found on the internet. Once we tell ImageJ what the known dimension is, we can select any length we want to measure and it will calculate it for us..

6. Safety

The ROV system has several fuses placed in its power line in order to protect from a short-circuit or an excess draw in power. There is a fuse on the main 48VDC as well as a fuse on the 12VDC line going to the motors. The DC-DC converters also have current overdraw protection which will cause them to cut off if the current exceeds a certain limit.

To keep the motors propellers from causing any damage, chicken wire has been wrapped around each motor and is used as a shroud to keep objects from making contact with the propeller while also allowing the pump to direct water to propel the ROV.

While working on the ROV, SeaDawgs Robotics keeps safety the top priority. Proper personal protective equipment (PPE) must be worn when in the lab, shop, or pool. For example, closed toe shoes and safety glasses are required when using power tools. Also, all of our facilities have access control measures to ensure that dangerous equipment may only be used when a supervisor is present.

7. Challenges and Lessons Learned

The biggest challenge for the SeaDawgs was waterproofing. Waterproofing problems were encountered on the electronics enclosure wires and camera enclosures. The original design for the wire pass throughs on the electronics enclosure involved pushing recycled plugs through holes drilled in the side of the cylindrical enclosure and using silicon to cover the spaces. Those plugs failed, we learned, because there was not a flat surface around the base of the plugs and the enclosure wall was not threaded. We did eventually find the correct amount and placement of silicon on the outside plus toilet bowl wax and FlexSeal on the inside to keep water from breaching the enclosure at those points, but learned that a better design would have been a flat surface and industry grade connectors for the pass throughs. We also had waterproofing issues with our first prototype of camera enclosure which was an acrylic cylinder with a resealable lid. Instead of that design, we utilized CPVC compression fittings and ½" CPVC pipe with an end cap. The SeaDawgs learned a lot about pressure, material properties of PVC and acrylic, and adhesives on the waterproofing journey.

8. Future Improvements

SeaDawgs Robotics has many ideas for improvements that can be made to future product designs. Higher quality cameras would allow for more accurate measurements and maneuverability. A more precise system to achieve neutral buoyancy would conserve power and be more user friendly to control. To give the ROV more tactile capabilities, a motor controlled gripping mechanism would improve upon the current mechanical solutions. Lastly, SeaDawgs Robotics will be implementing better electronics enclosure solutions, like a box instead of a cylinder, as discussed in our lessons learned.

9. Team Reflection

Preparing for this competition was a challenging but rewarding process for the SeaDawgs. As busy students all taking senior level course loads, our time had to be as effectively utilized as possible. This meant that the team had to work hard at keeping good communication between members so that parts and subsystems could be worked on without everyone present in the lab. Using the competition goals as a senior project helped move the design and build process along quickly, which allowed us time to refine peripherals and practice tasks after the ROV system was functional. This also allowed us to get practice with writing and presenting about our ROV. In the future, the SeaDawgs would recommend a larger, multidisciplinary team so that there is a larger pool of knowledge directly involved in the design process. The SeaDawgs have enjoyed the competition experience so far, and look forward to competing in June.

10. Acknowledgements

SeaDawgs Robotics would like to thank MATE for sponsoring the ROV competition and giving us the opportunity to participate. We would like to extend our sincerest thanks to the Bagley College of Engineering and the Electrical and Computer Engineering Department at Mississippi State University for believing in us and sponsoring our trip to competition. We wish to

acknowledge our wonderful advisor, Jane Moorhead, for her guidance and support throughout this project.
The SeaDawgs also wish to acknowledge Alan Turnage for his advice on ROS, Sylvester Stafford for his CAD help, Nico Ramirez for opening the Factory after hours so that we could cut our aluminum, Brandon Warner for welding our frame together, and Bryce Amacker for his all-hours advice on life and power. Lastly, we would like to acknowledge Tequila for always being there at the end of the day.

11. References

[1] "2015 MATE ROV Competition Manual EXPLORER CLASS" http://www.marinetech.org/files/marine/files/ROV%20Competition/2015%20files/EXPLORER_MANUAL_FINAL_v6b_cover.pdf , Accessed May 28, 2015
[2] Image of BeagleBone Black. http://beagleboard.org/black , Accessed August 22, 2014
[3] "Counter-electromotive force." http://en.wikipedia.org/wiki/Counter-electromotive_force Accessed October 14, 2014

Appendix A: Project Costing of the ROV

Expense	Description	Use	Amount	Running Balance
	Funds from the ECE Department			$200.00
	Funds from IEEE			$1,500.00
Bilge Pump Motors	Underwater motors with propellers	Propel the ROV while underwater	-$55.90	-$447.20
Motor Driver Boards	Pololu Dual VNH5019 Motor Driver Boards	Drives the bilge pump motors	-$29.95	-$89.85
6" PVC pipe	0.5 meters, Schedule 40 PVC pipe	Main electronic enclosure	-$6.79	-$6.79
BeagleBone Black	Linux Board with GPIO	Control the ROV's peripherals	-$62.89	$62.89
Voltage Regulator	5 volt Voltage regulator	Stepped 12 volts down to 5 volts	-$0.95	-$1.90
Servo - Micro	micro, generic servo motor	Provides pan and tilt to the camera gimbal	-$10.95	-$21.90
	Funds from the ECE Department			$200.00
DC-DC Converter	Step 48VDC down to 12VDC @ 30A	Transforms power for the ROV	-$164.35	-$164.35
Heat Sink	Heat sink for the DC-DC converter	Helps to dissipate the heat of the DC-DC converter	-$3.65	-$3.65
Wing Nut Plug	Schedule 40 PVC plug for 6" PVC	Seal the electronic enclosure	-$22.73	-$22.73
Acrylic Dome	Acrylic Dome	Window for a camera to look of the electronic enclosure	-$30.00	-$30.00
6" PVC Coupling	6" PVC Coupling	Helps attach the acrylic dome to the PVC pipe	-$11.45	-$11.45
Aluminum "L" Brackets	1/8" x 3/4" x 3/4" Angle 72" long	Build the frame of the ROV	-$4.96	-$29.76
Silicone	Auto/Marine Silicone	Seal the wiring plugs on the enclosure	-$4.58	-$4.58
Lexel Caulk	Lexel Caulk	Seal the acrylic dome to the enclosure	-$5.89	-$5.89
Chicken Wire	Chicken Wire	Shroud the bilge pump motors	-$9.97	-$9.97
Wire Connectors	Molex wire connectors	Connectors used to connect the electronics to the bilge pump motors	-$3.49	-$6.98

Protoboard	Protoboard	Used to solder electronics on to	-$3.49	-$3.49
Transition Cement	PVC to Acrylic transition cement	Cement the acrylic to the enclosure	-$4.97	-$4.97
Screws, Nuts, Bolts	Nylon screw, nuts, and bolts set	Attach the electronics to the enclosure	-$11.54	-$11.54
Acrylic Sheet	12"x24", 1/8" thick, clear acrylic sheet	Used as an electronic shelf and prop handler	-$15.76	-$15.76
Vernier Interface Shield	Arduino shield	Arduino shield used to interface with the flowrate sensor	-$51.46	-$51.46
PCB Board	PCB Board	BeagleBone Cape PVB board	-$290.22	-$290.22
Cameras	Waterproof cameras	Provides visual feedback to the driver	-$19.99	-$79.96
RCA to USB converter	RCA to USB converter	Converts the analog video to a digital image	-$19.99	-$19.99
Cat5e Calbe	18.29 meters of Cat5e cabling	connects the base station to the BeagleBene Black	-$15.95	-$15.95
10 AWG Wire	30.48 meters, 10 AWG, red & black wire	Provides power to the ROV	-$31.95	-$31.95
Power Connector	Competition power housing and contacts	Allows the tether to connect to the competition's power connector	-$3.30	-$3.30
4-Channel Video Box	4-Channel Video Box	Arranges all 4 video feeds onto one monitor	-$105.00	-$105.00
RCA Video Cable	30.48 meter, RCA video cable	Transmit video signals to the base station	-$13.99	-$55.96
Cable Sleeving	30.48 meter, tether sleeve	Cover and protect the ROV tether	-$23.33	-$23.33
			Total Funds	**$1,900.00**
			Total Spent	**-$1,506.99**
			Final Balance	**$393.01**

Appendix B: Project Costing for Travel

Expense	Description		Running Balance
Funds from the ECE department			$200.00
Funds from the Bagley College of Engineering			$9,040.00
Lodging	Dorm rooms		-$1,479.14
Meals	Per diem for 4 team members + advisor		-$1,250.00
Airfare			-$5,000.00
Shipping			-$500.00
Rental Car			-$850.00
		Total Funds	**$9,240.00**
		Total Spent	**-$9,079.14**
		Final Balance	**$160.86**