PURDUE
ENGINEERING

# 2015 Technical Documentation

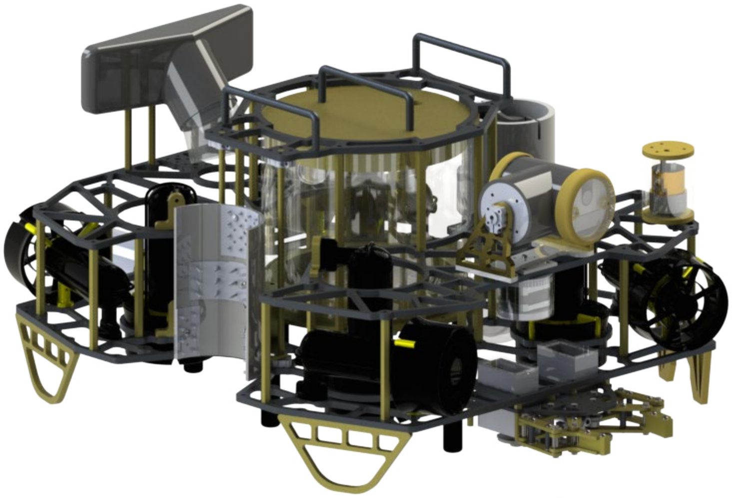
Competitive, Exploratory ROV Undertaking Leakage Examinations on Aquatic Networks

# International Big BlueBotix

## Purdue University

West Lafayette, IN USA

# ROV CERULEAN



## IBBB Team Members

Mentor-None

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| Joshua Berg | Mechanical Team (Lead) | Mechanical Engineering |
| Evan Widloski | Electrical Team (Lead) | Electrical Engineering |
| Matt Molo | Software Team (Lead) | Computer Science |
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# I. Introduction

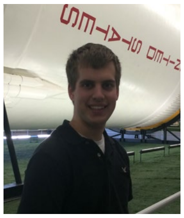
## Abstract

In the ever-advancing industrial world, mankind has been on a search for available crude oil. Recently, oil companies have begun drilling offshore in polar waters where vast oil fields have been found. This environment has left them in need of remotely operated vehicles (ROVs) that can collect scientific data on the surrounding area of a potential drill site, inspect and repair subsea pipelines, and even help establish new offshore oilfields.

International Big BlueBotix (IBBB) has designed and constructed ROV *Cerulean* to meet and exceed these needs. With the intention of keeping the ROV lightweight, stable, and reliable, ROV *Cerulean* has an aluminum framework with detachable mission-specific tools, eight thrusters, allowing for six degrees of freedom, and a specialized waterproof tube to house all electronic components enabling quick access for serviceability and troubleshooting.

All electronic hardware responsible for power management, vehicle movement, and sensor data collection have been designed and fabricated from the ground up. Coupled with the on-board BattleStation software designed and developed by IBBB, ROV *Cerulean* is well equipped to handle all tasks it is presented with.

The remainder of the document covers the design process and specification of International Big BlueBotix's ROV *Cerulean*. Also included are expense reports and a reflection on the design process.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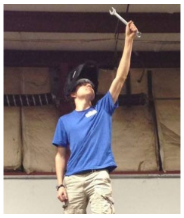
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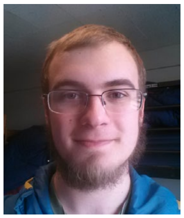
Dan Schillizzi
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Teal Dowd
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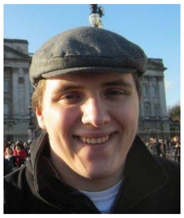
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Eric Colter
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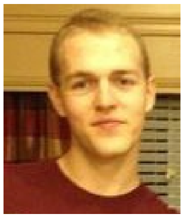
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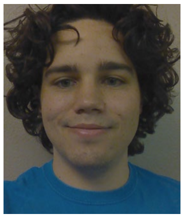
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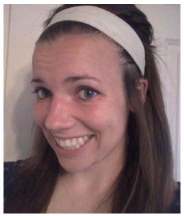
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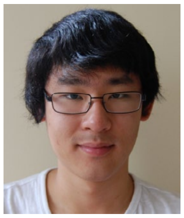
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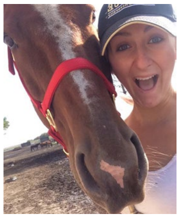
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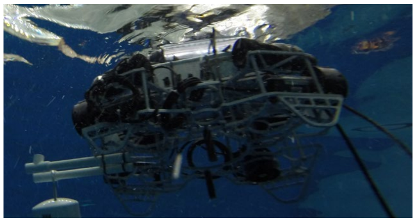
ROV Cerulean
Robotics
Freshman: 1st year competing
Remotely Operated Vehicle

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# II. Mechanical Design Rationale

## Overview

All mechanical aspects of ROV *Cerulean* were brainstormed and discussed before formal designs were made. Following the internal review process, all designs were converted to SolidWorks drawings. Stress analysis and other simulation data were used to fine-tune the CAD models. Team discussion stemming from integration challenges resulted in the final revisions.

## A. Frame

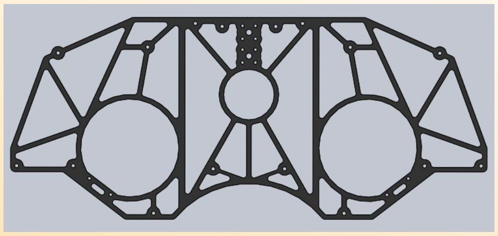


*Fig. 1 - Frame back plate*

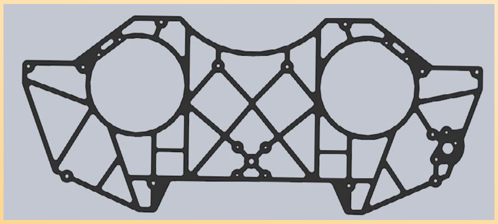


*Fig. 2 - Frame front plate*

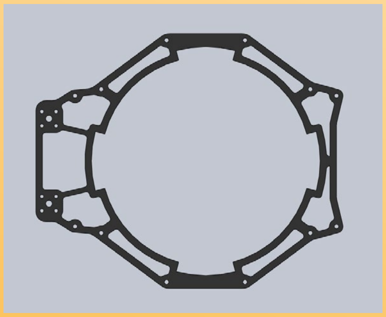


*Fig. 3 - Frame top plate*

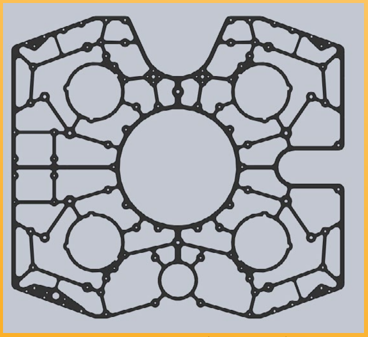


*Fig. 4 - Frame base plate*

ROV *Cerulean* consists of four aluminum plates *(fig. 1-4)* mounted to form three separate layers (*fig. 5*), designed to wrap around the centrally located electronics tube. The manipulator and the laser distance measurement tool are mounted to the bow to be used with every mission. All of the other mission-specific tools are mounted on the stern, starboard, and port sides of the ROV.

The base plate spans the entire bottom of the ROV. The four horizontal thrusters are mounted on the base plate at a 20-degree offset from normal to achieve the best balance between turn speed and forward thrust. This angle was determined by performing a thruster analysis at various angles until a desirable result was found. The vertical thrusters are placed at each corner of the vehicle. The use of four thrusters for movement along the z-axis not only gives the vehicle improved vertical thrust, but also allows for pitch and roll control. This gives the pilot greater maneuverability, an important requirement for the fixed manipulator. The middle plates protect the top of the horizontal thrusters and serve as a mounting point for the vertical thrusters. The top plate functions as a locking mechanism for the electronics tube end cap.

Each aluminum plate is made of .64 cm thick 6061-T6 Aluminum, allowing the frame to not only be strong but also remarkably light. A full aluminum plate itself would prove unnecessarily heavy and stronger than needed for a small ROV. The solution was to identify the major stress points in the plate when the ROV is under load and design the frame to minimize the stress using the smallest possible amount of material. This study was done in SolidWorks so that the plates may be manufactured using a water jet.

Cutting away unnecessary material in strategically placed locations maintained structural integrity while removing weight. In the end, a total of 3.2kg of material was removed from the base plate of the ROV itself. The cutouts reduce hydrodynamic drag both in the vertical and horizontal directions. This amount of material removal would be impossible with most plastics because they cannot handle the same degree of stress resulting in a flex or break. In running calculations on various plastic frames of the exact same dimensions, it was realized an identical plastic frame without the cutouts would all be more than 450 grams heavier.

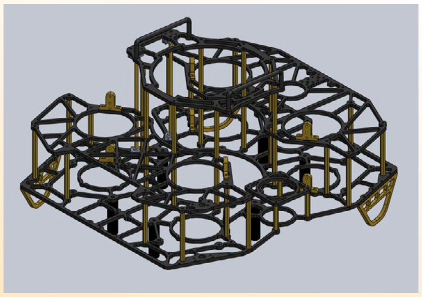


*Fig. 5 - Complete three layer frame*

## B. Electronics Enclosure

The electronics enclosure is a waterproof tube designed to house all electronics on ROV Cerulean *(fig. 6)*. A tube was chosen due to the fewer points of failure it has than a similarly sized box. Furthermore, having only one tube simplifies the ROV by keeping and managing all electrical components in the same place with the additional benefit of reducing cost by just manufacturing one tube instead of many smaller tubes. The enclosure also enables the team to quickly reach all the electronics at the same time if need be.

*Fig. 6- Electronics Enclosure with electronics inside*

The primary construction material consists of a polycarbonate tube, which is light, sturdy, and transparent. Both ends of the electronics tube are sealed with custom-manufactured aluminum end caps. The bottom end cap has specifically bored holes to allow mounting of the waterproof Binder USA connectors. Additionally, the top end cap includes two O-rings in order to provide redundant water protection of the electronics.

A design constraint of the tube design is to find the most efficient use of space. Many board orientations were considered in order to optimize space. Furthermore, most connectors were kept on one side of the tube for easy access.

## C. Buoyancy

$$\boxed{\text{Buoyant Force} = \text{Pressure} \times \text{Area}}$$

*Fig. 7- Buoyancy formula*

Buoyancy of ROV *Cerulean* is a primary concern. A neutrally or slightly negatively buoyant ROV is desired for optimal mobility. This allows easy ascending and descending in the water while allowing the ROV to hover at a constant depth when performing mission tasks. Additionally, the ROV tether is designed to be slightly positive in order to ensure it floats above the vehicle, well out of the way of mission

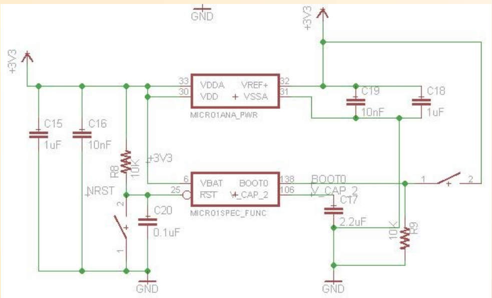


*Fig. 8 - Micro board schematic in EAGLE*

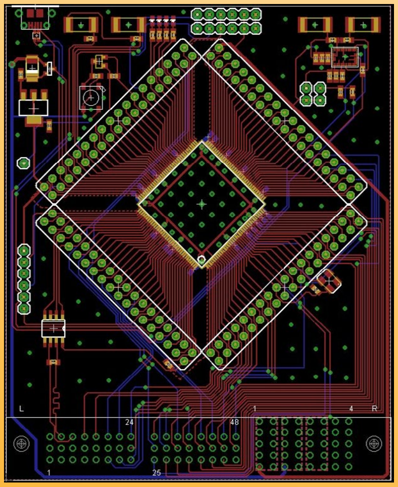


*Fig. 9- Micro board layout in EAGLE (power planes are supressed)*

objectives.

Buoyancy calculations were performed with the aid of SolidWorks *(fig. 7)*. Based on these results, extra mass was added to ensure appropriate buoyancy. Fine tuning adjustments (using washers as ballasts) are easily made between missions to compensate for the different buoyancies of the specific mission tools. Similar calculations were done on the tether and foam was added to make it slightly positively buoyant.

## III. Electronics Design Rationale

### Overview

All electrical designs were completed using CadSoft EAGLE for the creation of custom printed circuit boards (PCBs). These designed boards *(fig. 8 and 9)* were then sent to various print shops for fabrication. Finally, the team populated the boards with necessary electrical components and verified all functionality.

The ROV is driven by an Xbox controller, which is connected to the laptop via a USB cable. The laptop then passes signals to the top communication board using an Ethernet cable. Additionally, the 48V power supply is placed in series with a 40A fuse and the top communication board. The top communication board then passes both the power and command signals from the laptop through a single two-wire tether to the bottom communication board.

Surface to vehicle communication first passes through the bottom communication board where it separates the data from the power. The bottom communication board also interacts with the ROV's four cameras, providing them with data. The power and data streams are then passed to the appropriate boards.

The microcontroller board communicates with all the other boards, interprets data received from the bottom communication board, and controls the ROV. It also monitors all sensors, performs minor computations, and reports the ROV's status to the surface.

The power conversion board steps down 48V to four different needed voltages. However, due to the high current needed to run the thrusters, additional power bricks are used to step down the voltage from 48V to 24V.

The application board houses all of the mission specific hardware. It receives commands from the microcontroller board.

The motor distribution board provides fused power to each of the eight motor controllers and alerts the microcontroller board if a fuse is blown.

All of the above boards, except the top communication board and additional power bricks, are connected to the backplane. All board-to-board connections are made on the backplane and outside connections then run through the backplane to their desired area.

## A. Backplane

The backplane *(fig. 9)* is the center of the electronics system; it can best be compared to the motherboard of a computer. It replaces the disorder of wires that have both gotten in the way and confused the connections on previous IBBB ROVs. It provides the necessary power to each of the boards while also letting the boards communicate with each other. The few needed wires, from our waterproof connectors to the backplane, are all terminated in Molex branded connectors that are keyed and plugged-in to labeled receptacles. The backplane is also designed to be modular. Power conversion and computational needs are similar between all ROV designs. With minor revisions, the backplane design may be reused year after year.

## B. Communications Boards (Top and Bottom)

The ROV utilizes custom designed filters and the ASK transmission scheme to transmit video and data simultaneously down the ROV powerline. First, two commercial RF modulators frequency shift two video feeds to NTSC channel 3 (66MHz) and channel 4 (69MHz) and a NAND gate modulates the datastream at a frequency chosen to minimize harmonic interference with the video. These three signals are fed into a summing amplifier, injected into the ROV powerline, and transmitted to the surface. On the surface, the top communications board *(fig. 12)* decouples the signal from the powerline through a filter capacitor. The signal splits and passes through two different filtering circuits. The first circuit uses two Sallen-Key highpass filters to isolate the video signals and remove the data signal. The video can be viewed by tuning to channel 3 or 4 on the receiving TV. The second circuit

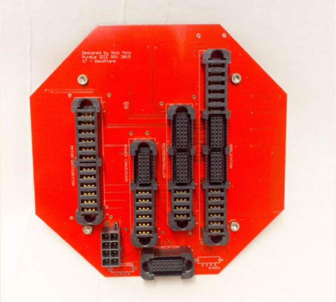


*Fig. 10 - Picture of ROV Cerulean Backboard*

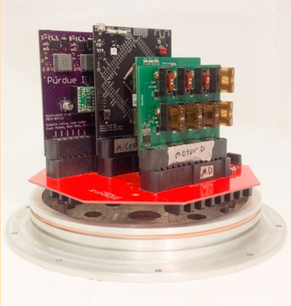


*Fig. 11 - Backboard with boards attached*

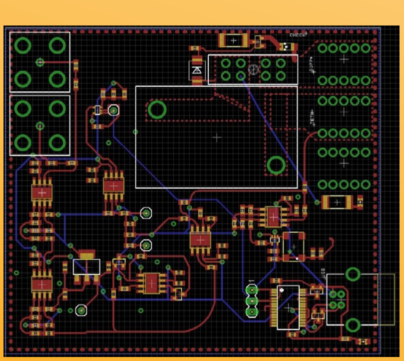


*Fig. 12 - EAGLE layout of top communications board*

demodulates the data so it is readable by the computer. The video signals need not be filtered out here because their amplitudes are very small (less than 50mV).

To transmit from the surface to the ROV, the same process is repeated but no video streams are transmitted. Since the transmission is half duplex, the data can only be sent in one direction at a time. However, this problem is mitigated by configuring the ROV in a master/slave model. The ROV only responds when spoken to.

Due to the complex nature of the bottom communication board *(fig. 13)*, a backup communication system has been devised which transmits the video and data all on separate wires. While this system is simpler, it requires more cabling and a thicker tether which increases drag.

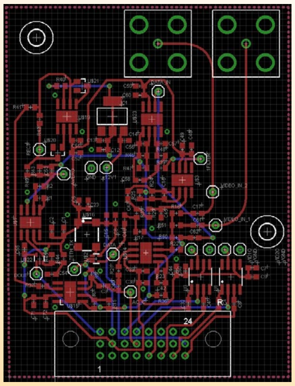


*Fig. 13 -EAGLE layout of bottom communication board*

## C. Power Conversion Board

The purpose of the power board *(fig. 14)* is to convert the input voltage to various other levels for use on different parts of the ROV as well as safely decouple the data from the powerline through an AC coupling capacitor and a high-current inductor.

The main ROV power passes through a current sensor IC so the total power draw of the ROV can be monitored remotely. A high-power buck regulator module steps 48V down to 12V, which is then converted to 5V and 3.3V via low-power linear regulators. Additionally, there is a 48V to 24V buck regulator which powers the Balluff Distance Measurement Tool. These regulators were chosen to minimize cost and maintain a tolerable factor of safety in heat dissipation.

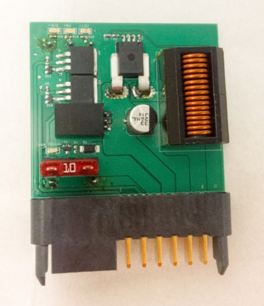


*Fig. 14 - Picture of ROV Cerulean Power Conversion Board*

## D. Microcontroller Board

The main control system on the ROV is located on the microcontroller board *(fig. 15)*. This board includes a STM32F4 ARM processor running at 168MHz, as well as a 9-axis inertial measurement unit (IMU). The ARM processor is the "brains" of the operations; every device on the ROV feeds a number of signals back into the processor giving the ability to monitor every part of the system. There are many advantages of using a custom system versus a commercial systems. Compared to an average Arduino, this processor is about ten times more powerful and allows for more computational complexity on the ROV. Additionally, a custom PCB means that any unnecessary peripherals can be eliminated, reducing board size and saving space

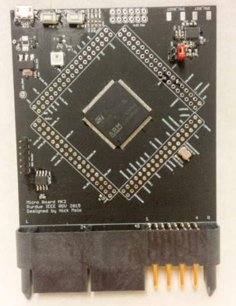


*Fig. 15 - Picture of ROV Cerulean Microcontroller Board*

in the ROV.

## E. Application Board

The application board *(fig. 16)* is designed to contain all mission specific hardware and has the most input and output channels of all boards. It holds the voltage probe circuitry, stepper drivers for the distance measurement tool, high power LED drivers, and motor controllers for the manipulator and valve turner. This board has various voltage and current protection mechanisms. For example, the voltage probe achieves voltage isolation up to 1 kilovolt through the use of an optocoupler array. Additionally, the stepper drivers and motor controllers are all current-monitored for collision detection.

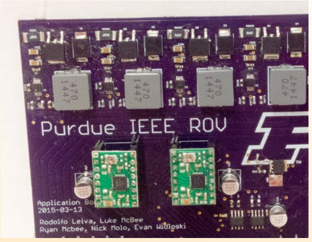


*Fig. 16 - Picture of ROV Cerulean Application Baord*

## F. Motor Distribution Board

The motor distribution board *(fig. 17)* provides power to all eight thrusters, and also allows for LED indication of blown fuses through a fuse-detection circuit. Along with this visual indication, the board also outputs a fuse detection signal, which is passed to the communication board and to the pilot on the BattleStation. Furthermore, the 48V output signal passes through the 24V converter bricks for the thrusters.

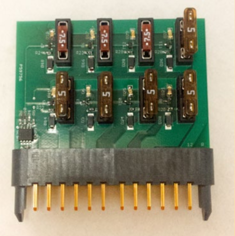


*Fig. 17 - Picture of ROV Cerulean Motor Distribution Board*

## G. Thrusters and Motor Controllers

ROV *Cerulean* makes use of eight SBT166 thrusters *(fig. 18)* manufactured by the SeaBotix Corporation, which can provide 2.2kg of thrust (2.8kg peak) and operate at depths of 500 feet. These thrusters have a sealed compartment for motor controllers that free space in the main electronics tube. While thrusters are reused from previous years to reduce cost, IBBB has designed custom motor controllers that offer several advantages over the stock units, including programmable operating limits, communication error detection, and automatic shutdown on loss of communication. The boards communicate with the bottom board via an RS-485 bus, which reduces the necessary I/O and provides noise immunity.

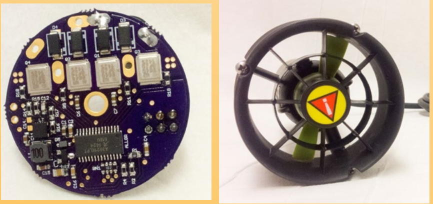


*Fig. 18 - Pictures of ROV Cerulean motor controller and thruster*

## H. Cameras and Lighting

The ROV uses a total of four analog, convex-lens cameras which provide a large viewing angle and are statically mounted in locations to allow the greatest sense of visibility and direction. The fourth camera is mounted on a two axis gimbal to allow for finer control

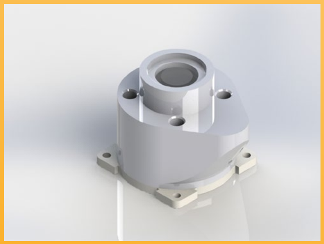


*Fig. 19 - Waterproof HDPE camera box*

and optimization for use with the laser distance measurement tool. The cameras are housed in custom waterproof HDPE boxes *(fig. 19)* designed to minimize total volume without obscuring the field of view. A grooved edge holds four high-power Cree XM-L2 LEDs *(fig. 20)* that provide visibility in low-light environments. Bandwidth limitations only allow streams from two cameras to be displayed at a time despite all four cameras being present on the ROV at all times. However, the user can select between which camera appears on NTSC channel 3 and channel 4.

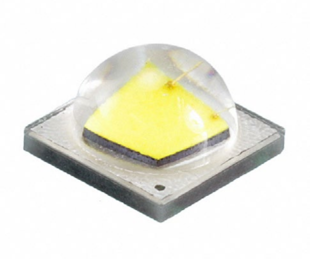


*Fig. 20 - Cree XM-L2 LED (source: Digikey.com)*

## IV. Misson Tools Design Rationale

### A. Manipulator

*Fig. 20 - Manipulator*

ROV *Cerulean* has one fixed manipulator *(fig. 20)* for simplicity thereby eliminating the need for extra cameras which would add weight, and off-vehicle-center mounting of the gripper, which is more challenging for the pilot. The ROV's thruster layout allows it to be able to pitch up and down instead of depending on a moving manipulator. Almost all of the objects in each mission are cylindrical or spherical in nature. Thus the claw was designed to wrap around the objects it grips. This is accomplished using mechanical linkages and multiple drive motors and gearing. The manipulator was made from 6061-T6 aluminum due to its strength and lightness.

### B. Distance Measurement Tool

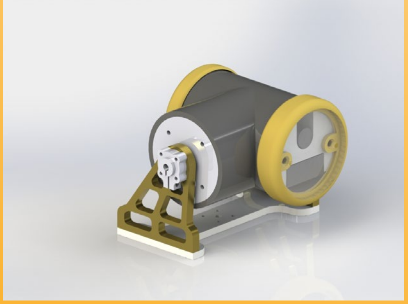


*Fig. 21 - Distance measurement tool (DMT)*

The basis of the distance measurement tool (DMT), shown in figure 21, is a laser and camera. The laser is calibrated for measuring distances in air to accuracy of better than one centimeter. After extensive testing in water, the laser was determined to have a linear relationship between the reported distance and actual distance in water. The software interface uses programmed constants to account for this discrepancy.

The tool measures the length of distant objects via the law of cosines. Assuming that the distance needed to be measure is length c, the DMT is able to measure distances a and b using the laser device, and the angle C using the stepper motor on which it is mounted. Using this information, the DMT can then calculate the length of the object that it is seeking to measure.

## C. Valve Turner

The valve turner design *(fig. 22)* is based off of simplicity and integration with other existing subcomponents. The design makes use of the preexisting space of a supporting foot on the ROV in order to be swappable for needed missions. A small, high-torque DC motor directly drives a shaft connected to the turning leg so that the rotational speeds of the motor and the turning leg match. No gearing was deemed necessary, since the motor has sufficient torque for the task.

The foot itself was based largely around the cross section of the pipe that it would have to turn. The foot extends down past the midway point of the cross section, and self-aligns to the valve so that it is able to have sufficient traction on the valve. Two slip pads attached near the base of the foot take the load from the valve off of the motor and instead place it directly on the frame. The motor can then turn the required amount of revolutions to open and close the valve.

## D. Flange Installer

The flange installer is composed of a metal cone mounted on the front of the tool to make alignment with the wellhead easy. The second part is the slider, which allows easy placement of the flange. See figure 23 for instructions on use.

## E. Voltage Measurement Tool

The voltage measurement tool as seen in figure 21, is designed to be as easy to use as possible. It consists of a grid of conductive springs mounted inside of a halved PVC tube. As the operator drives up against an object to be measured, the springs bend and deform around the voltage nodes without needing perfect alignment. This way, the operator can quickly and accurately measure three of the four voltages at once.

## F. Algae Collector and Pump

A bilge pump motor is used to move water through a length of tubing on the vehicle. A plastic vacuum cleaner nozzle *(fig. 25)* at the end of the hosing funnels algae samples through the pipe. Four standoffs keep the nozzle against the bottom of the ice sheet and above the

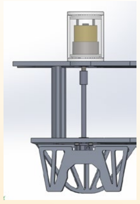
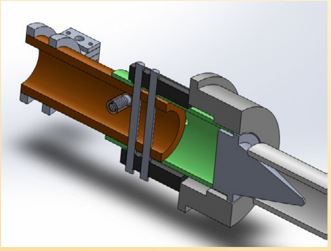
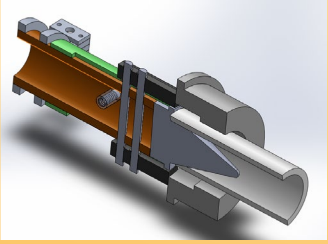


*Fig. 22- Valve Turner*

Step 1: Align on tube.



Step 2: Press the alignment cone forward onto the oil pipeline. The green tube will slide backwards depositing the flange onto the pipeline



Step 3: Back the ROV away from the pipline

*Fig. 23 - Flange installer use*

*Fig. 24 - Voltage measurement tool*

electronics tube. A mesh screen in the PVC fittings near the bilge pump at the end of the tubing safely collects the algae samples. The vertical orientation of the final segment of hosing traps the floating algae when the motor is off.

The bilge pump motor has been designed to work in other tasks as well. Reversing the motor and threading the tubing into a separate fitting permits it to push water. This allows the tool to be used to determine the pathways of flow through a pipeline system.

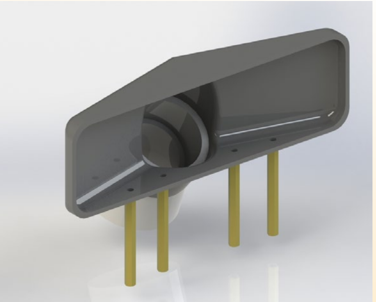


*Fig. 25 - Algae Collector*

## G. Lift Line Attachment and Gasket Hook

The lift line attachment mechanism (LLAM) requires no active control and operates mechanically performs entirely mechanically. The mechanism involved is similar to a bear trap (except safer); when the bear steps on the plate, the jaw standard is unlocked and the spring clamps the jaws shut *(fig. 26)*. Torsional springs allow for the clamping motion. Semicircular cut-outs on each of the clamping arms allow the pipe to be grabbed. The final part of the mechanism is a pin joint that has a catching section attached. When bowing outwards, the pin joint is caught and the clamping arms are left open. When the pipe is fed into the LLAM the pin joint is pushed inwards past the point of straight alignment allowing the mechanism to clamp fully.

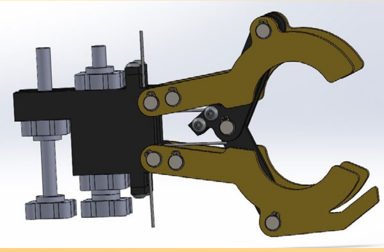


*Fig. 26- Lift line attachment mechanism*

Once the pipe is clamped, two shaft guides that secure the LLAM to the ROV also allow the mechanism to be pulled up manually using a rope. There is nothing constraining the mechanism from moving in the vertical axis along the two shaft guides, so the LLAM is free to be pulled upward. The final portion of the LLAM is a catch for one of the clamping arms for the gasket. As a result, the task of putting the gasket into the wellhead is performed before the corroded pipeline removal itself.

*Fig. 27 - Flow meter*
*Source: http://www.forestry-suppliers.com/product_pages/Products.*

## H. Flow Meter

The flow meter used is the MJP Student Stream Flowmeter from Geopacks *(fig. 27)*. The flowmeter works by using an impeller which is spun by the flow of the water. This impeller triggers a switch which causes a signal pulse in the digital reader. The digital reader measures the time between pulses to calculate the rotations per minute (rpm) of the impeller and displays this value on-screen. This value can be plugged in to the equation provided by the manufacturer of the flow meter:

$$\text{Speed (m/s)} = 0.000854 * C + 0.05,$$

where $C$ is the rpm displayed on the digital reader.

# V. Software Control

## A. BattleStation

The BattleStation is the main control of the ROV which is a desktop application written in C++ with Qt. The software logic is shown in the flow diagram of figure 33. It takes the input from the pilot and sends it over the tether for controlling the ROV. While the microcontroller on the ROV is powerful, the main logic of the system is in the BattleStation. Instead of sending raw data to the microcontroller, the BattleStation processes the joystick inputs, as well as many other settings and sends it over a tether in a custom packet. The custom packet *(fig. 28)* sends down all the states needed for each tool and device, so the microcontroller does not have to do these calculations. For the thrusters, the BattleStation calculates each value per thruster, which allows movement in all 6 degrees of freedom. For other tools, like the camera and lights, the BattleStation sends down states to ROV to tell them their position and light value. This flexibility with states keeps the system more configurable, allowing for on-the-fly changes.

Since the BattleStation sends down states for the ROV, a high data rate is needed. If only 1 instruction per second were sent down, the ROV would not be responsive. To help with this, a second thread in the main application was created. It takes the user input, converts it to the custom packet, and sends it to the ROV, at a 10 Hz rate. This makes the ROV control responsive to human users. The high data rate ensures that the packets have enough time to travel so they do not collide with each other (this is due to the tether and controller propagation delay). One protection used in the event of an error is a checksum. This takes all the data being sent, computes a unique value and sends it along at the end of the packet. The implication of the checksum is that a small change in the data causes a very large variation in the checksum. Because the probability of receiving corrupted data and a correct checksum is exceedingly small, the microcontroller can identify an incorrect packet and ignore it.

In addition to its computational and communication purposes,

| Byte # | Description |
|---|---|
| 00 | Header (0x12) |
| 01 | Motor 1 |
| 02 | Motor 2 |
| 03 | Motor 3 |
| 04 | Motor 4 |
| 05 | Motor 5 |
| 06 | Motor 6 |
| 07 | Motor 7 |
| 08 | Motor 8 |
| 09 | Foot turner |
| 10 | Tools 1 |
| 11 | Stepper Motors |
| 12 | LED 1 |
| 13 | LED 2 |
| 14 | LED 3 |
| 15 | LED 4 |
| 16 | LED 5 |
| 17 | RGB LED |
| 18 | CRCB Check |

*Fig. 28 - Packet from surface to ROV*

| Byte # | Description |
|---|---|
| 00 | Header Byte (0x12) |
| 01 | Vertical Stepper Angle |
| 02 | Vertical Stepper Angle |
| 03 | Horizontal Stepper Angle |
| 04 | Horizontal Stepper Angle |
| 05 | Fuse Detection |
| 06 | Motor Controller Faults |
| 07 | Motor Controller Faults |
| 08 | Laser Measurement tool |
| 09 | Laser Measurement tool |
| 10 | Miscellaneous tools |
| 11 | Checksum |
| 12 | Tail Byte (0x13) |

*Fig. 29 - Packet from ROV up to the surface*

| Bit # | Description |
|---|---|
| 00 | Cam Mux 1 |
| 01 | Cam Mux 2 |
| 02 | Bilge Pump Motor |
| 03 | Voltage Sensor |
| 04 | Laser Measurement Tool |
| 05 | Claw Input 1 |
| 06 | Claw Input 2 |
| 07 | Claw Input 3 |

*Fig. 31 - Bit description for tool byte*

| Bit # | Description |
|---|---|
| 00 | Horizontal Stepper Direction |
| 01 | Horizontal Step Amount 1 |
| 02 | Horizontal Step Amount 2 |
| 03 | Horizontal Step Amount 3 |
| 04 | Vertical Stepper Direction |
| 05 | Vertical Step Amount 1 |
| 06 | Vertical Step Amount 2 |
| 07 | Vertical Step Amount 3 |

*Fig. 32 - Bit description for stepper motor byte*

| Byte # | Description |
|---|---|
| 00 | Header Byte (0x12) |
| 01 | Motor Address |
| 02 | Command |
| 03 | Argument 1 |
| 04 | Argument 2 |
| 05 | Check Sum |
| 06 | End Byte (0x13) |

*Fig. 33 - Packet from ROV to motors*

the BattleStation helps the pilot and co-pilot visualize valuable information on the graphical user interface (GUI). For example, both users can identify problems based on values for distance, motor fault codes, and three-dimensional accelerometer data that originate from the microcontroller board *(fig. 29)*. Because humans process this information, a slow polling rate of once a second is permissible. The timer keeps track of how long the ROV has been in the water. The mission task list shows the task list for each mission, and allows the co-pilot to check off each task as it is accomplished. Additionally, the human operators can modify the configuration of the joysticks, serial communication link, and thrusters on the fly for increased customizability.

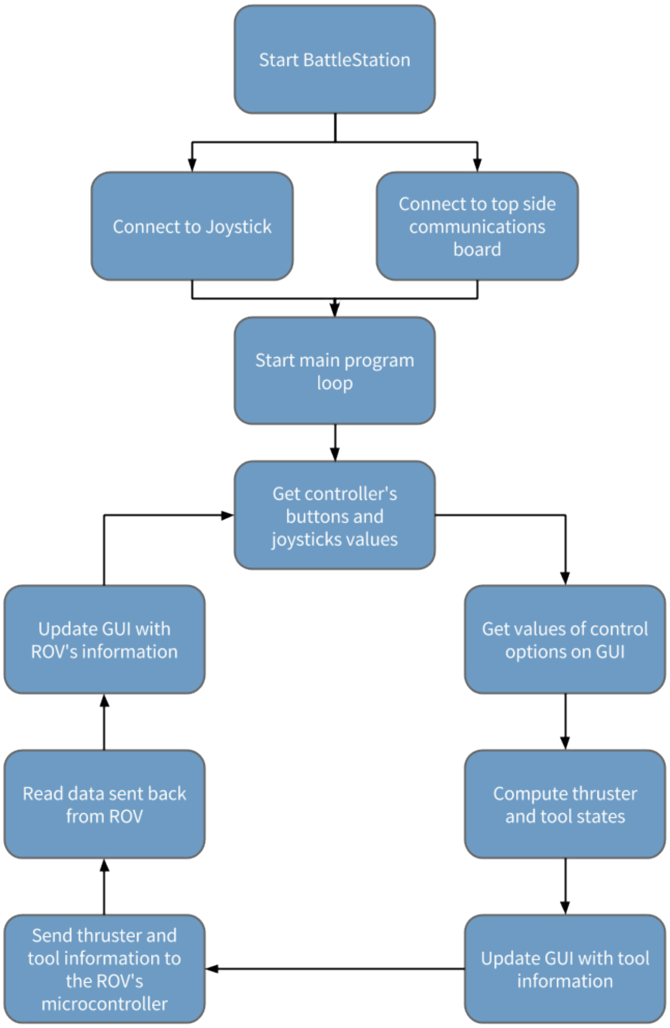


*Fig. 30 - Software Flowchart*

## B. Embedded Programming

An RS-232 interface is utilized between the surface and the ROV. Over RS-232, a custom protocol is implemented to best fit the vehicle design needs. There are two different protocols used: one for going from the surface down, and one for coming from the ROV up to the surface. Both protocols employ an error check algorithm called crc-8, cyclic redundancy check; by using this, any errors caused while the data was transferred were almost entirely eliminated.

The protocol from the surface down to the ROV contains all of the commands that the pilot needs to control and move the ROV. The ROV is also able to send data back up to the surface to give feedback to the persons controlling the ROV. The packet information is shown in figures 28,29,31, and 32.

The micro board communicates with the motor controllers using a 7-byte serial communication protocol *(fig. 33)*. This protocol contains the command to be run, two arguments for the command, and the address of the device the command is intended for. It contains a predetermined start, end byte, and a checksum just like the protocols mentioned earlier.

The micro board runs the majority of the code *(fig. 34)* when it receives a packet from the surface. After receiving a packet, the code applies the new data to controlling the different tools. The code then retrieves sensor data and fault checks and combines them into a packet that sent back up to the surface.

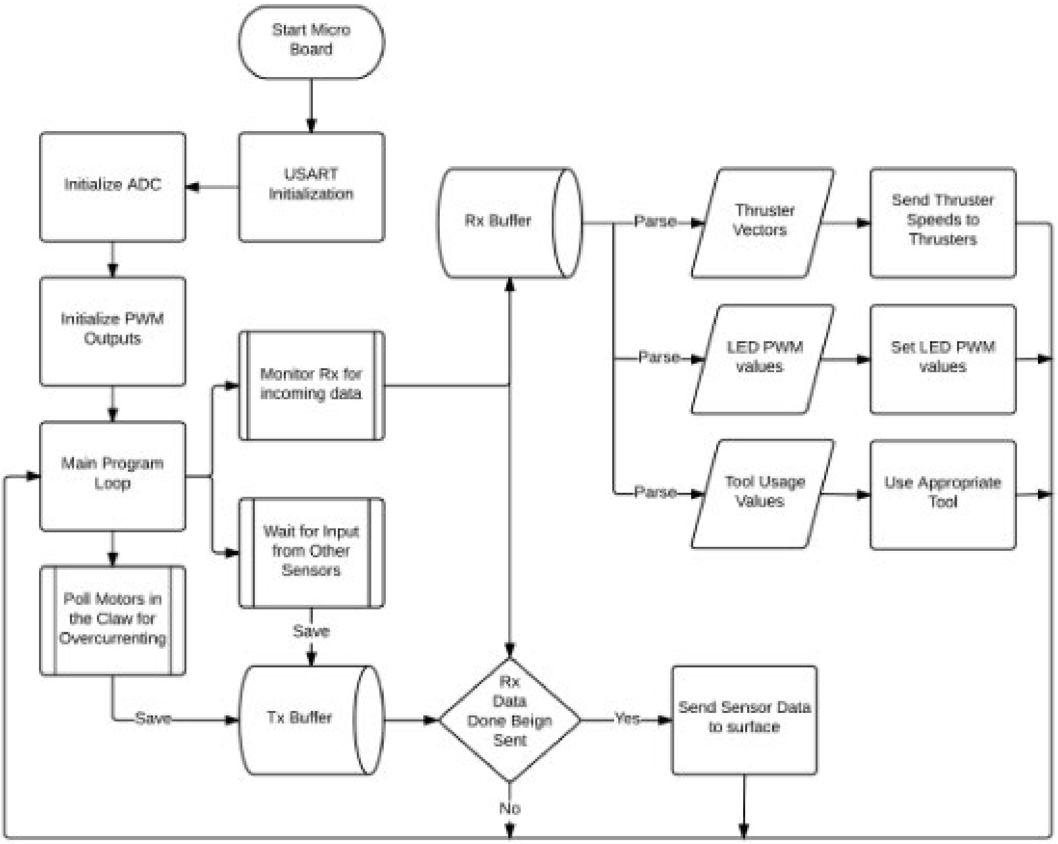


*Fig. 34 - Embedded Programming Flowchart*

# VI. Safety

## A. ROV Safety

IBBB is a company that takes pride in not only cutting edge developments, but also the level of safety precautions taken for its workers. The ROV makes use of both procedural and physical safety features which ensure the well being of its operators. For example, prior to powering the ROV on, the pilots must complete the "Safety Checklist" which is designed to mitigate human error during setup that could potentially damage the ROV or injure an operator (Refer to Appendix section B). During vehicle operation, a number of fuses throughout the system ensure a quick shutdown of malfunctioning tooling before serious damage can occur. Within the thrusters (which are one of the most dangerous parts of the ROV) a plastic grill prevents accidental insertion of fingers into the propeller and a software check shuts down the thruster in the event of loss of communication to the surface.

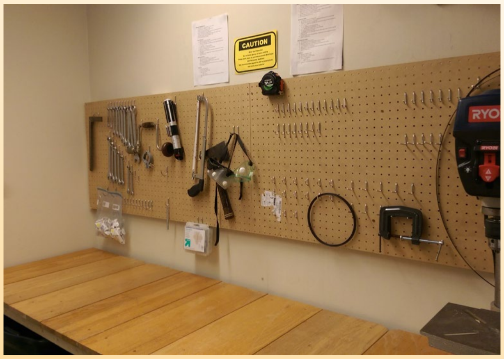
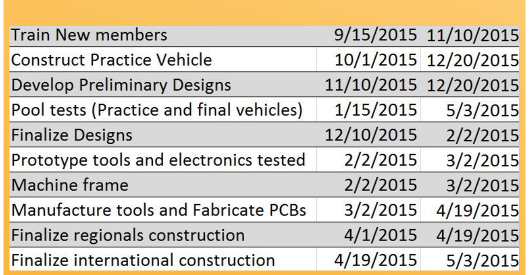


*Fig. 35 - IBBB Lab*

## B. Lab Safety

Many dangers are present away from the ROV and in the lab where the vehicle is built. IBBB has consulted with Purdue University staff on lab precautions to ensure the safety of technicians. Basic hand tool safety training is required before any person is allowed to work on the vehicle, and additional training is required for more powerful tools like the drill press and band saw. IBBB requires closed-toed shoes in the lab and ANSI-approved eye protection when operating power tools. Electrical technicians use an activated charcoal filter and are required to wash their hands after handling leaded products.



| | | |
|---|---|---|
| Train New members | 9/15/2015 | 11/10/2015 |
| Construct Practice Vehicle | 10/1/2015 | 12/20/2015 |
| Develop Preliminary Designs | 11/10/2015 | 12/20/2015 |
| Pool tests (Practice and final vehicles) | 1/15/2015 | 5/3/2015 |
| Finalize Designs | 12/10/2015 | 2/2/2015 |
| Prototype tools and electronics tested | 2/2/2015 | 3/2/2015 |
| Machine frame | 2/2/2015 | 3/2/2015 |
| Manufacture tools and Fabricate PCBs | 3/2/2015 | 4/19/2015 |
| Finalize regionals construction | 4/1/2015 | 4/19/2015 |
| Finalize international construction | 4/19/2015 | 5/3/2015 |

*Fig. 36 - IBBB Schedule*

# VII. Logsitics

## Company Structure and Schedule

IBBB is composed of three distinct teams to appropriately delegate the responsibilities of designing, manufacturing, and testing the ROV. The mechanical, electrical, and software team are all headed by individual team leads who report directly to the CEO. This facilitates a system where a common vision is shared between the teams while allowing necessary specialties to develop. In addition to the three primary teams, an administrative team helps the CEO with various responsibilities ranging from sponsorship coordination to technical report writing. Collaboration on the project was facilitated by, github.com for code and Dropbox for all other files. Additionally, email, Facebook, and GroupMe gave IBBB various and reliable forms of communication.

Every season IBBB introduces new members to the inner workings of the team. A schedule outline, shown in figure xx, was created at the beginning of the year; however, a more detailed and dynamic schedule was easily shared amongst the team and updated via Google Calendar. The team endeavored to build a prototype ROV before the mission specifications were released in order to allow practice building and driving a simple vehicle. After accomplishing this useful project, IBBB was able to utilize their new and refined skills in the development of ROV *Cerulean*. Fortunately, the creation of a prototype ROV enabled continued pool practice while ROV *Cerulean* was continuously refined.

# VIII. Conclusions

## A. Challenges and Troubleshooting Techniques

In building such a technically advanced vehicle, the team encountered many different challenges. One of the primary challenges was the design and construction of custom motor controllers. Custom motor controller design was required due to the inability of the SeaBotix motor controllers to adequately meet their listed specifications of running on 48V. The team quickly researched and constructed their own H-bridge with supporting circuitry to replace the old motor controllers. However, due to the complexity of the design, a variety of iterations were required as new problems surfaced. While troubleshooting we verified that many ICs did not properly adhere to their listed maximum voltage ratings.

The team employed a variety of troubleshooting techniques to address the problems. The main technique was to iterate and improve the motor controllers. Each version, the team was closer to a successful controller. Additionally, contact was made with professors and team veterans who were familiar with high voltage and current motor control designs. Finally, the controllers were run off of a lower voltage and ramped up to find their upper operating limit. This test resulted in the ultimate decision to utilize DC converter bricks on the final ROV to limit the motor controllers to 24V. While not as powerful as the desired 48V, being able to design, troubleshoot, and fix custom motor controllers, was a valuable experience for the team. What was learned will be used in the future to further improve this and future designs.

## B. Lessons Learned and Skills Gained

As a team composed mostly of underclassmen, there was a significant lack of knowledge at the beginning of the season. Fortunately through the hard work of several dedicated individuals, the team was able to learn what was necessary and finish the vehicle. One of the main lessons learned from this experience is the importance of formal training. While learning through problem solving is certainly a necessary skill, working with veteran members who have experienced similar problems can provide valuable insight while also saving time. Therefore, next season, the team plans to more fully invest in training new members along with retraining old members. While this takes up time that could instead be used on the ROV, it will save time in the long run by reducing the number of mistakes on the final project. The team eagerly awaits teaching new members what they have already learned.

In addition to the technical skills learned, a variety of non-technical lessons were acquired. One of these lessons was how to properly communicate with companies after IBBB submitted their design to a machine shop for manufacturing. Unfortunately, the shop was missing some paperwork and never notified the team. By failing to follow up with the shop, the manufacturing of the electronics tube was delayed. This delay prevented the full design of ROV *Cerulean* being finished before regionals. Fortunately, the team learned to always follow up with companies. By being in constant communication, problems will be mitigated in the future. Additionally, in order to maintain tighter control of the manufacturing process, the team plans to limit their reliance on large orders being done by external companies.

## C. Future Improvements

This year was a fresh start for the IBBB and our new team faced a lot of problems; some we managed to fix, others were beyond our grasp. The biggest improvement to be made is in experience. With a new and young team all the skills needed to design an ROV had to be taught: circuit design, PCB layout, CAD, manufacturing techniques, proper tool usage, time management, and all the tips and tricks the few senior members had to share. With every new revision or prototype, mistakes will be made, but we'll never stop learning from them.

On the ROV itself there are many things we wished to achieve but for one reason or another failed to accomplish. Our motor controller design was planned to run of the given power supply, but due to our chosen ICs tolerances we saw many failures. Multiple revisions were made trying to fix our issues, but we realized too late that our chosen IC would not work for us. To mitigate that we're instead using bulky DC/DC converter bricks to step down the voltages. This is the first thing on our list to fix for next year. Additionally, we are planning on moving to a digital camera system, rather than an analog one. This change will give us increased visual acuity to help better preform the mission tasks. Our custom built two-wire tether system will be improved to support the new cameras with higher bandwidth for data transmission.

On the mechanical side of things we faced many hardships during manufacturing that we did manage to overcome, but even so, knowing what to expect will help us produce an even better ROV. One of the biggest mechanical issues we face is sealing moving parts. Fortunately, we have a custom designed magnetic coupling system in the works which will solve many of these issues.

## D. Individual Reflections

I have learned how to lead a diverse team of strongly opinionated students to a common goal. Additionally, I learned the importance of understanding individual components of a system and how they fit into the larger picture. Overall, it has been a very rewarding year.
-Kyle Rakos (Team Captain)

I thought that this year was exciting. As a new member, I enjoyed the process of starting from almost nothing and creating a working robot. There were problems along the way, but I think that I learned more from the problems than I did from our successes.
-Luke McBee (Electrical Team – Hardware Programming Co-Lead)

It has been amazing to come in not knowing much about electronics and leaving with more than enough skills to build anything I want to now. I now know a little bit of each area of programming and designing electronics and am ready to keep honing those skills over the next three years.
-Ryan McBee (Electrical Team – Hardware Programming Co-Lead)

This year was a challenge that both educated and entertained. Coming in as a freshman who did not know much about circuits, I was able to learn a lot from being on the team. Not only that but I made some great friends while I was at it!
-Sam Deghuee (Electrical Team – Analog Team Lead)

The experience I have acquired through IEEE ROV has been beneficial not only to my academic experience but my professional experience as well. ROV has allowed me to use my knowledge to build a robot and also gain new knowledge in mechanics and other aspects of engineering. The year has been entertaining as well as productive. ROV has been one of my favorite parts of my college experience so far.
-Sanay Shah (Mechanical Team)

# IX. Appendix

## A. Planned Budget

| Expense Description | | Cost Est. |
|---|---|---|
| **Expenses** | | |
| **Mechanical** | Prototyping | $650 |
| | ROV Frame and Tool Machining | $5,000 |
| | Materials & Fasteners | $1,500 |
| | Tools | $1,000 |
| | Practice Mission Area Replica | $300 |
| **Construction Total** | | $8,450 |
| **Electronics** | Prototyping | $600 |
| | Computer for BattleStation | $700 |
| | Board Printing & Internal Components | $1,500 |
| | Piloting Station & Tether | $250 |
| **Electronics Total** | | $3,050 |
| **Competition Costs** | Lodging | $3,000 |
| | Travel | $7,000 |
| | Printing, Team Apparel, Team Activities, etc. | $1,500 |
| **Competition Total** | | $11,500 |
| **Total Expenses** | | $23,000 |

## B. Project Costing

| Item | Expense | Donations | Income |
|---|---|---|---|
| | Cost (USD) | Cost (USD) | Monetary |
| **ROV Construction** | | | |
| Motor Controllers Design and Construction | $849.99 | | |
| Motors | $96.32 | | |
| Miscelenous Electrical Components | $1,100.00 | $100.00 | |
| Microcontroller Components | $251.28 | | |
| DC to DC Converters and LEDs | $251.67 | | |
| Miscelanous Mechanical Components | $1340.55 | | |
| Binders | $402.98 | $413.06 | |
| Printed Circuit Boards (PCBs) | $806.34 | $396.00 | |
| Tether | $203.63 | | |
| Machining | $2,650.00 | $300.00 | |
| Laser Measurement Tool | | $900.00 | |
| **Other/Travel** | | | |
| Flights | $7,000.00 | | |
| Rental Car | $380.00 | | |
| Meeting Expenses | $552.33 | $50.00 | |
| Laptop for BattleStation | $694.43 | | |
| Lab Supplies | $772.80 | | |
| Team Shirts | $908.43 | | |
| Competition Lodging | $1,626.21 | | |
| Registration Fee | $150.00 | | |
| Mission Props | $239.85 | | |
| Regional Travel | $99.00 | | |
| **Donations** | | | |
| Michael Hayashi | | | $99.73 |
| Eastman Chemical | | | $100.00 |
| IEEE Student Branch | | | $234.72 |
| Kleppinger Family | | | $1,000.00 |
| IEEE-CIS | | | $600.00 |
| Bechtel | | | $600.00 |
| Black and Veatch | | | $1,000.00 |
| PESC Merit Fund | | | $3,833.34 |
| College of Engineering | | | $2,500.00 |
| Provost Matching Funds | | | $5,000.00 |
| Sales | | | $432.00 |
| Initial Funds from 2014 Team | | | $11,418.05 |
| **Reuse (Current market/resale value)** | | | |
| Seabotics Thrusters | $4,000.00 | | |
| DC to DC Converter Bricks | $700.00 | | |
| **Summary** | | | |
| ROV Construction | $7,952.76 | $2109.06 | |
| Other/Travel | $12,432.05 | $50.00 | |
| Donations | | | $26,942.56 |
| Reuse | $4,700 | | |
| Next Year Investment | $6,566.75 | | |
| Total | $31,642.56 | $2,159.06 | $26,942.56 |
| Funds Remaining | $0.00 | | |

## C. Safety Checklist

**Pre-Power**

- ☐ Clear the area of any obstructions
- ☐ Set up and connect camera monitors to laptop
- ☐ Verify power supply is “OFF”
- ☐ Connect tether to ROV
- ☐ Connect Ethernet adaptor of tether to Top Comunications Board
- ☐ Connect Anderson connectors of tether to power supply
- Check over ROV
    - ☐ Check electronics tube seal
    - ☐ Check manipulator and other payload tools

**Power Up**

- ☐ Pilot boots up laptop and starts BattleStation
- ☐ Captain calls team to attention
- ☐ Co-pilot calls out, “Power on,” and moves power supply switch to “ON”
- ☐ ROV deployment members verify ROV electronic status lights
- ☐ ROV enters water under control of deployment members
- ☐ Deployment members check for signs of leaks (e.g. bubbles)
    - o If leaks occur, go to Failed Bubble Check
    - o Otherwise, continue Power Up sequence
- ☐ Deployment members ensure that ROV remains stationary in water
    - o ROV is neutrally buoyant
    - o ROV is balanced in all directions
- ☐ ROV deployment members release any air pockets and shout “ROV ready”
- ☐ Pilot starts thruster test
- ☐ Deployment members adjust cameras to achieve desired viewing angles
- ☐ Continue to Launch procedures if no issues arise

**Failed Bubble Check**

- ☐ If many bubbles spotted during mission, the pilot quickly surfaces the vehicle
- ☐ Co-pilot turns power supply off and calls out, “Power off”
- ☐ Deployment members retrieve ROV
- ☐ Inspect ROV and troubleshoot
- ☐ If time remains after problems addressed, the return to Power Up sequence

**Launch**

- ☐ Pilot calls for launch of the ROV and starts timer
- ☐ ROV deployment members let go of ROV and shout, “ROV released”
- ☐ Mission tasks begin
- ☐ Go to Failed Bubble Check or Lost Communication if either problem occurs during the mission
- ☐ Continue to ROV Retrieval if mission completed

**Lost Communication**

Steps attempted in order. Mission resumes when one succeeds.

- ☐ Co-pilot checks Top Communications Board for serial packets sent
- ☐ Co-pilot checks tether and laptop connections on the surface
- ☐ Pilot attempts to reset the BattleStation
- ☐ Co-pilot cycles the power supply
- ☐ If nothing succeeds, the mission stops
    - o Co-pilot turns power supply off and calls out, “Power off”
    - o Deployment team pulls ROV to surface

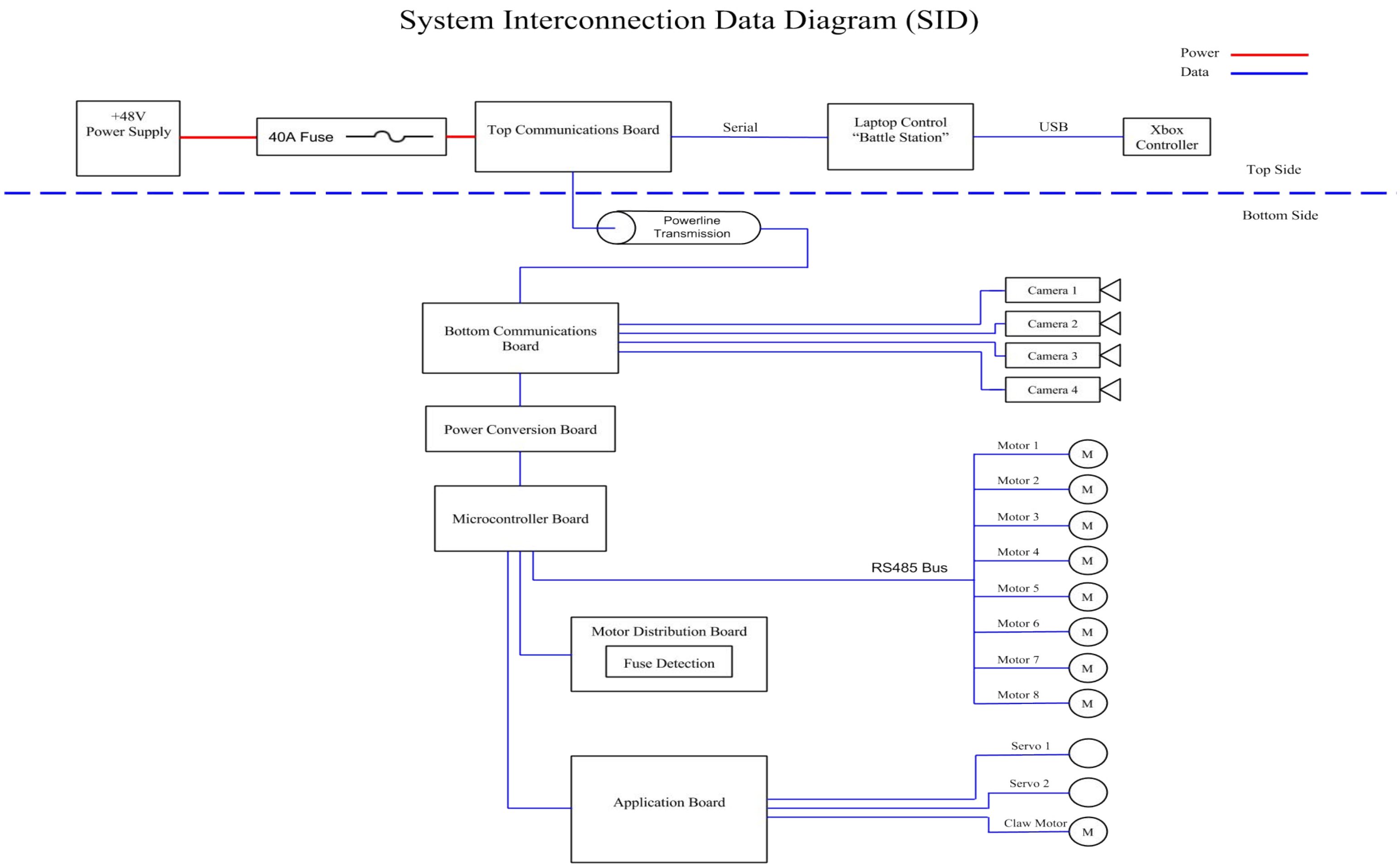
**ROV Retrieval**

- ☐ Pilot informs deployment members that ROV needs retrieval
- ☐ An ROV deployment member’s arms enter the water up to the elbows
- ☐ The ROV deployment member pulls the ROV up from water after making contact
- ☐ Deployment team yells, “ROV retrieved”
- ☐ Pilot stops timer

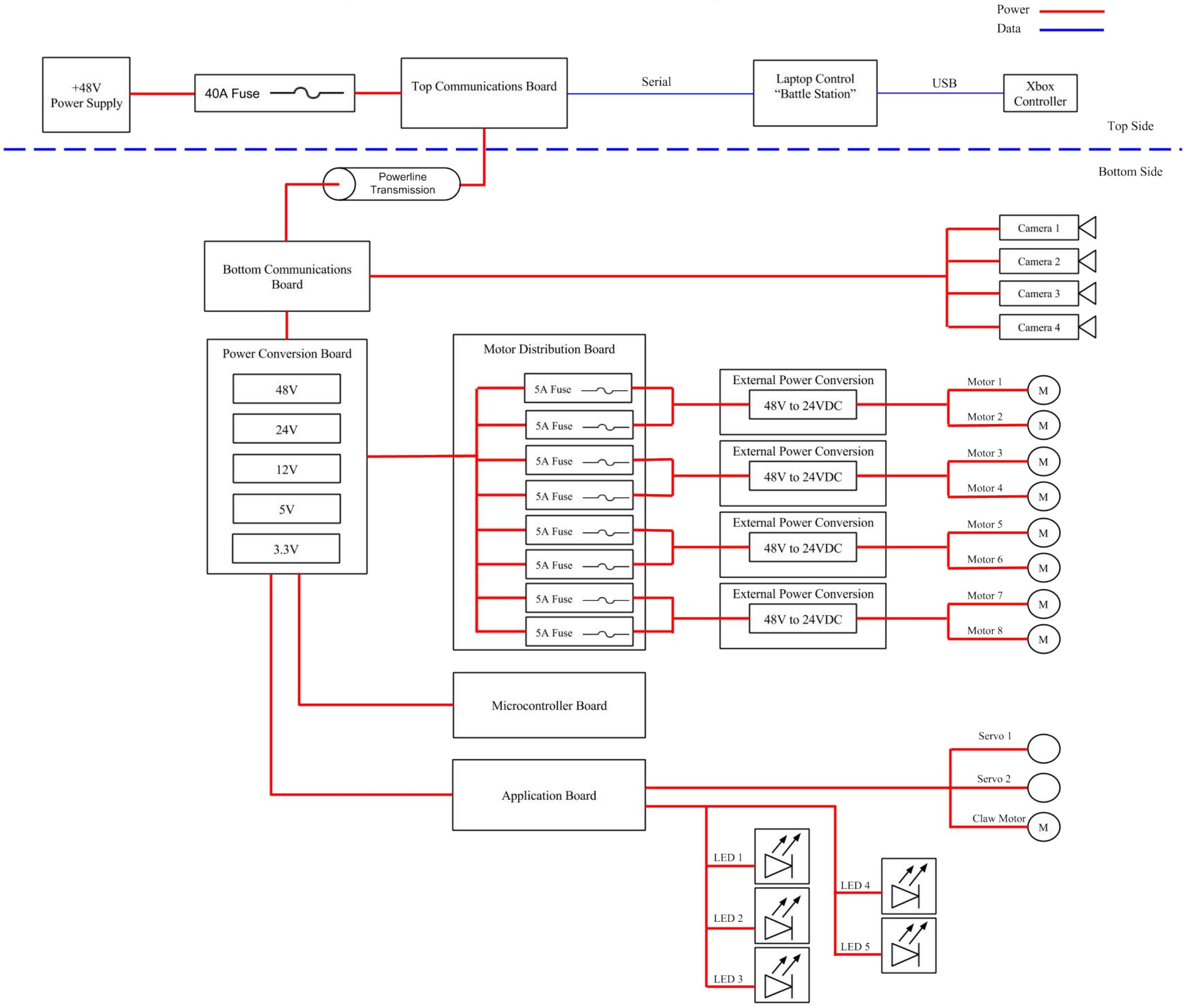
**Demobilization**

- ☐ Co-pilot turns power supply off and calls out, “Power off”
- ☐ Deployment members do a quick visual inspection for leaks or damage on ROV
- ☐ Pilot stops BattleStation and powers off laptop
- ☐ Anderson connectors of tether are removed from power supply
- ☐ Camera monitors are taken down
- ☐ Team vacates the area

## D. System Interconnection Diagram



System Interconnection Power Diagram (SID)



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