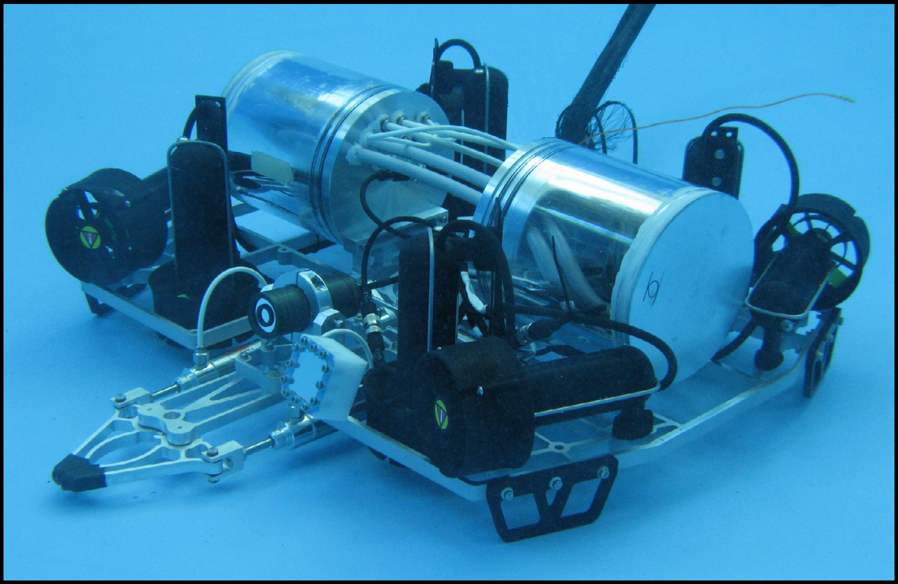
APERTURE
AQUATICS

Purdue University
IEEE ROV Team
West Lafayette, IN

Technical Report: ROV Hybris



Team Members
Mentor-None

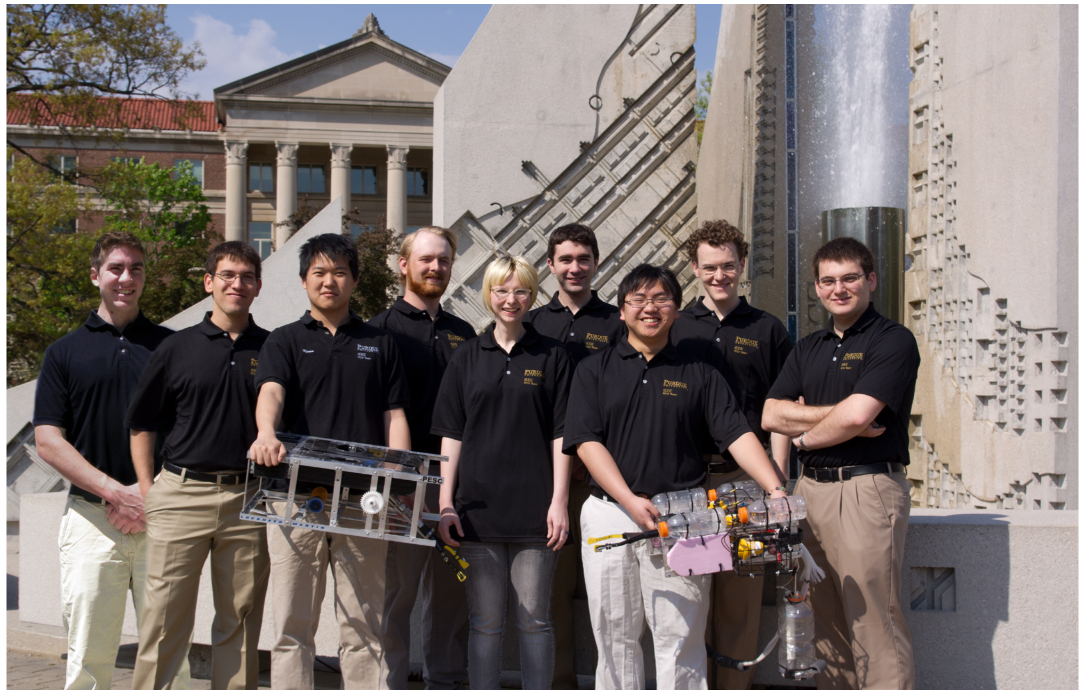
Name	**Position**	**Major**
Seth Baklor	Team Captain	Industrial Engineering
Lawrence Goldstein	Structure and Frame	Mechanical Engineering
Clayton Kleppinger	Electronics	Electrical Engineering
Robert Swanson	Electronics	Electrical Engineering
Clement Lan	Software	Computer Engineering
Kuan-Po Chen	Electronics	Electrical Engineering
Jack McCormack	Structure and Frame	Mechanical Engineering
Danielle Clifford	Technical Writer	Professional Writing
Jason Gary	Graphics	Computer Graphics Technology

Abstract

Aperture Aquatics has designed and constructed ROV *Hybris* to accomplish the tasks set forth by the 2011 MATE International ROV Competition. This includes deploying a custom-designed oil cap, collecting biological samples, and collecting a water sample at a specified depth. At 62 cm long, 58 cm wide, and 21 cm tall, ROV *Hybris* is capable of performing these tasks in a single dive.

Designed with reliability, speed, and dexterity in mind, ROV *Hybris* is capable of maneuvering with six degrees of freedom. It has four thrusters for horizontal movement and four thrusters for vertical movement. The payload tools have been designed specifically for the mission and include a main gripper, oil cap deployment mechanism, and fluid sample collection system. All of the electronic hardware, responsible for power management, vehicle movement, and sensor data collection, has been designed and fabricated from the ground up. The on-board and base station software was designed and developed by the company. Although it was a significant challenge to custom design electronic hardware, ROV *Hybris* is fully functional.

The remainder of this document covers the design process and specifications of Aperture Aquatics' ROV *Hybris*. Also included are an expense report and a reflection on the issues that arose in the design process.



Team members with vehicles from previous years

Table of Contents

Mission Summary

Task 1: Remove the Damaged Riser Pipe

ROV Hybris begins the mission with a carabiner clip held in its grippers. The carabiner clip has a rope tied to it which is held by team member at the surface. The vehicle attaches the carabiner to the U-bolt on the damaged riser pipe and releases it. Then the vehicle grips the PVC ring that simulates cutting the riser pipe and removes it by moving backwards. Immediately after the ring is removed, the rope attached to the U-bolt is pulled by the team member holding it until the pipe is removed from the mission area.

Task 2: Cap the Oil Well

The vehicle begins the mission with the oil cap attached in the center. After completing task 1, the vehicle lines up the cap with the wellhead using the down-facing camera. Using the vertical thrusters, the vehicle lowers the cap over the wellhead until the lower clips latch over the bottom of the PVC coupling. Then the oil cap motor lowers the rubberized stopper into the wellhead until fully capped. During this process, the rear-facing camera is used to monitor the process and assure a proper seal. Then the vehicle releases the cap by retracting the pins that hold it in place via a pneumatic piston. The capping procedure is complete and the vehicle raises vertically until the cap is no longer in the center of the vehicle.

Task 3: Collect Water Samples and Measure Depth

ROV Hybris displays depth on the computer screen at all times. The pilot uses this display to identify the correct bucket sample. Once identified, the rotating sample tube is deployed to the straight down position. Using the down-facing camera, the pilot lowers the sample tube into the sample bucket. The sample pump is actuated once to clear the system of ambient water, then again to collect the actual sample. The pilot then removes the sample tube and retracts it back into the frame. This sample is on board the vehicle in the rear sample storage tube until the end of the mission.

Task 4: Collect Biological Samples

At the beginning of the mission, the basket is hanging over the manipulator but not held in it. This is because the carabiner clip is already being held. Because the vehicle is moving forwards towards the mission area, the basket does not fall off the vehicle prematurely. Once near the mission area (approximately two meters above it), the vehicle executes a sharp reverse maneuver to drop the basket. After completing tasks 1 through 3, the vehicle collects each biological sample individually using the grippers and delivers them to the basket. Once all three samples are in the basket, the ROV grabs the basket in the grippers and returns to the surface.

All four tasks are expected to be completed within five minutes.

Design Rationale

Shape and Frame

Much consideration went in to the positioning of everything being attached to the frame. The first decision was to place the oil cap in the center of the vehicle for the greatest control and strength during deployment. The thrusters were located as far out as possible for the greatest available leverage for roll and pitch. Locating the electronics tube was most challenging with the oil cap located in the center of the vehicle. This led to two separate tubes on either side of the oil cap. A fixed manipulator was placed low in the front of the vehicle for accomplishing a wide variety of tasks. Finally, a rotating fluid sample tube was placed between the oil cap and manipulator to make it as close to the center of the vehicle as possible to ease the mating procedure with the fluid sample port. This fluid is then pumped to a storage tank near the back of the vehicle, behind the oil cap.

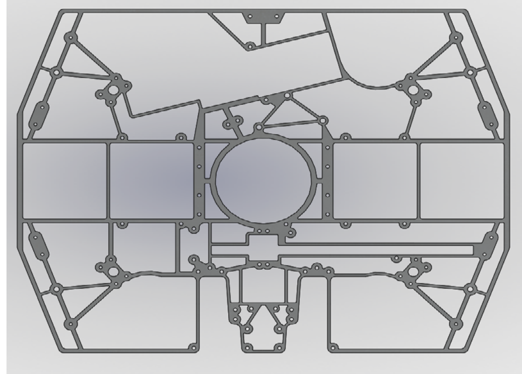


Fig. 1 - A two dimensional image of ROV Hybris' *aluminum frame*

The frame of ROV *Hybris* (Figure 1) was cut by a water jet from a single piece of .635cm thick aluminum. This material was chosen because of its strength and lightness. The shape of the frame was designed in Solidworks only after the design of every item being attached to it was finalized. Because of this, each tool is designed based on purpose instead of designed to fit in a vehicle we already made. The Purdue IEEE ROV team did not have the tools necessary to cut such a complex piece, but Janicki Industries kindly donated the use of their waterjet.

To protect against corrosion, every stainless steel bolt that goes through the frame is covered in Tef-Gel Fastener Lubricant. The head

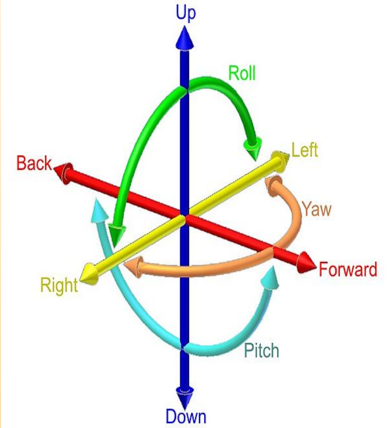


Fig. 2 - A visual representation of six axis movement.
(Image courtesy Wikipedia.org)

of the bolt is also spaced away from the frame by a washer. To protect the bottom of the frame from the ground, it is raised with four delrin feet only a few cm above the ground. These small feet have been found to be strong enough to easily hold up a team member, as shown in Figure 3 below.

Fig. 3 - A team member standing on four delrin standoffs.

Thrusters

In deciding which thrusters to use on ROV Hybris, two options were considered. Custom thrusters designed and used on Purdue's 2010 ROV were considered, but the higher risk and turnaround time outweighed any potential benefits the company would gain. As a result, the company made the decision to use eight Seabotix BTD-150 thrusters (Figure 4). Each thruster is 17 cm long and produces 28.4 N of thrust.

The four horizontal thrusters are placed at a 20 degree offset to achieve the best balance between turn speed and forward thrust. 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. Pitch and roll control gives the pilot greater maneuverability during the capping process and fixed manipulator use.

The output of each of the thrusters is determined by the base station software's thruster mixing algorithm, and is discussed in the software section of this report.

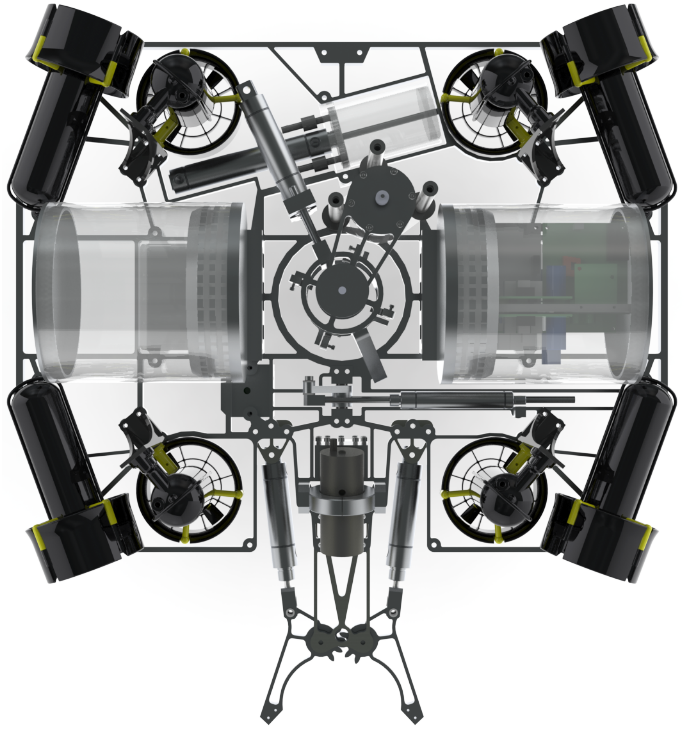


Fig. 4 -A top-down render illustrating Hybris' motor placement.

Cameras

There are three cameras on-board ROV *Hybris*: the front/manipulator camera, the rear facing camera, and the down facing camera (Figure 5). All three cameras are located around the same point on the ROV to reduce any pilot confusion when switching cameras. Each camera is positioned to provide vision to all of the vehicle's tools. The system on the ROV can transmit two of the three cameras at any given moment, with the front facing camera constant and the remaining two cameras switched on the Xbox360 controller. The front facing camera is an LCA 7700 series camera, chosen for its video quality and focus at a large variety of distances. The other cameras are Super Circuits Wide Angle Board Cameras in custom waterproof enclosures. These cameras were chosen for their low weight, small size, and wide viewing angle.

Buoyancy

ROV *Hybris* has many waterproof enclosures that will provide a significant amount of buoyancy on their own. The two large central

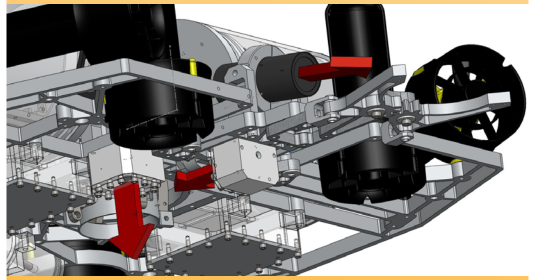


Fig. 5 - A render indicating the direction each camera faces.

tubes provide approximately 4kg of positive buoyancy. With all parts assembled, the ROV will still sink slightly. To address this problem, a small amount of hydrostatic proof foam is cut to fit in the crevices of ROV *Hybris* and painted for a proper seal and finish.This step will take place two weeks prior to traveling to the international competition to ensure that all modifications that might need to be made can be completed beforehand. Until the foam is attached, drink bottles are used as temporary buoyancy (but removed for photos in this report to allow for easier visualization of the final product). These buoyancy methods are intended to make *Hybris* positively buoyant. To finely tune the ROV, stainless steel washers are added or taken away from stainless steel bolts on each corner until the vehicle is balanced.

Tether buoyancy is acheived by including a .635cm by .635cm strip of stiff home insulation foam throughout the length of the 30m tether. This strip is installed inside the tether wrapping. The size of the strip was calculated based on the sum of the in-water weight of the tether. Home insulation foam was chosen because it is known through earlier experiments to work to at least 6m without signs of compression. Although it crushes slightly at the competition's 12m depth, the compression should not be significant enough to hurt the vehicle's performance.

Manipulator

The design of ROV *Hybris* has only one manipulator for simplicity. Having multiple manipulators tends to lead to extra cameras, extra weight, and off-vehicle-center mounting of the gripper, which is more challenging for the pilot. *Hybris*' manipulator (Figure 6) is used for collecting the three biological specimens in the mission, attaching a line to the well riser, and removing a ring on the riser, which simulates cutting the riser pipe. The most concerning of these tasks is collecting sea cucumbers, simulated by water wiggles, which are known for their difficulty to grasp. Experimentation showed that a gripper with high friction and low contact surface area would be best. The larger size of the crabs meant that the grippers would also need a section with a wider throat. To create higher friction and ensure that there are no sharp edges at the gripping point, the tip of the manipulator is wrapped in special heat shrink that gives a rubberized texture.

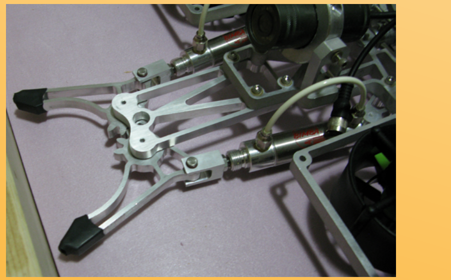


*Fig. 6 - *Hybris*' manipulator in the open position.*

The manipulator system was made from aluminum due to its strength and lightness. It is powered by dual pneumatic pistons. Electric drive was considered, but ruled out since pneumatic systems are often stronger, more reliable, faster acting, and more space efficient.

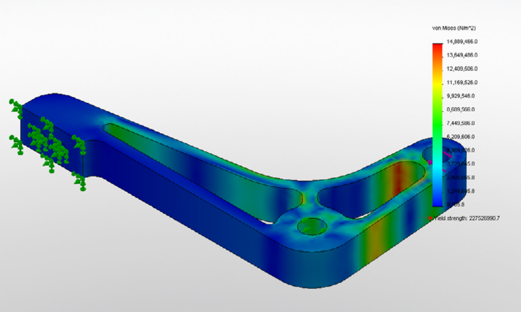


Fig. 7 - A force in arm analysis of the initial gripper design.

Basket

Because of ROV *Hybris*' small size, it was determined that an external payload system was needed to transport the three biological specimens to the surface. Due to *Hybris*' immense speed advantage, delivering the specimens to a separate basket does not consume a significant amount of mission time. The basket (Figure 8) is made from an aluminum mesh sheet that was bent into a loop and attached to a separate flat circle on the bottom. The two pieces are held together by cable ties and string. Wherever sharp edges were present, felt was used as a cover to prevent the basket from getting caught on any part of the mission area or the vehicle. To make it easy for the vehicle to hold the basket, an aluminum bar was bent into the shape of a handle and attached to the basket. *Hybris*' manipulator design took this handle into account early on and can acquire the basket from any angle.

Fig. 8 - ROV Hybris' *external payload system.*

Fluid Collection System

When designing the pump system, it was arbitrarily determined that the design was to allow no greater than 2% dilution. This constraint ruled out many previously considered ideas such as syringe style pumps with only one in/out port. The final design of ROV *Hybris*' fluid collection system (Figure 9) is separated into two parts: the rotating sample tube and the fluid collection pump.

The rotating sample tube is a 20cm stainless steel tube that extends below the vehicle while collecting a fluid sample. The material ensures the relatively thin, .64cm outer diameter tube will be able to take the weight of the ROV resting on it in the event of collision. Because the length of the tube effectively doubles the height of the vehicle while deployed, it needs to be able to retract. A pneumatic piston is used with a custom hinge to rotate the tube exactly 90 degrees. The frame has a slot built into it for the tube when it is retracted. The location of this tube is in the nearest possible location to center to allow stability while sampling the fluid.

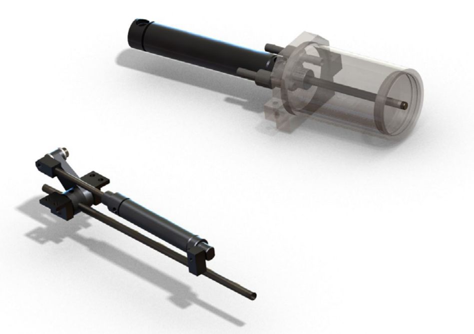


Fig. 9 - A render of the fluid collection system.

The end of the sample tube is attached to a Polyurethane tube which

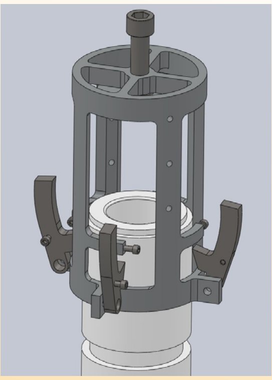


Fig. 10 - The oil cap slides over the PVC pipe.

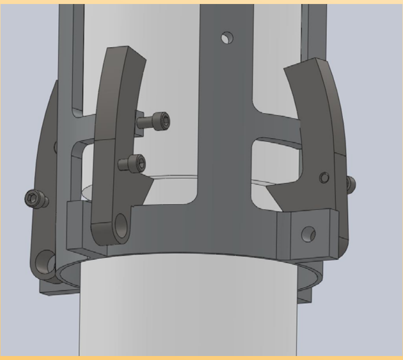


Fig. 11 - The clips attach to the end of the PVC coupling.

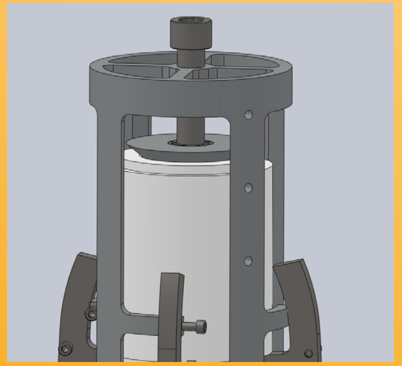


Fig. 12 - The stopper is then pressed into the opening to form a seal.

connects the sample tube to the fluid collection pump. This positive displacement piston pump collects approximately 125 mL of fluid, which allows a sufficient factor of safety above the required 100 mL. The pump is actuated by a pneumatic piston. To assure the fluid collected remains safely stored and pure, there are two separate one-way valves for in-flow and out-flow. These valves also allow the pilot to cycle the pump twice before collecting the sample to clear the system of ambient water before collecting the actual sample.

Oil Cap

The oil cap system (Figure 13) on ROV *Hybris* utilizes the ridge on the bottom of the top most PVC coupling as a clamping point. Aluminum clips are drawn inward using a rubber band (not displayed in these SolidWorks renders). The design of these clips allow them to be pushed out of the way and fit over the PVC coupling while sliding down it. There are four of these clips around the aluminum oil cap frame. Once clipped, a motor and belt inside of a custom enclosure drives a bolt down through a threaded hole in the top of the cap. The bottom of this bolt is attached to a flattened aluminum cone that is rubberized with a special type of spray paint. The motor sits on rails that allow it to drop with the bolt. When fully dropped, the stopper sits inside the top of the oil well head and seals it. Then the oil cap is released from the ROV by retracting an aluminum block, using a pneumatic piston with three pins in it which rigidly hold the cap before deployment.

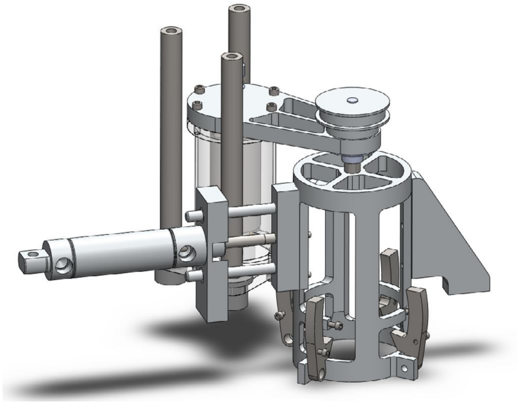


Fig. 13 - ROV Hybris' *oil cap system.*

Depth Sensor

ROV *Hybris* uses a water resistant pressure sensor built by Intersema, the MS5541-CM. It contains a precision piezoresistive pressure sensor with a resolution of 120 Pa, well within the resolution of 1005 Pa required by the mission. The only limitation of this sensor is that it cannot be submerged for more than four continuous hours. Because some practice sessions extend beyond this length, a dummy connector was made to go in its place when not needed.

The depth sensor electronics are waterproofed by hot glue. This assembly is attached with cable ties to the frame. The sensor communicates with the on-board microcontroller which sends all of its information to the base station computer. The depth is calculated using the equation below, before being displayed on the graphical user interface.

$$\text{Water Depth} = \text{Pressure} / (\text{Density} * \text{Gravity}) = \text{Pressure} / (1.00 \text{ x}103 \text{ kg/m}^3 * 9.81 \text{ m/s}^2)$$

Eq. 1 - Calculating depth using pressure

Tether

The tether on ROV *Hybris* consists of an Ethernet line, a twisted pair of 10 gauge marine power lines, an air line to the vehicle and a return line, and a 50lb stress relief line. All of these cables, as well as the tether's buoyancy (see buoyancy section on page 4), are wrapped in a snakeskin-like material to protect them and make the tether easier to handle. There are no external cable ties or buoyancy to catch on any part of the mission area. The stress relief line is attached to the rear of the vehicle to keep stress off of critical connection points. Everything on the tether is un-pluggable using Binder-USA electrical connectors to allow for easy transportation.

Electronics

The electronics system (Figure 15) for ROV *Hybris* was designed and built to provide full control of the ROV's propulsion system, pneumatic system, and sensor data from a wide variety of sensors. This system includes a main microcontroller, power distribution, dual motor drivers, IMU sensor, computer interface adapter, and LED lighting circuit boards.

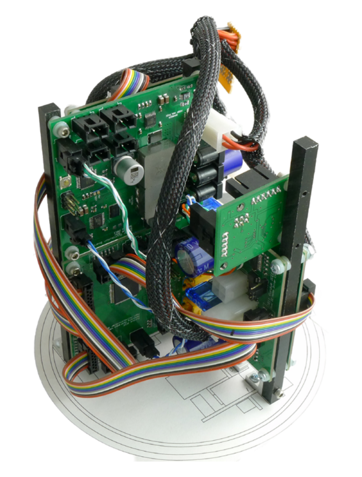


Fig. 14 - The electronics mounted to the rail system

The main microcontroller board is designed to be the central hub for the entire electrical system. This board is responsible for providing the control signals for all five dual motor driver boards, controlling the four solenoid valves, video multiplexing, and communicating to the base station via the tether. This board also communicates with the IMU sensor board and the power distribution board. This system is designed to provide a series of checks and balances during the boot sequence and normal operation to protect the electrical system and the ROV from improper operating conditions. The extended length of the tether also requires the usage of the RS-485 serial protocol. This protocol provides much greater transmission distances than the more common RS-232 serial protocol.

The power distribution board provides the necessary voltage levels for all of the microcontroller circuitry, cameras, and solenoids. There are two high-voltage buck converters designed to reduce the +48V to +5V and +12V. Voltage and current measurement circuitry is used to monitor the +48V and +12V rails. This data is requested periodically by the power distribution board microcontroller. When this microcontroller receives a signal from the main microcontroller board, voltage and current information is transmitted to the main microcontroller board to then be sent to the base station. The power distribution board microcontroller is also used to control the dimming signals for up to four LED lighting boards.

The dual motor driver boards are designed to control two Seabotix BTD150 thrusters each. Each motor driver circuit can be operated directly from the +48V power rail. To protect the thrusters and to keep the current and voltage waveforms within the provided specifications, the duty cycle of the pulse width modulation (PWM) signal is limited from 25% to 75% with 50% duty cycle being the neutral point. This will limit the average voltage seen across the motor terminals to +/-24V and approximately 6A current draw under load. This greatly simplifies the power conversion requirements of the ROV and eliminates the need for bulky DC-DC converters. Each motor driver circuit requires five control lines including PWM for velocity and direction, disable, reset, and two fault pins.

The IMU sensor board is responsible for managing all of the inertial measurement sensors, internal electronics enclosure temperature, and the depth sensor. This circuit board has a three-axis accelerometer, three-axis gyroscope, and a three-axis magnetometer.

Each of these sensors have internal temperature sensors that are used to provide temperature compensation for the sensors. These internal temperature sensors can be used to relay the internal temperature of the electronics enclosure. There is an additional six-pin connector that breaks out the necessary pins for power and communication for the depth sensor.

The computer interface adapter board is used to act as an RS-485 to USB bridge to provide simple connectivity between the ROV and the base station. This circuit also breaks out the two video feeds being supplied from the ROV.

The LED lighting board is designed to act as a high brightness LED driver circuit. It was designed to operate off of the +48V main supply rail and to provide a constant current of 350mA to four, high-brightness LEDs.

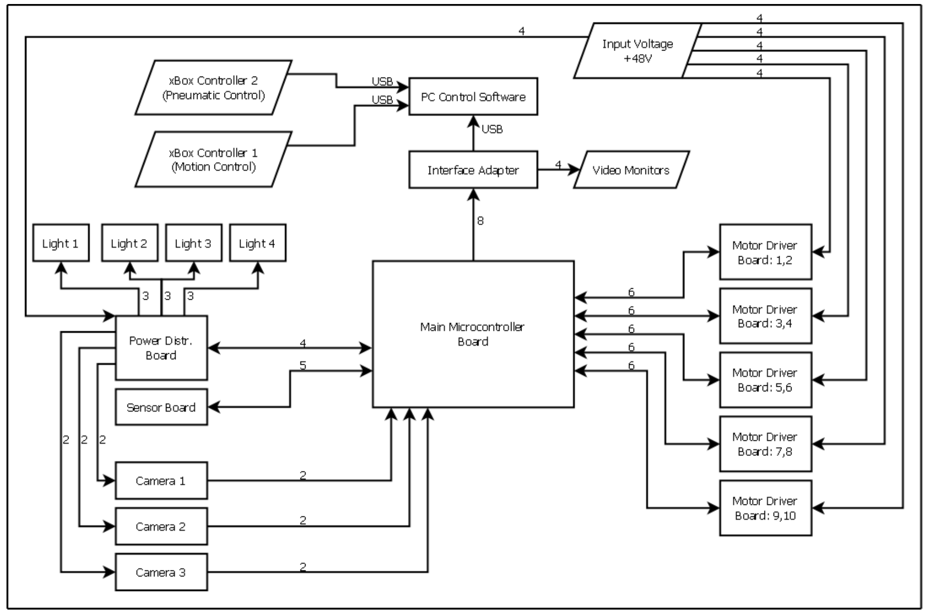


Fig. 15 - Full System Diagram

Electronics Tubes

The most noticeable feature of ROV *Hybris* is its two identical, symmetrical 15.25cm diameter, 15.25cm long polycarbonate tubes. Each tube has two aluminum end caps. One end is a simple cap that is sealed using marine epoxy. The other cap has a dual O-ring seal. Because of the complexity of this side, the team was not able to fabricate it. Thankfully, Colborne Foodbotics of Chicago offered to

Fig. 16 - The drilled end caps for the electronics tubes.

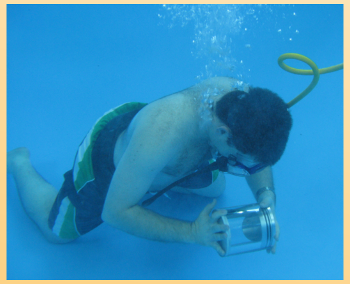


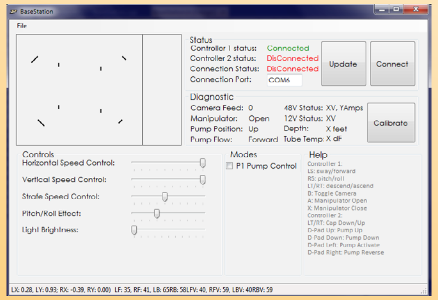
Fig. 17 - Team Leader Seth Baklor checking the electronics tubes for leaks.

Fig. 18 - Lawrence Goldstein also checks for signs of leaking.

donate the finished pieces. The O-ring seal acts as a waterproofing and support system to hold the tube on without the need for any extra hardware. Each tube also has a push to connect pneumatic fitting that is left empty during assembly to allow air to vent as the tubes are pressed on. During operation, these fittings are sealed by connecting the two tubes together. All fittings and wires go through only one end of each tube (the ends closest to the oil cap) and are sealed with marine epoxy. All components are mounted on rails that are in turn mounted to the end cap where the wires go through. These features allow the tubes be taken off and replaced without unplugging or moving any electronics.

Software

The software developed for ROV *Hybris* is split into two categories: on-board software and base station software. The on-board software is responsible for reading and transmitting sensor data, monitoring the power system, and providing movement to the vehicle via updates received from the base station. The base station software translates user input to thrust vectors and transmits the current vector to the vehicle. It also displays relevant information such as sensor data and thrust vectors to the pilot via a graphical user interface (GUI).



Status
Controller 1 status: Connected
Controller 2 status: DisConnected
Connection Status: DisConnected
Connection Port: COM6

Diagnostic
Camera Feed: 0
Manipulator: Open
Pump Position: Up
Pump Flow: Forward
48V Status: XV, YAmps
12V Status: XV
Depth: X feet
Tube Temp: X dF

Controls
Horizontal Speed Control:
Vertical Speed Control:
Strafe Speed Control:
Pitch/Roll Effect:
Light Brightness:

Modes
☐ P1 Pump Control

Help
Controller 1:
LS: sway/forward
RS: pitch/roll
LT/RT: descend/ascend
B: Toggle Camera
A: Manipulator Open
X: Manipulator Close
Controller 2:
LT/RT: Cap Down/Up
D-Pad Up: Pump Up
D-Pad Down: Pump Down
D-Pad Left: Pump Activate
D-Pad Right: Pump Reverse

LX: 0.28, LY: 0.93; RX: -0.39, RY: 0.00) LF: 35, RF: 41, LB: 65RB: 58LFV: 40, RFV: 59, LBV: 40RBV: 59

Fig. 19 - Screenshot of GUI

The on-board software is written in embedded C, using the avr-gcc libraries to provide mappings to the hardware registers. There is separate code for the power distribution board, the IMU sensor board, and the main board. The power distribution board activates the 12V line and monitors the 48V and 12V lines, reporting the current and voltage as well as any errors to the main board. The sensor board reads data from the sensors on the I2C bus and the pressure sensor used for depth measurement using the SPI interface and sends the data to the main board. The main board receives thruster vector data from the base station software and translates this into a PWM duty cycle, which is then output on the appropriate pins. Any button presses that activate or de-activate sub-systems are also interpreted by the main board and executed accordingly. The data received by the power distribution board and IMU sensor board are sent to the base station software to be displayed for the pilot, and any error codes are resolved if possible and reported to the base station. See Appendix B for flowcharts of the on-board code.

The base station software is written in C++/CLI using Windows Forms to implement the GUI. The GUI (Figure 19) displays the current thruster vector (depicted graphically), the current depth of the vehicle, controller and connection status, sensor data, and a help box for the pilot. The display also contains elements that allow the pilot to control various aspects of the vehicle, including speed limiting, light brightness, and transfer of control. The base station software also translates user inputs from an Xbox360 controller to thruster vectors. Every 10 ms, the state of the controllers' axes and buttons are polled. The joystick and trigger values are normalized, and the percent thrust of each thruster is calculated by the thrust mixing algorithm. The button presses are recorded using a sliding average, and if the average falls between .45 and .55, the button is considered pressed and the appropriate signals are toggled. This information is sent to the main board, where the thrust percentages are translated into PWM duty cycles and the toggled signals are interpreted. See Figure 20 for the base station software flowchart.

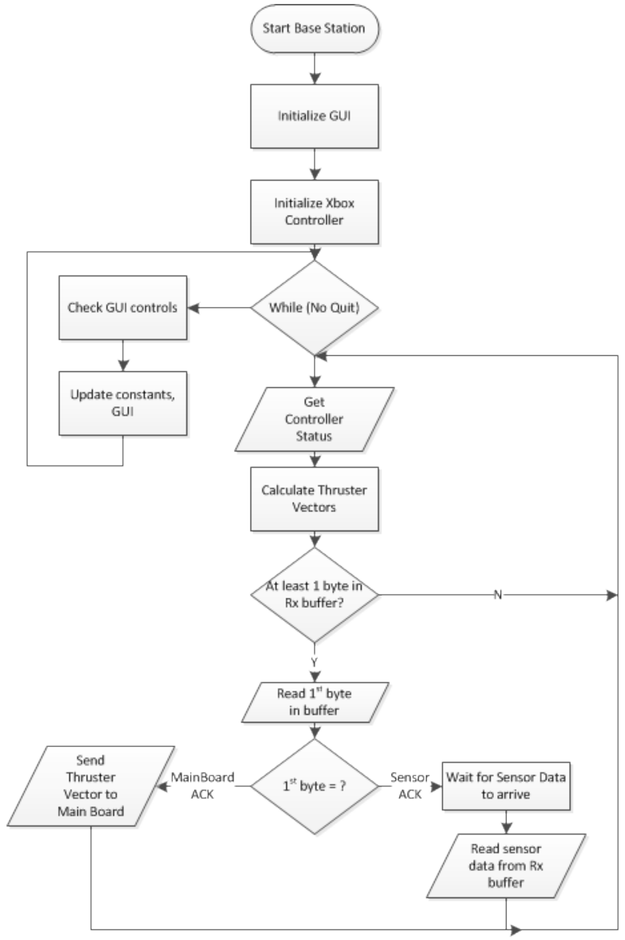


Fig. 20 - Flowchart of Base Station Software

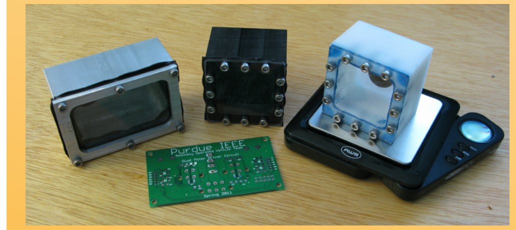


Fig. 21 - Camera enclosures used for waterproof testing and Hybris*' motor driver board.*

Pneumatic Systems

ROV *Hybris* utilizes five pneumatic pistons for its mission tools, two of which are identically actuated. This leaves four pneumatic systems in total: manipulator actuation, oil cap deployment, fluid sample tube rotation, and fluid sample pump. All pneumatic pistons are controlled by an on-board pneumatic solenoid which is controlled by the custom microcontroller board. Air is pressurized by a compressor on the surface and sent down the tether using .32cm inner diameter polyurethane tubing. Between the compressor and the tether is a pressure regulator and an emergency quick release valve for safety. Before the air is sent to the solenoid bank, it passes through a pressure accumulator to assure faster repeated actuation of the pistons. Instead of venting used air to the pool, it is exhausted back to the surface through another accumulator and line. This process creates a greater pressure differential since the ambient pressure of air is much less than that of water at 12m. For a schematic of the entire pneumatic system, see Appendix C.

Reflection

Challenges

Our greatest challenge was ensuring waterproof seals for the on board electronics enclosure. The waterproof enclosures for *Hybris'* cameras were used as practice for designing and fabricating the more important electronics enclosures. The first enclosure was made from aluminum and had a rubber gasket face seal with a polycarbonate top. Testing was then done by installing a bicycle tire valve to the side wall and adding the pressure needed to simulate certain depths. Because of the seal types chosen, its ability to keep pressure in should be identical to its ability to keep pressure out. The aluminum enclosure was deemed water proof beyond 60m, but too heavy to be practical. The next box was made of delrin plastic, chosen for its ease of machining, low weight, and low cost. When tested, the rubber gasket face seal performed just as well as it did on the aluminum enclosure. However, during extremes testing of 60m, the side wall of the delrin showed slow leaking. Plastic was still desirable due to the extreme weight reduction, but something other than delrin was required. High-density polyethylene (HDPE) was chosen next as an option as it shares delrin's ease of construction, low cost, and low weight. Once constructed, the HDPE enclosure was actually 30% the weight of the original aluminum enclosure. When tested, the rubber gasket face seal did not work well with this material. This was replaced by an RTV sealant placed between the polycarbonate cover and the HDPE face. This was chosen as the final design for the waterproof enclosures. Elements of this design were used again for pressure accumulators, lights, and the electronics enclosure.

Troubleshooting Techniques

The dual motor driver board circuitry contains two identical h-bridge circuits, and during the course of testing the hardware, we noticed that the left-side motor driver circuit would perform as expected but the right-side motor driver would display a fault condition. The fault condition was indicating that there was a short circuit either across the supply or the load. In looking at the circuit, it did not appear that there were any external factors that might cause a short circuit. Using a microscope, the solder joints were inspected to see if any of the pins were incorrectly shorted together or a loose strand of wire. When no inconsistencies were visually detected, a multimeter was used to check continuity between all of the traces, however this did not give us any more information about the issue we were having. Luckily, one of the other team members, Kuan Po-Chen, was reviewing the circuit schematic and board layout files and noticed that the LSS, low-side sense, pin did not properly route to the ground plane. The short circuit fault condition turn out to have been caused by a missing connection versus an extra connection that we were originally looking for. This problem was easily fixed by soldering a small gauge wire from the LSS pin to the nearest ground connection.

Lessons Learned and Skills Gained

One of the most beneficial new skills gained, among many, is the use of CNC machining. While we were able to utilize a student-run machine shop last year, they didn't have the necessary precision or technical abilities needed to make something as advanced as ROV *Hybris*. With the acquisition of our own CNC mill, we now have the ability to cut our own pieces with an accuracy of within 0.075 mm. It also opened the door to complex shapes in both engineering plastics and aluminum. Only one team member had any CNC experience before this year, but now over five of us have used the machine at one point or another.

Using a CNC mill has also required us to learn how to use a CAM software along with our design software, SolidWorks. The CAM software company, CamWorks, was willing to give us a substantial discount.

Fig. 22 - The Aperture Aquatics workshop with CNC mill.

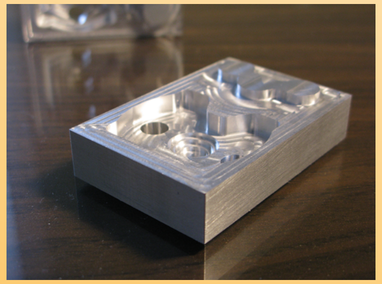


Fig. 23 - An example of the CNC mill's ability to cut complex shapes.

Fig. 24 - CNC machined motor mounts for ROV Hybris.

Using this software proved just as challenging as designing the ROV itself because it does not usually understand your intentions. However, we have managed to learn enough to make all the complex shapes we designed.

Future Improvements

Compared to all previous Purdue ROVs, *Hybris* is a technical marvel. Her evolution above anything made prior, both mechanically and electronically, makes future improvements challenging to consider. However, there are a few luxuries that the vehicle could still benefit from. High definition video would allow the use of a larger screen. This would likely require fiber optic communication. Also, a single board electrical system could significantly reduce the size of the overall system. However, it is questionable how much these additions would actually assist in making the vehicle better at completing the mission it is designed for.

Individual Reflections

Seth Baklor - *Team Captain and Founder*:
As a Ranger class competitor in 2008, I never thought I would be a part of one such high class Explorer team. The level of quality and sheer power of ROV Hybris far surpasses anything I have seen in the competition throughout the past four years. However, it has taken the team three years to get here. For the first time, we not only have the right team members, but all of those team members have at least one year of experience to know what they should expect throughout the design process. Because the vast majority of the team is returning, the work atmosphere was much more like friends than new acquaintances. I lost track of how often the electronics design group met independently. Teammates began debating over conflicting ideas instead of just agreeing with the first proposed idea. Every member of the team took so much ownership over their part of the project that I have been left to a leadership role of making sure they have the tools they need.

Clement Lan - *Software Lead*:
My main contribution to the team has been the on-board and base station software for the past two years. In this role, I feel that as a software developer, I have grown considerably. Last year, I felt that my work was more of a hack job, without much foresight and planning. However, knowing from my experience what worked and what didn't, I was able to take more care in the development of the software, optimizing in certain areas and adding additional functionality that was not in place last year, such as the graphical user interface and extensive sensor data. Given more time, I believe that the software could be improved even further to be more modular and provide even more control over the vehicle. However, that is something that someone else will have to undertake in the future.

Rob Swanson – *Electronics:*
In my second year with the team, I have witnessed our ambitions and accomplishments grow immensely over the last year. I was involved primarily with the ground up design of the new electronics system, which was very exciting. After the team had decided what the vehicle was going to need for this year, we had free range in creating new custom electronics to implement the desired features. The exciting part for me personally was the ability to bring an idea from schematic to a functioning circuit. This involved taking a captured schematic and creating a hand routed printed circuit board layout. We had all the board designs fabricated, and then all the boards were hand populated and assembled. With this system being the most complex electronics system I have fabricated, it was very exciting to see the theoretical designs come to life. Ultimately, implementing the systems into the vehicle and seeing everything operate in harmony is the most rewarding part of the hardware design, which is not something that you get to experience in a standard college course.

Clayton Kleppinger - *Electronics:*
This has been the second year that I have participated on the Purdue IEEE ROV Team. As a senior in electrical engineering, one of my requirements for graduation is the fulfillment of a senior design project. Working with Clement and one of the ECE guidance councilors, the ROV electronics system became the senior design project requirements. I knew that I would be spending a lot of time working on the ROV this semester and it would be an additional bonus if I could get credit that counts toward graduation.

I learned a great deal about circuit and PCB design while working on this project; however, working within a small multidisciplinary team is an experience that I would not have had access to by taking the regular senior design class. While I was allowed a great deal of freedom with the design of the electronics system, communication between myself and Lawrence, the lead mechanical engineer, was important throughout the process of designing the ROV.

Team Safety

The Purdue IEEE ROV team considered safety during both construction and operation of ROV Hybris. Operation of all power tools required the use of OSHA approved glasses. The use of tools new to the team, such as a CNC mill and horizontal band saw, were safer than hand drills and hack saws when used properly because the work piece is not held by hand. Operation of the vehicle is made safe through many measures. Pneumatically, the ROV has a pressure regulator and an emergency quick release valve that can empty the system in a few seconds. Every part of the pneumatic system is rated to at least 689 kPa, well above the operating pressure of 270 kPa. Electronically, the ROV has a large array of fuses and systems designed to not cause damage if communication is lost with the surface. Mechanically, there are as few sharp edges as possible throughout the ROV. There are a couple points on the ROV's tools that team members know to be aware of when in operation, such as the gripper and oil cap holding mechanism. In the team's three years of operation, only a few minor scrapes and no serious injured have occurred.

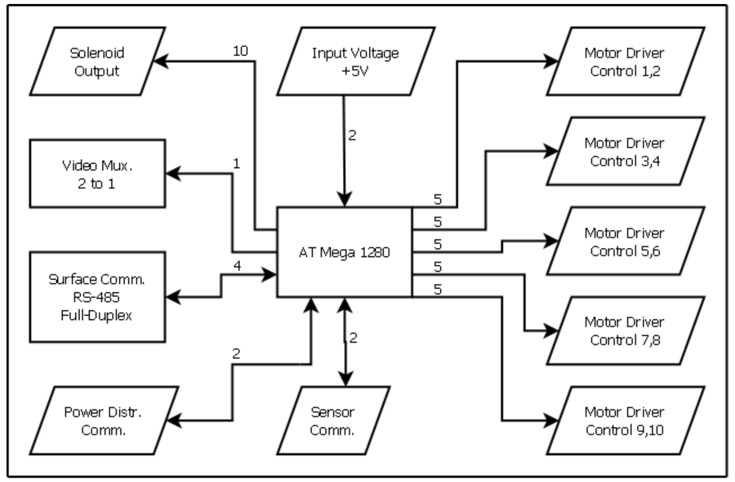
Expense Report

Item	QTY If Applicable	Expense Cost USD / Unit	Donations Cost USD / Unit	Income Monetary
ROV Construction				
Waterjet Aluminum Frame (Janicki Industries Donation)			$800.00	
Raw Aluminum Stock		$492.92		
Stainless Steel Bolts & Washers		$221.38		
Raw Plastic Stock (Delrin, HDPE, and Acrylic)		$368.63		
Bearings		$118.61		
Wide Angle Camera	2	$89.99	$10.00	
High Quality Camera (Previously Owned)		$250.00		
Fluid Sample System (One-Way Valves and Sample Tube)		$15.00		
Pneumatic Systems (Solenoids, Fittings, Tubing, Pistons)		$1,154.86		
Electronics Tube O-Rings	4	$1.54		
Seabotix BTD150 Thrusters (50% discount from $1000)	8	$500.00	$500.00	
Oil Cap Deployment Motor		$354.23		
Depth Sensor		$62.92		
Tether Wire (Power & Ethernet)		$265.15		
Waterproof Electrical Connections (Binder-USA Discount)		$238.19	$238.19	
Air Compressor		$99.00		
Carabiner Clip		$7.50		
Touchscreen Windows PC (Previously Owned)		$1,000.00		
Video Screens	2	$34.98		
Custom Electronics (Microcontroller, Motor Drivers, etc)		$700.00		
Other/Travel				
Prototyping Costs (Electrical and Mechanical)		$400.00		
Piloting & Presentation Cart		$220.00		
AC ROV Power Supply (For Practice Runs)		$350.00		
SolidWorks	10		$1,300.00	
CAMWorks		$300.00	$18,645.00	
Competition Fee		$50.00		
Rental Van		$1,705.00		
Hotel (Estimated)		$1,200.00		
Gas to Houston (Estimated)		$700.00		
Poster (Estimated)		$150.00		
Donations				
Indiana Space Grant Consortium				$5,000.00
Lockheed Martin				$2,300.00
Purdue Engineering Student Council				$4,500.00
Family Donations				$2,879.49
Summary Please Note: Quantity is taken in to account before values are summed				
ROV Construction		$9,604.49	$5,058.19	
Other/Travel		$5,075.00	$31,645.00	
Donations				$14,679.49
TOTAL		$14,679.49	$36,703.19	$14,679.49
Total Remaining Balance	**$0.00**			

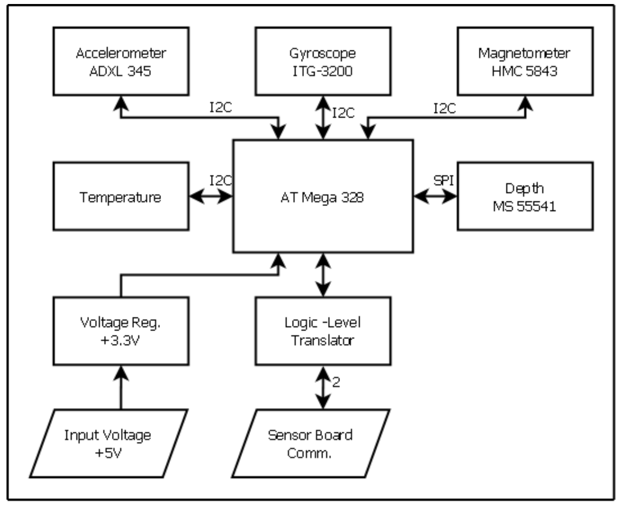
Acknowledgements

Aperture Aquatics would like to thank:
All the volunteer judges of the MATE Competition
Arlene and Sandy Baklor
Sydell and Dave Berman
Penny Bank
Sue and David Liebman
Ed Baklor and Jeff Cannon
Robin and Isaac Angel
Purdue School of Electrical and Computer Engineering
Chuck Harrington
Seatech 4-H ROV Team
Char Swanson
Lisa and Michael Kleppinger

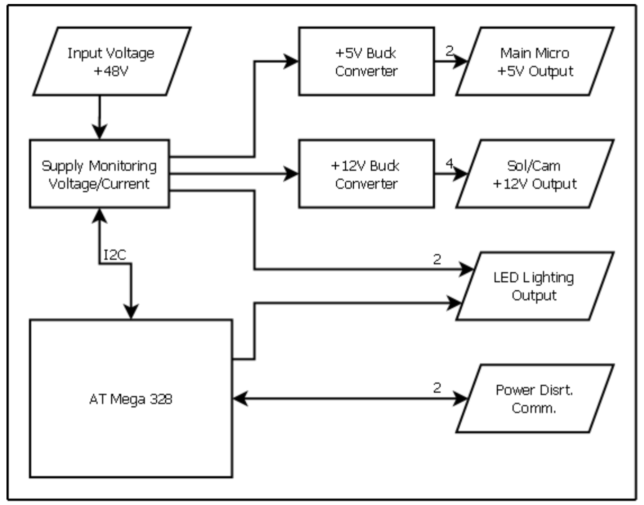
Appendix A - Electrical System Block Diagrams



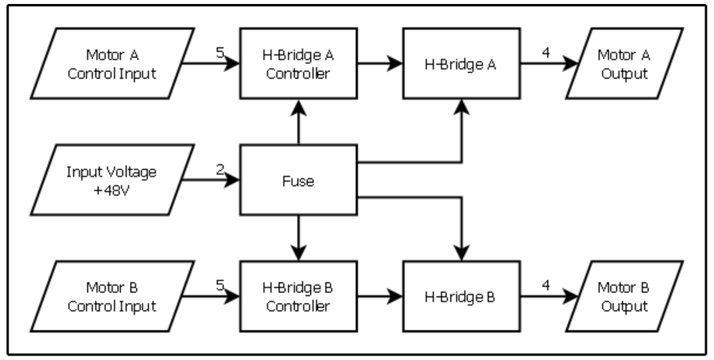
A1 - Main Microcontroller Board



A2 - Sensor Board



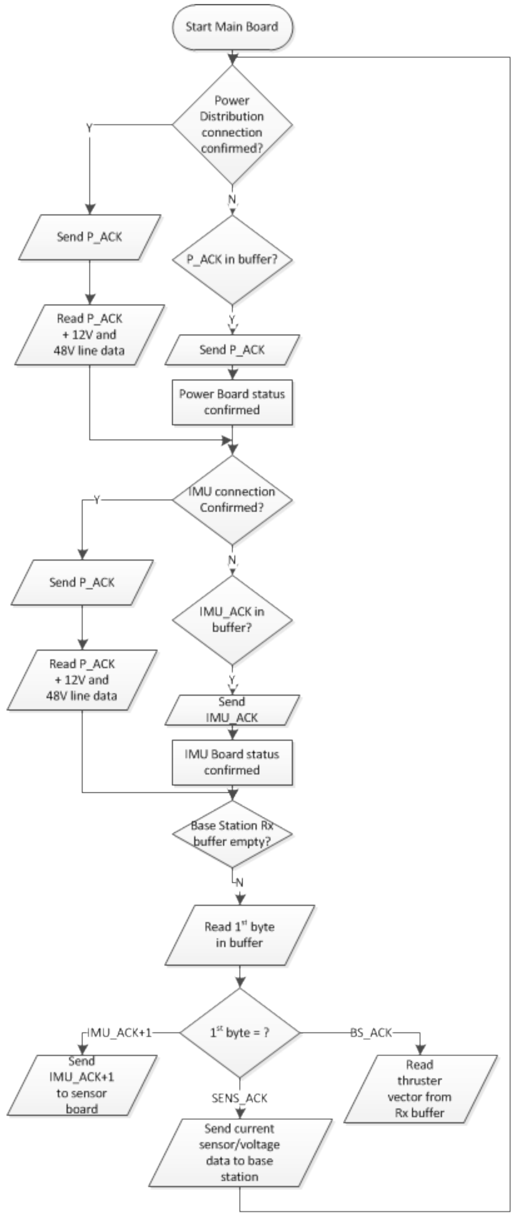
A3 - Power Distribution Board



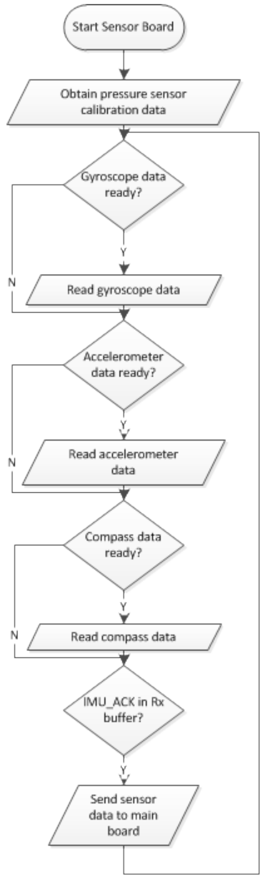
A4 - Motor Driver Board

Appendix B - Software Flowcharts

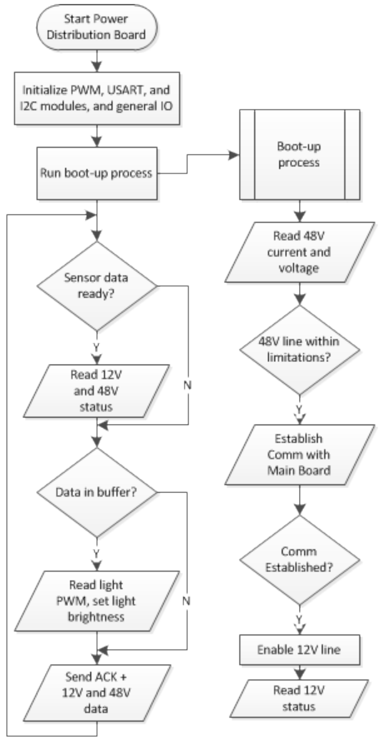
B1 - Main Board Flowchart



B2 -Sensor Board Flowchart



B3 - Power Board Flowchart



Appendix C - Pneumatic System Diagram