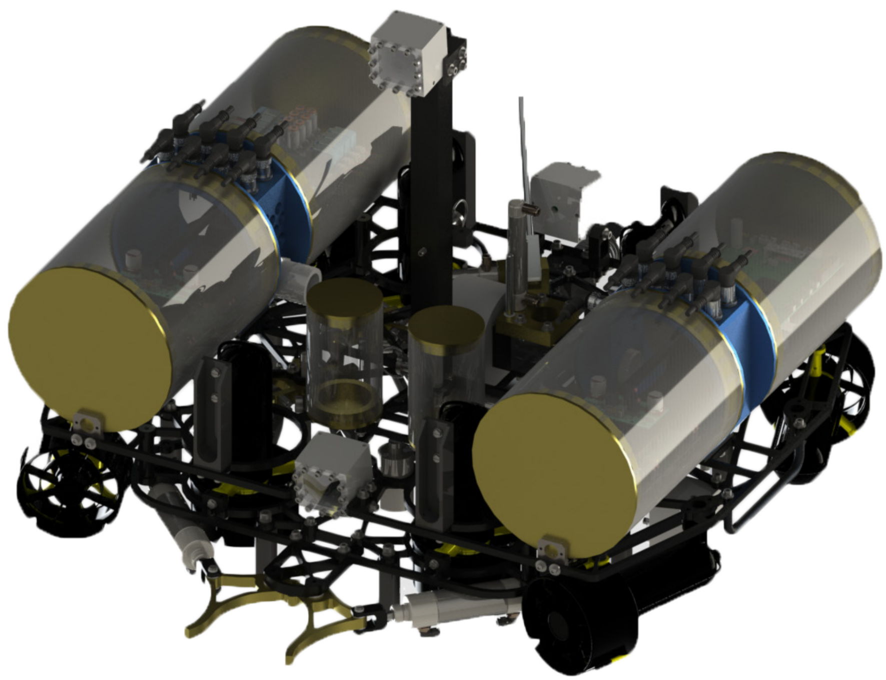
2012 Technical Report

PURDUE OFFSHORE TANKER ASSESSMENT AND TACTICAL OPERATIONS SUBMERSIBLE

Purdue University
IEEE ROV Team

West Lafayette, IN, USA

ROV PotaTOS



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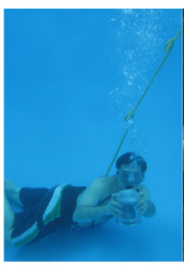
Purdue Offshore Tanker Assessment and Tactical Operations Submersible

Abstract

Aperture Aquatics has designed and constructed ROV *PotaTOS* to meet and exceed the requirements set forth by the 2012 MATE International ROV Competition. This includes surveying the wreck site, relocating endangered coral and select shipwreck parts, and removing harmful oil from inside the wreck. At 68 cm long, 61 cm wide, and 47 cm tall, ROV *PotaTOS* is capable of performing all these tasks in a single dive.

Designed with reliability, stability, and speed in mind, ROV *PotaTOS* 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, lift box release, deployable tape measure, multi-purpose sensor, fuel collection system, and patch rack. All of the electronic hardware responsible for power management, vehicle movement, and sensor data collection, have 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 *PotaTOS* is fully functional.

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



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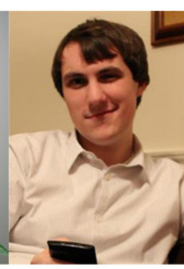

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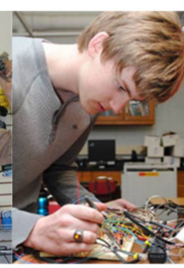

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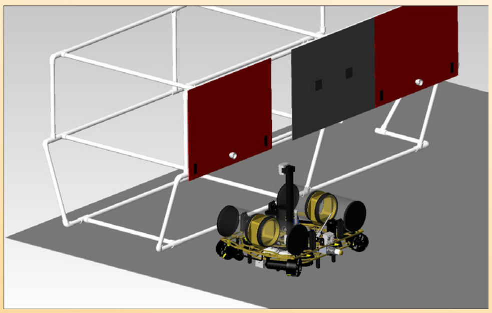

Fig. 1 - A render of ROV PotaTOS conducting a simulated sonar reading

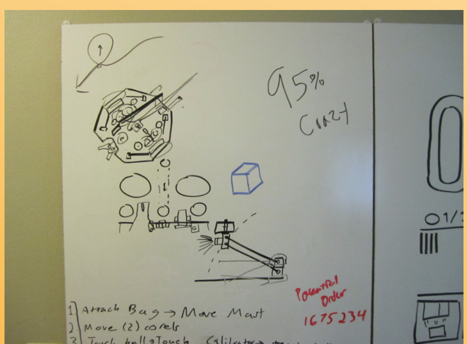

Fig. 2 - Early design sketches of ROV PotaTOS

Mission Summary

Task 1: Survey the shipwreck

The shipwreck's length is obtained via a simple tape measure with a hook on the end that latches to the back of the ship. ROV *PotaTOS* uses its thrusters to extend the tape and the pilot reads it using the rear facing camera. While measuring the ship, the ROV is facing the same direction as the wreck and the pilot uses ROV *PotaTOS*' magnetometer to determine its heading. To determine if debris around the wreck site is metal or non-metal, ROV *PotaTOS* hovers over objects in question which allows its inductive proximity sensor to determine if the object is magnetic. Utilizing either the main front facing camera or its 'periscope' camera, the ROV takes stable simulated sonar images *(See Fig. 1)*. If there are no obstructions on the floor, the 'periscope' camera is at the ideal height to take a sonar reading. If there are obstructions, the main front facing camera is used in conjunction with the ROVs immense stability to simply hover for an acceptable reading. The co-pilot uses all this information to create a detailed map of the wreck site.

Task 2: Remove oil from shipwreck

ROV *PotaTOS* begins the task by moving the shipwreck mast to a designated area. This is achieved by first grabbing a U-bolt attached to the mast with the vehicle's main manipulator. A lift box attached by a tether near the back of the ROV is than filled with air. This provides the lift needed to move the mast and forces the ROV to pitch downwards which puts the ROV in a crane-like position. Once the mast is laid down, the ROV releases the air bag tether which can then be removed from the mission area. The vehicle transports endangered coral from the ship's hull to a designated area using its main manipulator. This method limits transit to one coral at a time, but the vehicle's immense speed and the simplicity of the operation compensate for any time that might have been lost. ROV *PotaTOS* uses its spring loaded multi-purpose sensor to determine if fuel remains inside the tank. If an environmental threat is found, ROV *PotaTOS* pierces through two openings to the tank using a specially designed guide to make the task easier for the pilot. Oil is then pumped to the surface through the tether and replaced with sea water using two pumps at the surface. To seal the tank and ensure that no trace oil leaks out, ROV *PotaTOS* carries two patches to seal the two holes pierced by the ROV. These are held in such a position that the pilot only needs to side strafe 20 cm from the oil extraction position and descend slightly.

Design Rationale

Shape and Frame

ROV *PotaTOS* derives its shape from the mission requirements. The position of the oil extraction tubes and oil tank patches in the center of the vehicle were the first design choices made. The next decision was to have the manipulator at the front of the vehicle and the multi-purpose sensor at the rear in order to assure that they would not interfere with each other. With all components in a narrow path along the length of the ROV, there was ample room along the entire length of ROV *PotaTOS* on the starboard and port side for large, waterproofed enclosures. The periscope is placed in the center of the vehicle for maximum effectiveness. The vehicle's thrusters, cameras, and other tools fill in the remaining space.

The frame of ROV *PotaTOS* consists of two .64 cm thick anodized aluminum plates *(See Fig. 3-5)*. These plates were designed by placing all the components of the ROV on to solid plates in Solidworks, a computer-aided design software. Then all mounting holes were cut through the plates and as much material removed as possible without compromising strength. This lightens the vehicle and reduces hydrodynamic drag. The two layers are bolted together with five 3.8 cm long, 1.3 cm diameter standoffs. This two layer frame provides less drag, more strength, more mounting options, and less weight than the single layer frame on Aperture Aquatics' 2011 vehicle, ROV Hybris. All of this is possible because each layer of the frame can have significantly less remaining material than the one frame of ROV Hybris.

To protect against corrosion, every stainless steel bolt that goes through the aluminum frame is covered in anti-corrosion Tef-Gel brand fastener lubricant. The head of the bolt is also spaced away from the frame by a washer. To further protect the vehicle, every aluminum piece on ROV *PotaTOS* is anodized. To protect the bottom of the frame and tools from the ground, it is raised with eight Delrin feet that are 5.7 cm long. These feet are cylinders with a rounded tip which allow ROV *PotaTOS* to move in any direction while on the floor, an important ability while lining up sonar if a periscope reading is possible.

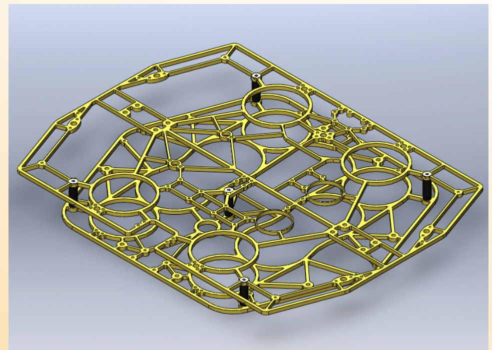

Fig. 3 - Render of ROV PotaTOS' upper and lower aluminum frames

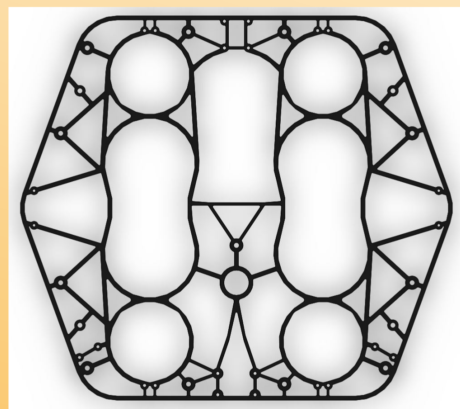

Fig. 4 - ROV PotaTOS' lower frame

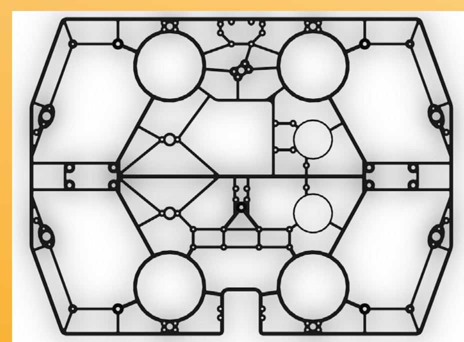

Fig. 5 - ROV PotaTOS' upper frame

Fig. 6 - Lawrence Goldstein refurbishing the thrusters from Hybris

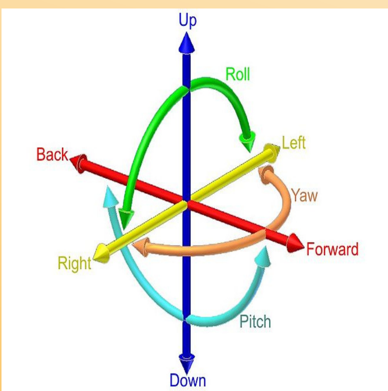

Fig. 7 - Visual representation of six axis movement (Image courtesy Wikipedia.org)

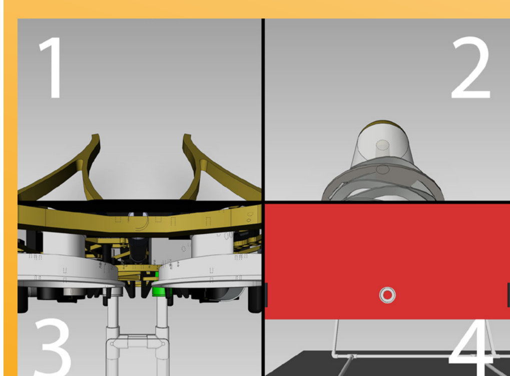

Fig. 8 - Render of each individual camera's field of view

Thrusters

ROV *PotaTOS* utilizes the same eight Seabotix BTD-150 thrusters from Aperture Aquatics' 2011 ROV. The thrusters have proven extremely powerful, reliable, and well sized. Each thruster is only 17 cm long and produces 28.4 N of thrust. Recycling these thrusters saved the company a significant amount of money, only incurring the cost of a simple refurbishment. Custom designed thrusters were considered, but the higher risk and turnaround time outweighed any potential benefits the company would gain *(See Fig. 6)*.

The four horizontal thrusters are placed at a 20 degree offset to achieve the best balance between turn speed and forward thrust. This angle was determined by performing a thruster analysis at many different 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. Pitch and roll control gives the pilot greater maneuverability which is needed for the fixed manipulator *(See Fig. 7)*.

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.

Cameras & Periscope

There are four cameras on-board ROV *PotaTOS*: the main front camera, the rear facing camera, the lower tool operations camera, and the periscope camera. To assure proper vision for the pilot, simulated cameras were added to the Solidworks model of ROV *PotaTOS* where the cameras would be mounted. This also required the use of calculations based on Snell's Law to determine the actual field of view after accounting for refraction through the camera case's polycarbonate cover and the water. The electronics system on ROV *PotaTOS* can transmit two of the four cameras at any given moment *(See Fig. 8)*. Switching between the cameras is done by the pilot on the handheld controller. All four cameras use the same high resolution analog camera from Super Circuits inside custom HDPE waterproof enclosures. Analog cameras were chosen for added reliability, lower cost, and simplicity. These particular cameras were chosen for their low weight, small size, and high quality. These cameras do require LED lighting which is discussed further in electronics.

The custom enclosures are made on a CNC mill from a solid cube of HDPE *(See Fig. 9)*. This material was chosen after testing Delrin, Aluminum, and HDPE together. Aluminum worked as a watertight material, but was too heavy. Delrin leaked through the side walls of the enclosure when at depths below approximately 35 m. HDPE was both watertight and lighter than either the Delrin or Aluminum *(See Fig. 10)*.

The periscope camera is mounted on the top of a square tube of aluminum which is removed by simply taking out one pin at the base that holds the tube to the frame. This 'periscope' camera perfectly aligns with the sonar target when the ROV is resting on the ground if there are no obstructions. Also mounted to the aluminum tube are LED lights for the camera and a tether relief block mount *(see tether section Page 9)*. If the periscope cannot be used due to obstructions on the ground, ROV *PotaTOS*' main front camera can be used as an alternative with the pilot hovering the ROV. When the ROV does not need to perform its sonar task during a particular dive, the periscope can be replaced with a much smaller square aluminum tube. This tube provides the tether relief block mount while reducing the overall height of the ROV.

Electronics Enclosures

A completely unique method of providing on-board watertight enclosures was used on Aperture Aquatics' 2011 ROV, Hybris. The enclosures worked very well to a depth of over 12 m. They also offered relatively quick and easy access to the electronics inside of the enclosure. This old design consisted of 15.25 cm diameter, 15.25 cm long polycarbonate tubes. Each tube had two aluminum end caps. One end was a simple cap that was sealed using marine epoxy. The other cap had a complex dual O-ring seal. All electronics were mounted to the same end as the O-ring seals which allowed the polycarbonate tubes to be removed with no electronics or pneumatics being unplugged *(See Fig. 11)*.

The company decided that a similar design was desirable for ROV *PotaTOS*, but there were a few lessons learned from ROV Hybris. There needed to be significantly more volume in the new system, but simply increasing the length of the polycarbonate tubes could cause mechanical issues since the tubes are only supported by their

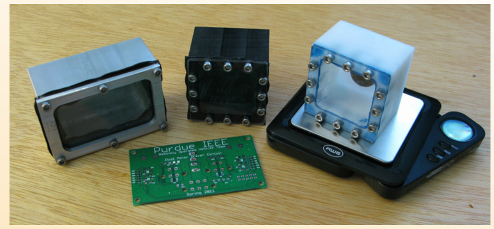

Fig. 9 - Camera enclosure prototypes made of various materials including Aluminum, Delrin, and HDPE

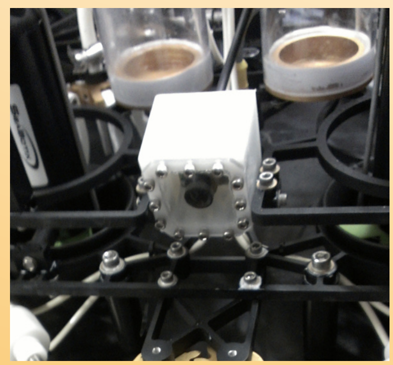

Fig. 10 - One of ROV PotaTOS' custom camera enclusures

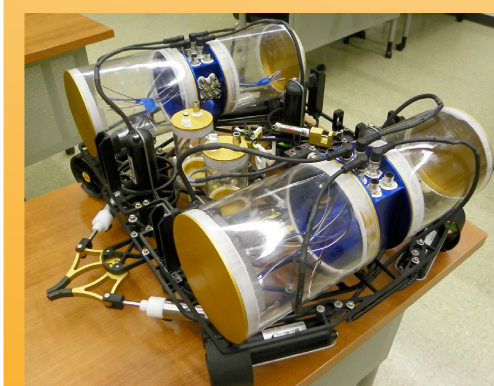

Fig. 11 - ROV PotaTOS with electronics enclusures on display

Fig. 12 - ROV PotaTOS' 'carriers'

Fig. 13 - ROV PotaTOS' manipulator in the closed position

O-ring seals. To solve this issue a new dual-sided cap, known as ROV *PotaTOS*' 'carriers', allows polycarbonate tubes to fit on to both ends. The carriers are also hollow in the center which essentially creates one long watertight enclosure twice the length of the 2011 model. Because ROV *PotaTOS* has two of these carriers and tube sets, there is approximately four times the watertight enclosure volume as compared to ROV Hybris. These carriers are by far the most complicated single part Aperture Aquatics has ever created, each requiring well over 30 hours of professional machining*(See Fig. 12)*.

Buoyancy and Ballast

Because ROV *PotaTOS* was designed entirely in Solidworks, accurate volume and mass estimations were available to allow for buoyancy calculations. Because the watertight enclosures are so large, there is enough enclosed air to offer enough buoyancy to balance ROV *PotaTOS*. In fact, there is so much buoyancy that the primary concern for the company is ballast. The lower frame of ROV *PotaTOS* has a hole on each corner for .64 cm diameter bolts. These bolts can be weighted with enough stainless steel washers to finely tune the vehicle to a neutral buoyancy. This method of ballast also offers an easy method of fine tuning balance to assure that the vehicle sits level in the water.

$$F_{net} = 0 = mg - \rho_f \mathbf{V}_{disp} g$$

Eq. 1 - Neutral Buoyancy Equation

Manipulator

ROV *PotaTOS* has only one fixed manipulator for simplicity. Having multiple manipulators leads to extra cameras, extra weight, and off-vehicle-center mounting of the gripper, which is more challenging for the pilot. This manipulator is used to attach the ROV to the mast for transportation, relocating of endangered coral, and any other general gripping need. Because of the ROV's thruster layout, it is able to pitch up and down instead of depending on a moving manipulator. 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 *(See Fig. 13)*.

The manipulator 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.

Lift Box and Release

To allow ROV *PotaTOS* to lift and move extremely heavy wreck debris, the ROV is equipped with a lift box system *(See Fig. 14)*. As opposed to conventional ROV lifting systems that attach a lift bag directly to an object, the lifting system on ROV *PotaTOS* is attached to the ROV itself via a rope. Anything being moved by the ROV is held in its manipulator. This method offers greater control over the object being moved than conventional methods. Because the heavy object is held at the bow and the lift box is attached near the stern, ROV *PotaTOS* is forced to pitch down. This creates an almost crane-like position with better visibility of the ground. To assure this lifting system does not get in the way when not in use, the vehicle has the ability to release the rope attaching the ROV to the lift box using a pneumatic piston (*Figure 15*).

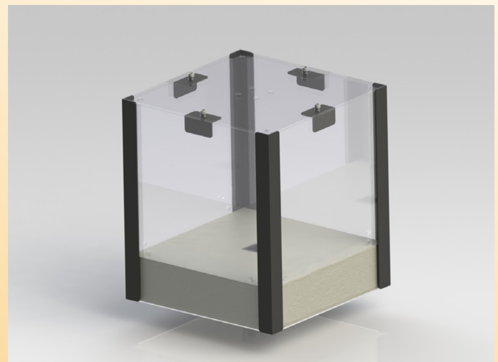

Fig. 14 - Render of ROV PotaTOS' lift box

The lift box itself is a rigid polycarbonate box. The rigid box was chosen over a lift bag due to its simplicity, ease of construction, cost of construction, and more predictable characteristics while air is being added. To ensure that the lift box stays above the ROV at all times, even when air is not added to it, a block of foam makes up the bottom of the rigid box. This foam only provides 2.25 kg of lift; enough to ensure that the box remains near the surface of the water, but not enough to hinder the ROV from descending. The lift box has an air line attached to it from the surface that can supply enough air to fill it in under 7 seconds. This amount of air along with the foam provide a total maximum lift force of 7.7 kg. In extremely heavy lifting operations, ROV *PotaTOS*' four vertical thrusters can add up to 11.6 kg of lifting force for a total of 19.3 kg. Small holes are placed across the top of the box to allow constant venting of air instead of needing to have a controllable release valve. The rate at which air is added to the box is significantly faster than the rate at which air is vented.

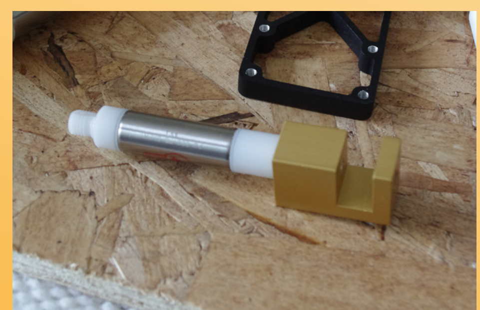

Fig. 15 - ROV PotaTOS' lift box release

Tape Measure

Knowing the length of a shipwreck is key to identifying it. The company considered many complex options such as lasers, sonar, image processing, and radar. Lasers, sonar, and radar would be challenging to use because the cross sectional area of the tip of the

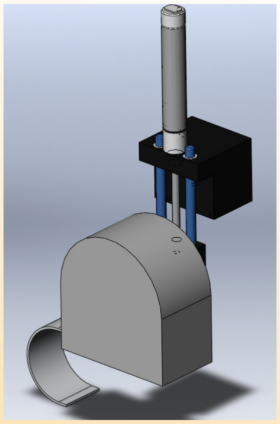

Fig. 16 - ROV PotaTOS' tape measure attatchment

Fig. 17 - Modifying the tape measure for mission use

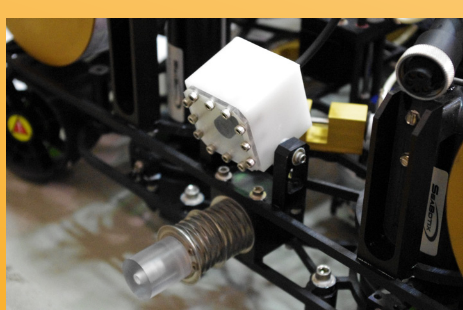

Fig. 18 - ROV PotaTOS' multi-purpose sensor and camera

shipwreck's bow is extremely small. Image processing (capturing an aerial photograph of the shipwreck and comparing the length of the wreck in the photo with the length of a known object) was deemed too inaccurate. Instead, ROV *PotaTOS* is equipped with a simple tape measure *(See Fig. 16)*. The tape itself and the spring that retracts it are made of stainless steel to prevent corrosion. The end of the tape measure is attached to a hook that is designed to catch the stern of a shipwreck *(See Fig. 17)*. Once the hook is in place, the ROV pulls out the tape until the measurement of the bow is visible through the rear camera. The best position for the tape measure would be at the center of the stern of the ROV, but the multi-purpose sensor's position prevents that. The tape measure is thus positioned directly in front of the multi-purpose sensor. To assure that the hook used to deploy the tape measure does not catch on objects unintentionally, it raises 5 cm for storage when not in use.

Sensor

ROV *PotaTOS* is equipped with a simulated multi-purpose sensor to emulate an ultrasonic thickness gauge sensor and a neutron backscatter device *(See Fig. 18)*. This sensor is used to determine if the shipwreck still has fuel in its hull. It is made of 2.54 cm diameter, 12.7 cm long solid polycarbonate with a rubberized rounded tip. This shape and high friction material makes it easier for the pilot to hold the sensor against the intended surface. The sensor is spring loaded so that the pilot can apply a small constant force against the ship's hull to keep the sensor from skipping across the surface. It is mounted at the stern of the vehicle which allows the pilot to back the vehicle up to the surface being measured, monitoring the sensor's status using the rear facing camera.

Inductive Proximity Sensor

Knowing if wreck debris is metal helps identify what it is. The simple method to identify metal is to use a dangling magnet and watch to see if it is attracted to the object in question. However, this method can be slow and unreliable. The most common method of metal detection consists of an oscillator producing an alternating current that passes through a coil producing an alternating magnetic field. If a metal object passes in to this magnetic field, it is detected. These coils are often extremely large and heavy which is undesirable for mounting to the vehicle. The detection range of these metal detectors has very large tolerances which could lead to false readings from other metal objects in the area, such as rebar support beneath a pool. ROV *PotaTOS* is equipped with a large Inductive Proximity Sensor used to identify if an object is metal or non-metal. The drawback of this type of sensor is that they are designed for extremely short detection ranges, ROV *PotaTOS*' being only 3cm. This means the pilot must maneuver the ROV directly over the object, but it does also ensure no false readings. It is mounted slightly forward of vehicle center facing down. When this sensor is triggered, the pilot gets an onscreen indication, the handheld controller vibrates, and there is an audible tone.

Fuel Collection System

If the multi-purpose sensor determines that fuel remains in the shipwreck's hull, ROV *PotaTOS* is equipped with a fuel collection system to remove the environmental threat. To gain access to the fuel tank, the vehicle has two drilling apparatuses called "drill stars." Each one of these stars has six vertical supports to help the pilot align with the fuel tank opening, giving them their star shape *(See Fig. 19)*. The center of the stars has a stainless steel pipe that is used to penetrate the openings of the tank and fuel is then pumped through these pipes. There are two stars to allow pumping seawater in to the tank through one side while pumping fuel out from the other. The seawater being pumped in to the tank and the fuel coming from the tank both travel through their own tubing inside the tether. This system allows for significantly larger fluid transfer capacity than an onboard fluid storage system. However, pumping fluid through a long tether requires an extremely powerful pump. Aperture Aquatics utilizes two separate pumps; one to push seawater down the tether from the surface and the other to suck fuel through the tether.

Patch Rack

Once the fuel is removed, the openings made by the ROV must be sealed again. This is to assure that no trace amounts of fuel remaining in the tank are allowed to leak out. The ROV uses magnetic patches (simulated by velcro patches) to seal both the inflow and outflow port. ROV *PotaTOS* is equipped with a "patch rack" to carry these patches without the need to surface mid-mission to retrieve them *(See Fig. 20 & 21)*. This rack is located next to the ROV's "drill stars" which allows the pilot to simply ascend slightly, side strafe, and then descend to patch the fuel tank openings. The patches are then released by a pneumatic piston.

Fig. 19 - ROV PotaTOS' drill stars and penetration system

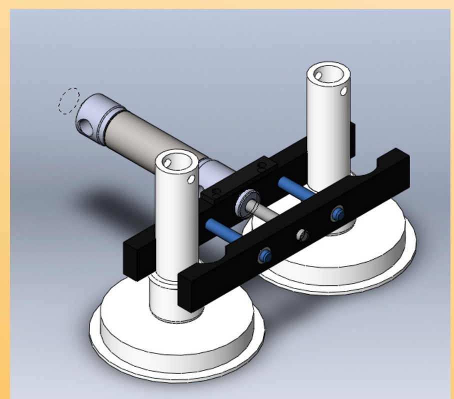

Fig. 20 - ROV PotaTOS' magnetic patches and rack

Fig. 21 - ROV PotaTOS' finished patch rack

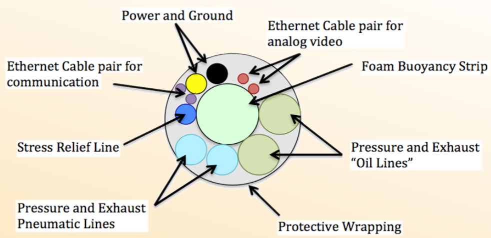

Fig. 22 - Diagram illustrating the innards of PotaTOS' tether

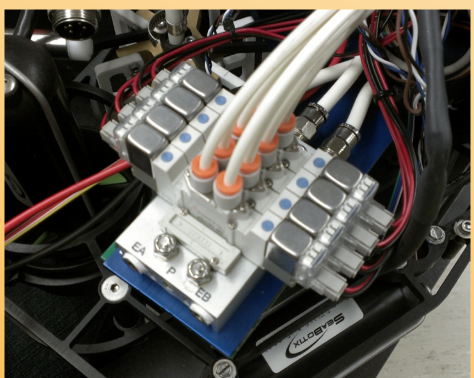

Fig. 23 - Pneumatic solenoid bank which directs air to the pistons for each tool

Tether

ROV *PotaTOS* is equipped with a 23 m long neutrally buoyant tether for power, communication, pneumatic air supply, and fuel pumping. For power, the tether has a twisted pair of 10 AWG wire. Communication is handled through an Ethernet wire, using two twisted pairs for analog video transmission and another two twisted pairs for serial communication. There are two pneumatic tubes in the tether: one to send pressurized air to the ROV and another to vent air used by the system to the atmosphere. In addition, there are two fluid tubes in the tether. One tube is used to pump fuel up from the shipwreck and the other is used to pump seawater down to the shipwreck. To make the tether neutrally buoyant, there is a strip of foam along its length with a cross section of .92 cm x 1.3 cm. To protect the tether and make it easier to manage, there is a snake-skin like wrap on tether*(See Fig. 22)*.

Pneumatic System

The pneumatic system on ROV *PotaTOS* is used to drive four of the vehicle's tools: the manipulator, the patch rack, the lift bag release, and the tape measure deployment system. A compressor is plugged directly in to the tether. The other end of the tether is plugged in to a pressure accumulator on the ROV. This accumulator assures that pressure supplied to the tools does not drop when multiple tools are actuated simultaneously. The air supplied by the accumulator feeds into a pneumatic solenoid bank *(See Fig. 23)*. This bank has a valve for each tool and is controlled by the ROV's electrical system (which is controlled by the Xbox 360 controller). Air from these valves is directed to appropriate pneumatic pistons to drive each tool. Once air is used, it is vented to another pressure accumulator. This accumulator serves the same purpose as the other, assuring a stable supply of pressure. The air from this accumulator travels up the tether again to a venting silencer at the surface. This silencer quiets the pneumatic system without negatively impacting performance. The pneumatic system vents at the surface instead of at the ROV to increase the pressure differential since the pressure created by surrounding water at depth would reduce the effective pressure of the system.

Electronics

The electronics system of the Aperture Aquatics ROV *PotaTOS* is designed to provide complete user control over all of the ROV subsystems, including thrusters, video cameras, pneumatic actuators, and tooling.

The main microcontroller board is the central point of communication and control for the subsea electronics system. The board has a myriad of different components and integrated circuits. To drive all these components multiple voltage supplies are needed. The main board *(See Fig. 24)* takes in the vehicle's +48V system power line and passes it into a 12V DC to DC converter. This 12V output is then utilized to power the cameras, inductive proximity sensor, and the +5V rail. This +5V rail is created via another DC to DC converter and is used to power the external logic found on the DC/DC module boards and the motor driver boards. *(See Fig. 25)* It is also used to power the +3.3V rail on the main board. The +3.3V rail is generated via a linear regulator and powers all the logic found on the main microcontroller board, including the main processor. The processor used is a STM32-F4 that utilizes a Cortex M4 series ARM processor. This processor is responsible for sending and receiving data from the tether, parsing sensor data from sensors, interpreting and calculating the necessary thruster commands, controlling the pneumatic actuators, controlling the video multiplexing, and controlling the LED lighting. The tether communication protocol used is RS-485. It offers increased range over RS-232 (especially at higher baud rates) and provides noise immunity due to the differential pairs used. The internal communications for subsystem to subsystem communication is I2C. The DC/DC modules, the IMU daughter board, and the magnetometer act as slave devices on the I2C bus, and will transmit the necessary sensor data when requested to by the main processor. This sensor data can include internal enclosure temperature, 24V bus voltage and current, and IMU positioning data from an accelerometer, gyroscope, and magnetometer. Thruster speeds and directions from the user input device (XBox 360 controller) are interpreted by the microcontroller which sets the necessary direction pins and sets the PWM duty cycle. The microcontroller will also continuously monitor for any fault condition flags from the motor drivers and report that information to the user on the topside software. The LED lighting drivers are also commanded and powered via the main microcontroller board. This gives the user control over

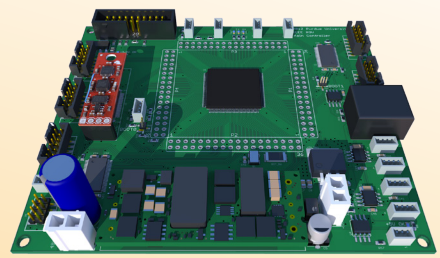

Fig. 24 - Main Microcontroller Board

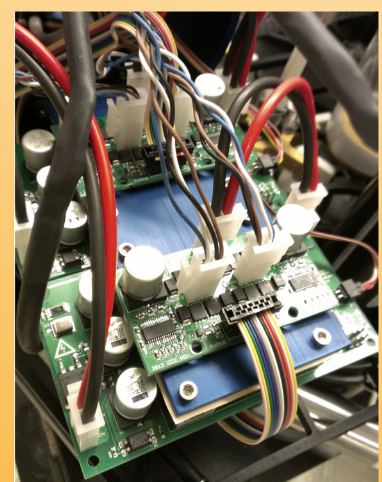

Fig. 25 - DC to DC converter and Dual Motor Driver

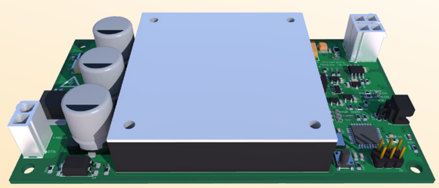

Fig. 26 - DC/DC Module

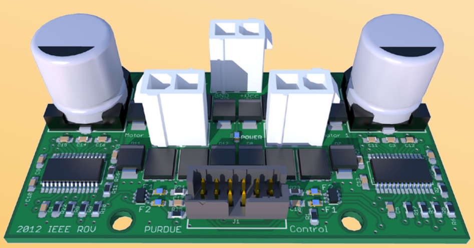

Fig. 27 - Dual DC Thruster Driver

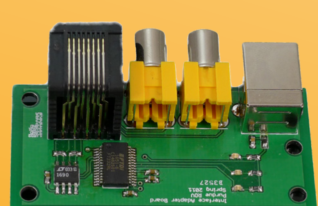

Fig. 28 - Interface Adapter Board

the color and the brightness of all of the external LED lighting.

The DC/DC module contains the main DC/DC converter bricks, as well as the necessary passive components to correctly bias and stabilize the internal DC/DC converter circuitry *(See Fig. 26)*. The vehicle requires four total DC/DC modules, one for each dual DC thruster driver *(See Fig. 27)*. There are also additional hardware features that prevent the +48V tether voltage from being plugged in incorrectly. On the +24V side of the DC/DC converter module, there is circuitry that monitors the +24V output voltage, the +24V output current, and a temperature sensor used to monitor the enclosure ambient temperature. There is an Atmel ATMega168 microcontroller that interprets the sensor data and communicates the data over the internal I2C bus to the main microcontroller board. Under extreme conditions, the DC/DC module can make its own decisions as to the health of the ROV electronic system. Code functions can be enabled to automatically shut down the DC/DC brick if extended over-current conditions are detected or the DC/DC converter output voltage is too high or low. These conditions may have arisen due to a short circuit due to component failure or water ingress, and these automatic safety functions can protect other electrical subsystems from a catastrophic failure.

The dual DC thruster driver is a very similar design based upon last year's design. It is still open-loop control; however it has been modified from last year's design to run at a lower DC bus voltage, which helped reduce the cost and size of some of the components that are used in its construction. The control scheme has also been updated from the locked-antiphase control scheme to a more conventional 0-100% duty-cycle control with a direction input pin. The onboard H-Bridge controller IC only requires a PWM input, a direction input, and a reset pin to control the thrusters. The controller provides two fault output signals that can be interpreted by the main microcontroller board. These signals can be used to detect if there is a short circuit between the high and low sides of the H-Bridge, as well as across the load. The fault outputs can also indicate over-temperature and undervoltage faults. Based upon the power requirements of the DC thrusters, each dual DC thruster driver is paired with one of the four DC/DC modules.

The interface adapter board acts as the topside interface between the RS-485 and video signals that come from the ROV and the computer and video monitors *(See Fig. 28)*. It is responsible for converting the

RS-485 data into USB, and it breaks out the multiplexed video lines with simple RCA video connectors.

The solenoid control board is simply a high-power shift register which interfaces between the main microcontroller board and the pneumatic solenoids *(See Fig. 29)*. Simple serial data is shifted into the 8-bit wide shift register, where it then becomes a parallel output which will activate or deactivate the solenoids.

The power breakout board helps to simplify the internal wiring and +48V power distribution to the main board and each of the DC/DC modules *(See Fig. 30)*. This board has one input connector for the +48V wiring from the tether and seven individually fused outputs. The first output of the device sends power to the main microcontroller board. Four additional outputs are used for the DC/DC modules. The remaining two connectors are left open for debugging or future development. Each channel also has a LED indicator to help to quickly determine the status of the fuse.

The LED driver and LED lights were constructed in two separate circuit boards in an effort to reduce the amount of wiring outside the vehicle. Each LED light PCB has two, high-brightness, RGB LEDs. Each of these colors can be turned on individually in a variable manner or all colors at once. The LED drivers are constant current sources, set to provide each color LED approximately 350mA of current from the 12V power rail to achieve maximum brightness.

Software

The control system of ROV *PotaTOS* is meant to give the user an easy and intuitive way of controlling the vehicle. The control system has two distinct parts; the on-board software and the base station software. The base station is the brains of the operation. It takes user input in the form of an Xbox 360 controller and computes thruster vectors for the vehicle's movement, as well as the position of the pneumatic systems and which video feeds are currently displayed *(See Fig. 31)*. The base station was written in C++ and designed to be multi-threaded with the intentions of allowing for simultaneous sending and receiving of data with the vehicle processor. Using readily available libraries for the game pad controller, we were able to easily interface the controller with our software. It also displays relevant sensor data and thrust vectors to the pilot via a graphical user interface, as can be seen in the GUI screenshot *(See Fig. 32)*.

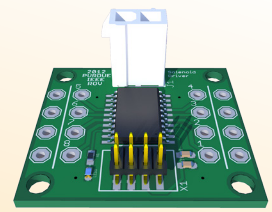

Fig. 29 - Solenoid Control Board

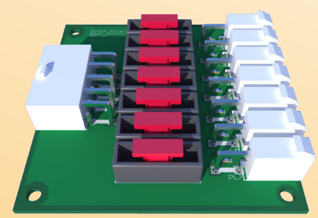

Fig. 30 - Power Breakout Board

Fig. 31 - Xbox 360 Controller

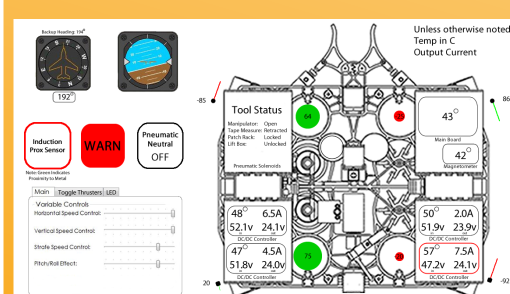

Fig. 32 - Graphical User Interface displaying relevant sensor data and thrust vectors

The base station software is responsible for core tasks such as communication with the vehicle processor, monitoring of the power systems, interpreting sensor data, controlling pneumatic actions and movement of the vehicle. In addition to these core tasks, the base station has additional functionality to change the color of the high brightness vehicle LED's and is capable of detecting and disabling individual motors or converter bricks in the case of a hardware failure *(See Fig. 33)*.

The on-board vehicle software is written in embedded C. There is separate embedded C code for the main board and the DC/DC board, where the main ARM processor code is compiled using the EWARM libraries and the DC/DC module code is compiled utilizing the AVR-GCC libraries.

The DC/DC conversion board software monitors the output current and voltage of the DC to DC converters, as well as the ambient temperature. The board is also capable of enabling or disabling the converters as commanded by the main controller board. Each of the four DC/DC conversion boards communicates via I2C as slave devices to the main controller master device. The firmware continuously updates the current, voltage, and temperature data (taken using the analog to digital converter module). Then, when data is requested, the firmware sends the requested data back over the I2C bus.

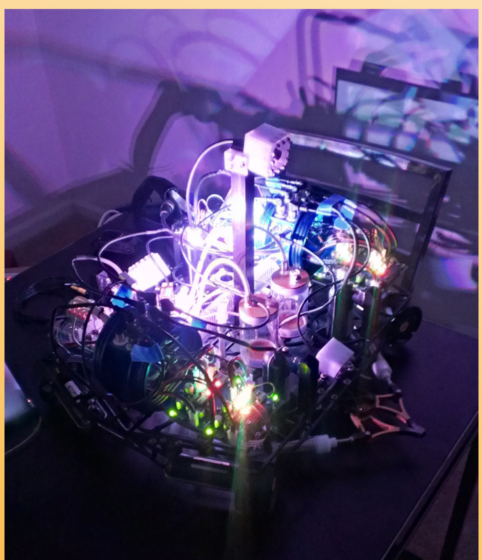

Fig. 33 - ROV PotaTOS' LED lights illuminate its surroundings

In addition to talking with the DC/DC conversion boards, the main controller board also talks to the 9 degree of freedom IMU and the magnetometer over the I2C serial bus. These devices are polled for current information about the vehicles position, such as degrees from North, roll, pitch, and yaw, as well as acceleration data. Monitoring simple digital inputs, the main controller board can monitor the status of each motor driver, making note of any flagged fault. An additional digital input is polled looking for a change of status on the inductive proximity sensor. When the sensor observes metal, that state of the sensor is toggled and observed on the pin. This change of state is then reported back to the user as metal present. The main board utilizes the RS-485 serial protocol to communicate with the base station, receiving control values for the motors, pneumatics, cameras, and the lights on board the vehicle, as well as sending sensor data back up to the user. Any sensor data received is sent back to the base station and displayed on the graphical user interface, such as positional data and electrical voltages and currents. To control the solenoids, the processor takes the received instructions and assembles a byte of data to serve as a solenoid status byte. This byte is then output via the serial periphery interface to the solenoid shift register, which then activates the appropriate solenoid. The motor commands received indicate speed and direction. The processor takes the direction and toggles a digital output to each motor driver to set the driver to the correct direction. The speed information is output as a desired pulse width modulation signal to the motors. The high brightness vehicle LED's are also controlled with the pulse width modulation scheme, allowing variable LED brightness. The processor also uses general purpose digital outputs to create logical high and low switches to control which camera view is selected by the video switchers.

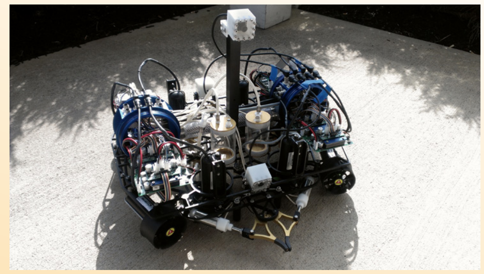

Fig. 34 - ROV PotaTOS without it's electronics enclosures

Challenges

Waterproofing the ROV becomes more challenging as the vehicle gets more complicated. There are more and more electrical connections that must pass through the water to operate each of the vehicle's systems. The team's three prior years of experience have themselves been a test bed for different seal systems, glues, and suppliers. Many commercial products do not meet their published ratings while others far surpass expectations. An example of this on ROV *PotaTOS* is that only Loctite brand marine epoxy is trusted with waterproof seals. Only the formula advertising 2 hours and not 50 minutes can be trusted to maintain a pressurized seal (both of which are available and often difficult to distinguish between). Another example is bulkhead electrical connections. Of the four suppliers tested by the team in the past (many of which have doomed other ROV teams), only Binder USA plugs have kept water from entering enclosures. These connectors do take up a significant amount of room, however, and are challenging to fit in to the limited space available on the electronics 'carriers'.

Fig. 35 - Heat shrinking a thruster splice

Because the Binder USA plugs are only available as a bulk head or with a tail, the team had to splice these with the wires from the cameras, LEDS, thrusters, and sensor *(See Fig. 35)*. In total, there are 39 splices that would be exposed to water if not otherwise protected. Splices are also inherently weak connections that are prone to failure, which happened to the team's 2010 ROV Competence. The team researched proven methods of splicing and found a large amount of documented research from NASA. By wrapping each wire around each other or wrapping a single strand of wire around the two wires being spliced, the strength of the connection can be significantly improved. This method more than doubled the time it took to solder each connection, but the results are apparent. Waterproofing these connections requires a multi-layer process that involves a layer of heat shrink cable wrap, a layer of liquid electrical tape, and another layer of heat shrink cable wrap. The first layer of heat shrink protects each individual connection from short circuiting to another. The layer of liquid electrical tape assures that water cannot reach the electrical connections. The final heat shrink layer wraps each connection together to protect from physical damage potentially caused by snagging or otherwise being exposed.

Troubleshooting Techniques

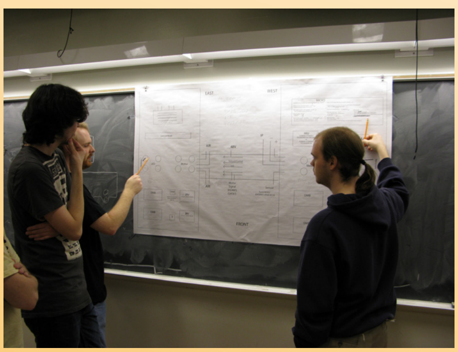

Fig. 36 - Block diagram used for some critical thinking in the early design phase.

The large number of electrical parts on ROV *PotaTOS* led to a significant amount of confusion early on, especially for new members of the team. Understanding what each board was responsible for, and thus what each board designer was responsible for, would be critical to a functioning system. These issues were essentially new for the Purdue team since most of past electrical systems were only designed by two members. Now, there were six members working on an even more complex system. The initial attempts to solve this were simple weekly meetings where all the electrical team members would have open discussion about what the system should look like. These meetings often ended with just as much confusion as they had begun. To help the team understand the discussion better, a very large poster sized electrical block diagram of the entire ROV was printed and hung on a wall. *(See Fig. 36)* Each member then had pencils to write out what they were thinking or what was needed for each board on to the poster. This poster method offered immediate clarity and remained available as reference throughout the early design phase. This method will be used again by the team in future years.

Lessons Learned and Skills Gained

The experience of building *PotaTOS* has taught both new and returning members many important skills. Most important of which is team work. No course can teach the ability for electrical and mechanical engineers to work together to make an end product that is up to professional standards. The Purdue team always treats its vehicles as test beds for learning. The electronics team learned how to work with an ARM processor for building the board and coding the vehicle's software. There were a few new electrical members whose previous skill set ranged from designing some simple PCBs to never having done much soldering at all. The team had four new mechanical engineering members that had their first experiences with Solidworks 3D modeling. Some of the mechanical team members even helped with populating the electronics boards. A new challenge for the mechanical group this year was working with an outside machine shop. Because the team had enough funds to outsource some of its most complex pieces, an on campus University affiliated machine shop was contracted. This meant that the mechanical group had to learn how to make drawings that could be read by a professional machinist. Making these drawings well can be extremely challenging in that the engineer must effectively communicate the design intentions, what tolerances are and are not important, and any other important criteria. If the machinist understands what the engineer is hoping to accomplish, they can often find ways to simplify the construction and reduce cost.

Future Improvements

There are few things to improve on ROV *PotaTOS*. Many opportunities for software exist given the electronic hardware already equipped on the vehicle; such as auto pitch and roll stabilization, depth holding, 'dead reckoning' measurement (using the vehicle's accelerometer to estimate distance travelled as a method to measure the length of the shipwreck), and overall quicker vehicle response. However, many of these features require a significant amount of time beyond what is available for the project. There is one mechanical design flaw that reduces the potential rigidity and strength of ROV *PotaTOS*' frame. The heaviest components, her thrusters and her electronics tubes, are outside of the last vertical supports attaching the bottom frame and the top frame. This applies unintended forces on the outside edges of the top frame piece, especially when the vehicle is in air as both forces are downward. However, in water, the thrusters apply downward force far out from this support point while the electronics tubes provide upward force (due to their buoyancy) closer to this support point *(See Fig. 38)*. This combination of forces and distances creates a balanced moment of forces around the concerning support point, as illustrated in *Figure 39*. Therefore, the flaw is not significant during a mission run. While the frame is plenty strong for all practical purposes even when in air, the flaw could be fixed by adding a diagonal support beam to connect the outside edges of the top and bottom frame.

Group Reflection

Fig. 37 - Early assembly

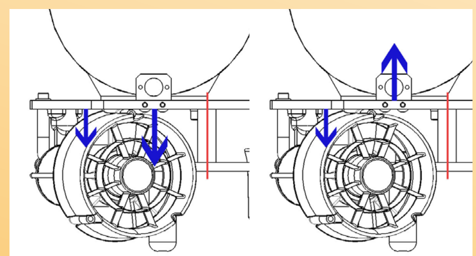

Fig. 38 - Weight distribution in air vs. submerged

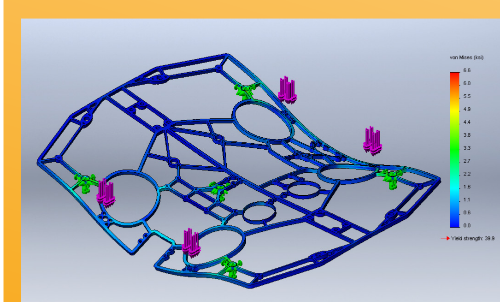

Fig. 39 - FEA Deflections

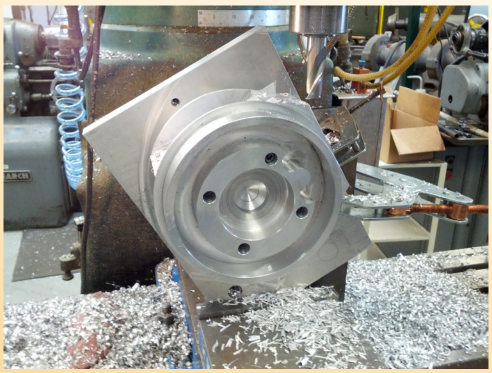

Fig. 40 - Carriers in the process of being milled

Fig. 41 - The team workshop

This is the fourth year for the Purdue IEEE ROV team. The team began in 2009 with four team members, a $500 budget, and a 5th place international finish. The team returned in 2010 with seven team members, a $6000 budget, and a 4th place international finish. In 2011, the team had nine team members, a $14,700 budget, and a 2nd place international finish. The speed of growth of the team's skills, knowledge, and abilities has surpassed that of all expectation. For 2012, the Purdue team returns seventeen members strong with a $24,000 budget and conviction to both perform best in the pool and place first in the international competition.

The sophistication of the new vehicle is immense, but that also means the complexity is immense. How far we want to let ourselves go is a debate the team has every year. If we go too far, we would never be able to complete the vehicle in time and within budget. Last year's ROV tested these limits with over 3500 man-hours and a completion date within a week of the international competition. However, we cannot lose sight of the fact that leaving our comfort zone and learning from it is the entire reason we compete. It's hard to imagine where the team can go next.

Team Safety

The Purdue IEEE ROV team practiced safety during both construction and operation of ROV *PotaTOS*. Operation of all power tools required the use of OSHA approved glasses. The use of advanced tools owned by the team, such as a CNC mill and horizontal band saw, are safer than hand drills and hack saws when used properly because the work piece is not held by the user. 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 on-board fuses and systems designed to prevent damage if communication is lost with the surface. There is also a main inline fuse on the tether at the surface. Electrical system activations on the vehicle are slightly staggered over approximately two seconds to reduce high inrush at vehicle start up. 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 patch rack mechanism. In the team's three years of operation, only a few minor scrapes and no serious injuries have occurred.

Outreach

The Purdue IEEE ROV Team believes that educating grade school students about the benefits of STEM (Science, Technology, Engineering, and Mathematics) and the Marine Engineering industry is important. This could open up a new world of opportunity to those students the team reaches. The team has utilized its 2011 ROV, Hybris, throughout the year as an ambassador for STEM learning at events such as Celebrate Science Indiana and on campus grade school visits *(See Fig. 42)*. These events put the vehicle and the team in front of thousands of young students from Indiana. Another new initiative for the team is reaching out to a Ranger class team to foster a long term mentoring partnership. This year, the Purdue team worked with the Eli Whitney School in Chicago *(See Fig. 43)*. While this was limited to only one visit and a few phone calls, the team hopes that this partnership can grow stronger in the coming years. Finally, the team has made an attempt to educate as many Purdue students as possible about the Marine Engineering Industry *(See Fig. 44)*. Most students on campus have no knowledge of what opportunities are available to them and presenting the vehicle at many public events is helping to change that.

Fig. 42 - Celebrate Science Indiana IEEE Booth

Fig. 43 - Seth explaining alternative Ranger control box to students at Eli Whitney

Fig. 44 - ROV Hybris being presented at the Shell Energy Expo at Purdue University

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External Bill of materials - http://db.tt/bMjWoyNt
Technical Documents from Manufacturers of Purchased Items- http://db.tt/m1PgHYwu

Expense Report

Item	QTY If Applicable	Expense Cost USD / Unit	Donations Cost USD / Unit	Income Monetary
ROV Construction				
Waterjet Aluminum Frame		$450.00		
Assorted Machining from Local Machine Shop		$6,500.00		
Raw Aluminum, Stainless Steel, and Plastic Stock		$1,920.00		
Stainless Steel Bolts & Washers		$146.00		
Glues and Tef-Gel Corossion Protection		$65.00		
Bearings		$110.00		
Pneumatic Systems (Solenoids, Fittings, Tubing, Pistons)		$543.36		
Electronics Tube O-Rings	8	$6.25		
Multi-Purdue Sensor Spring		$35.00		
Seabotix Thruster Refurbishment (parts discounted)	8	$213.65	$150.00	
Board Cameras (from Supercircuits)	4	$123.72		
Tether Materials (Power Line, Ethernet, Pneumatic Tubes)		$370.00		
Binder-USA Waterproof Connections (50% off)		$424.08	$424.08	
Stainless Steel Tape Measure		$16.24		
Laptop to Drive ROV (Previously Owned)		$1,000.00		
Video Displays (televisions)	2	$147.66		
Custom Electronics (Microcontroller, Motor Drivers, etc)		$4,317.35		
Salt Water & Fuel Pumps and Adapters	2	$170.00		
Other/Travel				
Driving to Orlando (3 Round Trips with Team Member Cars)		$2,250.00		
Hotel in Orlando (6 Rooms)		$2,020.00		
SolidWorks	15		$1,300.00	
Competition Fee		$50.00		
Prototyping Costs (Electrical and Mechanical)		$950.00		
Poster		$150.00		
Presentation Materials		$90.00		
Power Tools and Accessories				
Set of Mission Props for Practice		$108.20		
Air Compressor		$242.99		
Donations				
Purdue Office of the Provost				$5,000.00
Indiana Space Grant Consortium				$5,000.00
Purdue Engineering Student Council				$4,000.00
Purdue IEEE Student Chapter				$2,697.62
Northrop Grumman				$2,000.00
Purdue College of Engineering				$1,500.00
Lockheed Martin				$1,450.00
Purdue Student Government				$1,000.00
Family of Team Members (see acknowledgements)				$2,000.00
Summary **Please Note: Quantity is taken in to account before values are summed**				
ROV Construction		$18,786.43	$1,624.08	
Other/Travel		$5,861.19	$19,500.00	
Donations				$24,647.62
TOTAL		$24,647.62	$21,124.08	$24,647.62
Total Remaining Balance	**$0.00**			

Table 1 - Expense Report

Acknowledgements

Monetary Donations

IEEE
INSGC
PESC
PURDUE ENGINEERING
LOCKHEED MARTIN
NORTHROP GRUMMAN
PURDUE OFFICE OF THE PROVOST

Purdue Student Government
Sandy Baklor and Arlene Kaufman
Dave and Sydell Berman
Sue and David Liebman

Discounts or Non-Monetary Donations

SeaBotix
binder USA
SolidWorks
ArtSoft Mach3

Aperture Aquatics would also like to thank:
All the volunteer judges of the MATE Competition
The MATE Center for providing us with this opportunity
Shedd Aquarium for hosting the Midwest Regional
Veteran team members Clayton Kleppinger and Clement Lan for mentoring our new electronics members
Purdue Research Machining Services for being such a great machining resource
Purdue School of Mechanical Engineering for allowing the ROV to be an ME Senior Design Project
Purdue School of Electrical and Computer Engineering for offering guidance in fund raising
Chuck Barnett for use of the Electrical Engineering Lab
Chuck Harrington for use of his Machine Shop
Robin and Isaac Angel for allowing us the use of their pool
Friends and Family for putting up with us during the build season

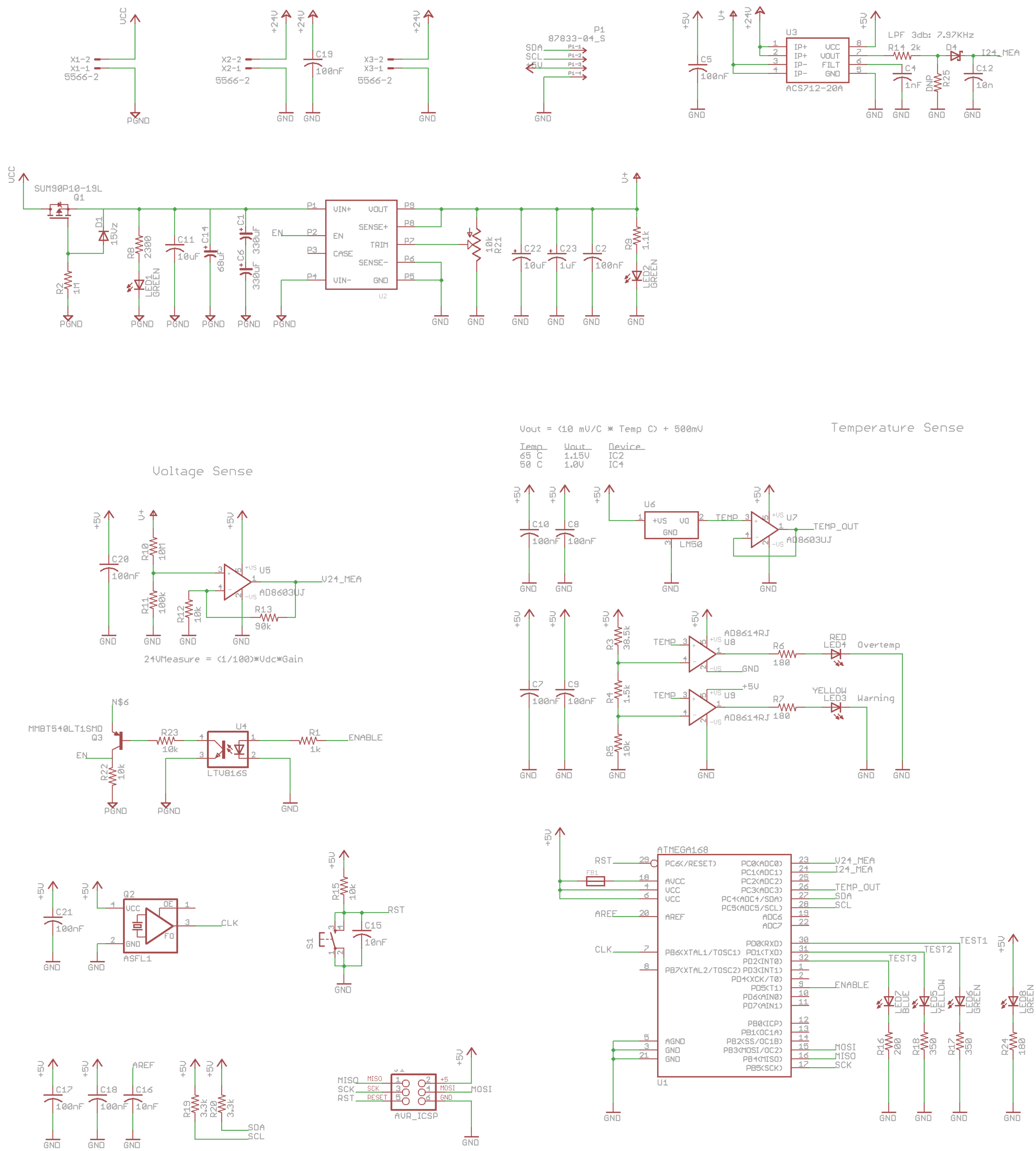
A-I 2012 Technical Report

PURDUE ENGINEERING

Purdue Offshore Tanker Assessment and Tactical Operations Submersible

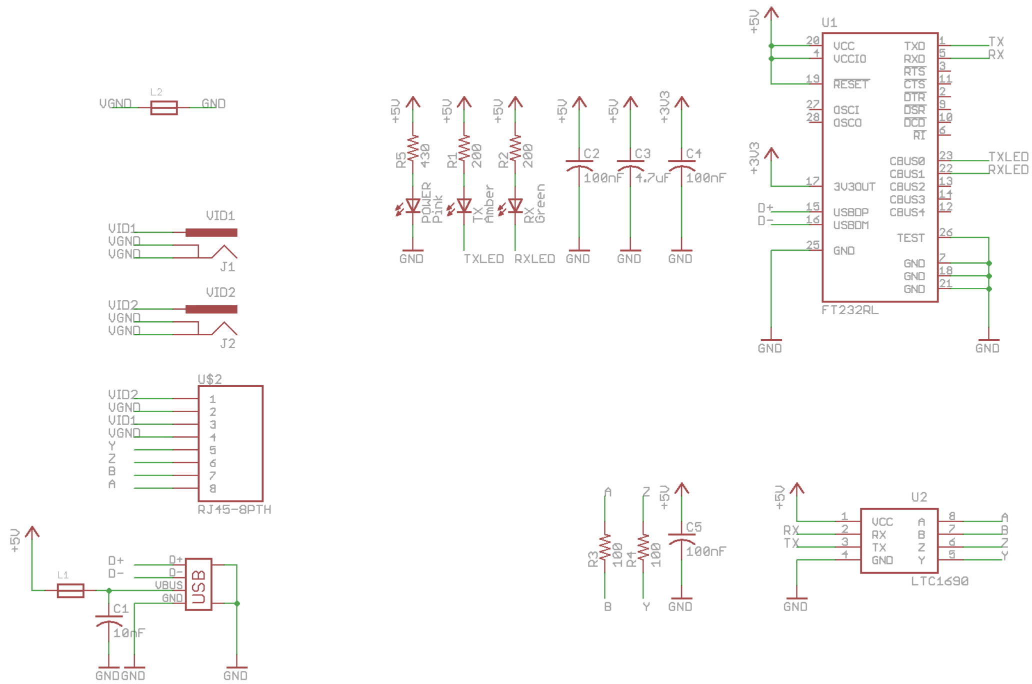
Appendix A - Electrical System Schematics

DC-DC Module Board Mk2

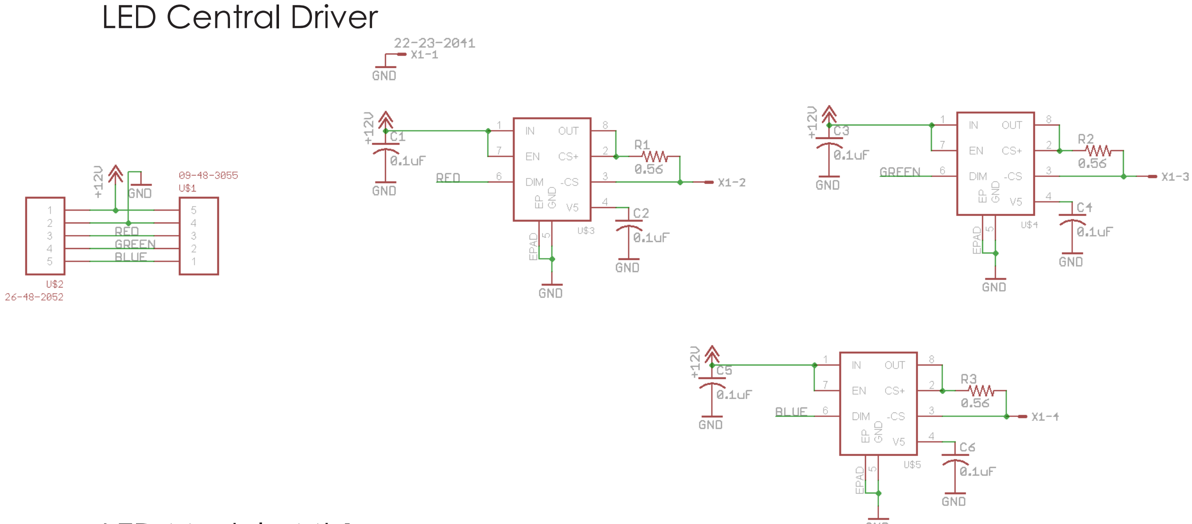


Appendix A - Electrical System Schematics

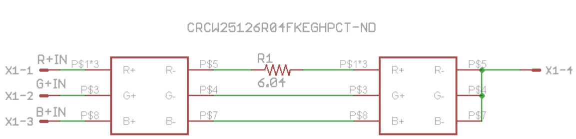
Interface Adapter



LED Central Driver



LED Module Mk1



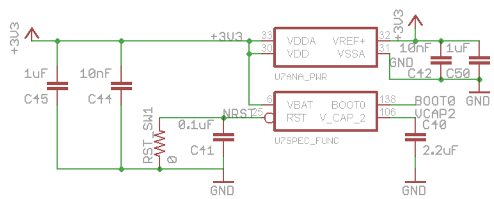
A-III 2012 Technical Report

PURDUE ENGINEERING

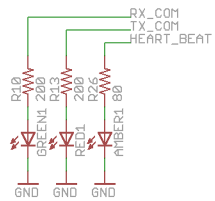
Purdue Offshore Tanker Assessment and Tactical Operations Submersible

Appendix A - Electrical System Schematics

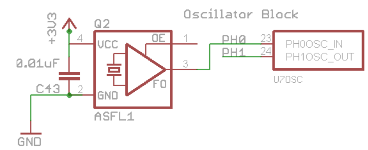
Microcontroller Board Mk2



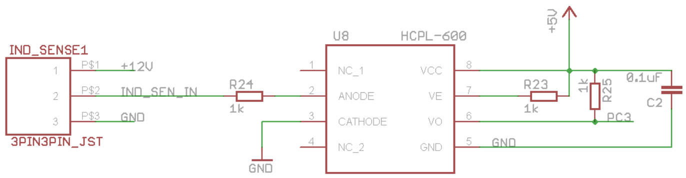
ADC Power



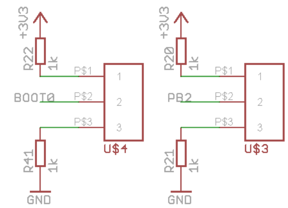
Microcontroller status LEDs



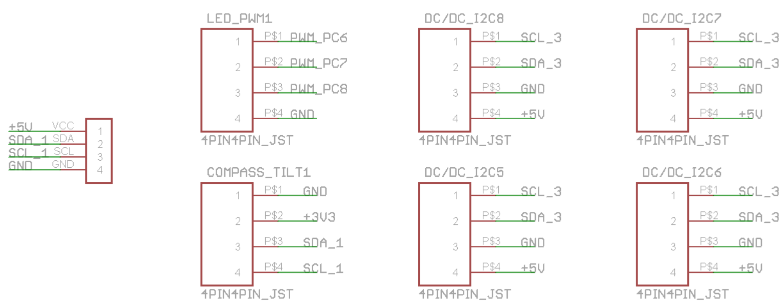
Microcontroller Oscillator

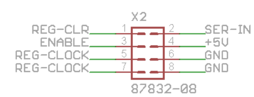


Induction Proximity Optical Isolator



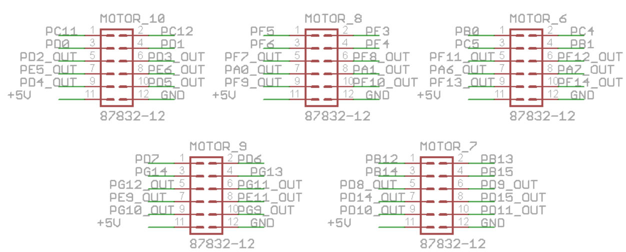
Microcontroller Boot Selection Pins



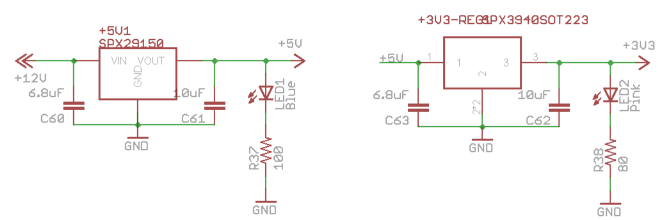


Solenoid Board Connector

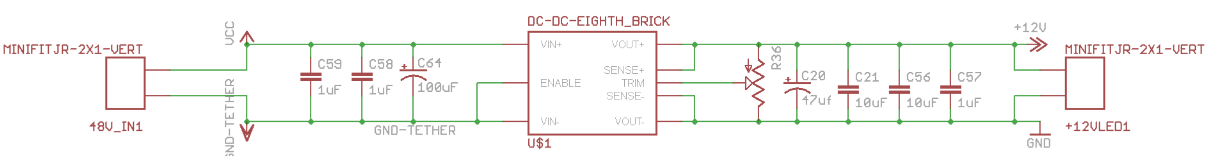
Connectors



Motor Connectors



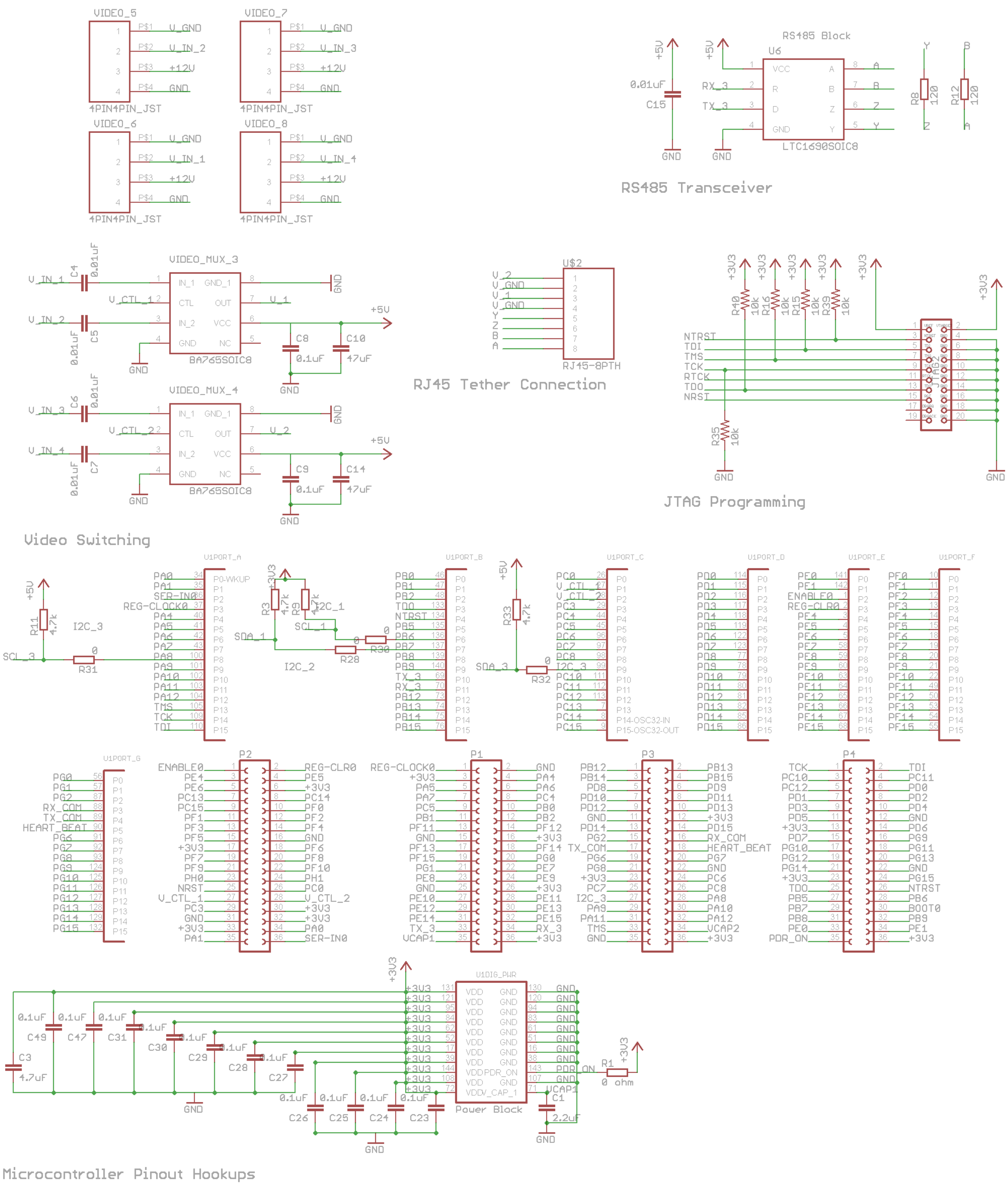
Power Distribution Network



DC/DC Converter (48V to 12V)

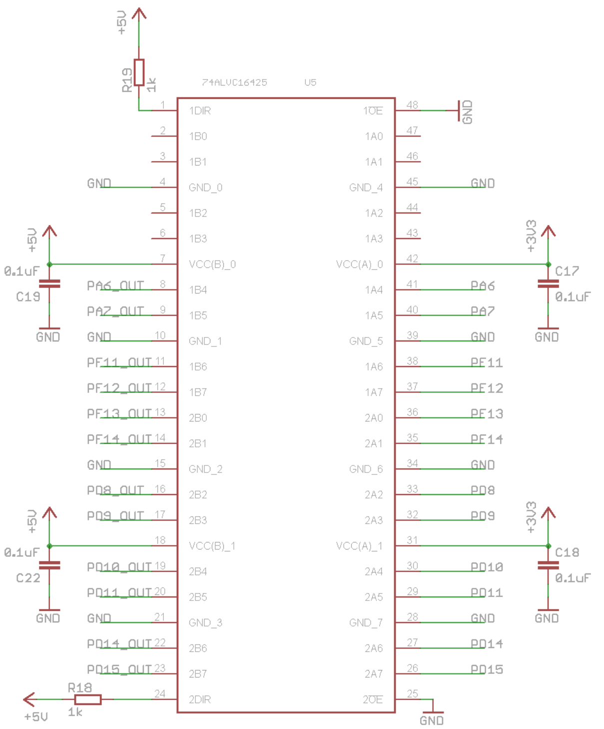
Appendix A - Electrical System Schematics

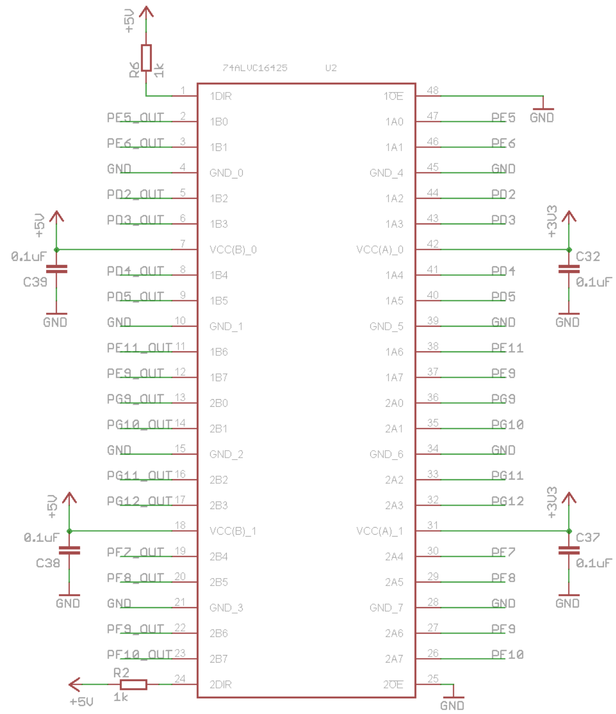
Microcontroller Board Mk2 (continued)



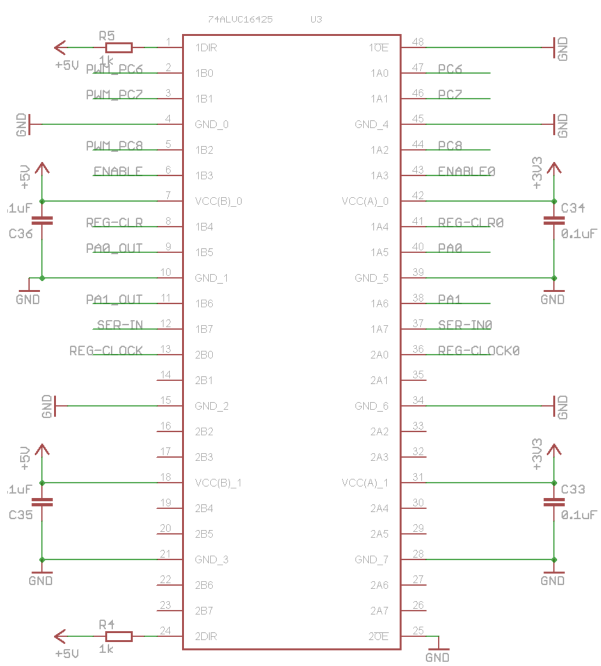
Appendix A - Electrical System Schematics

Microcontroller Board Mk2 (continued)





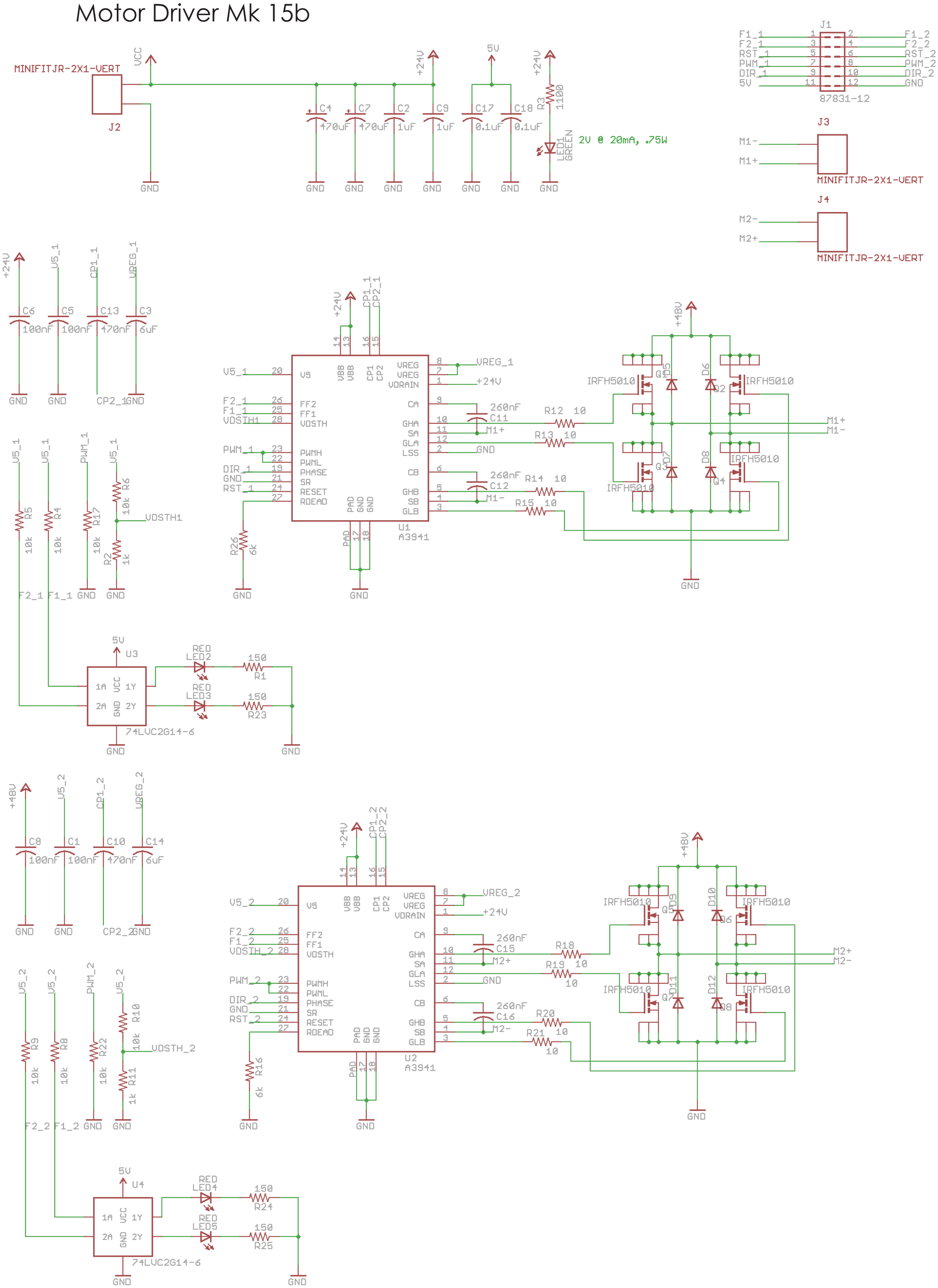
Level Shifters



Level Shifter

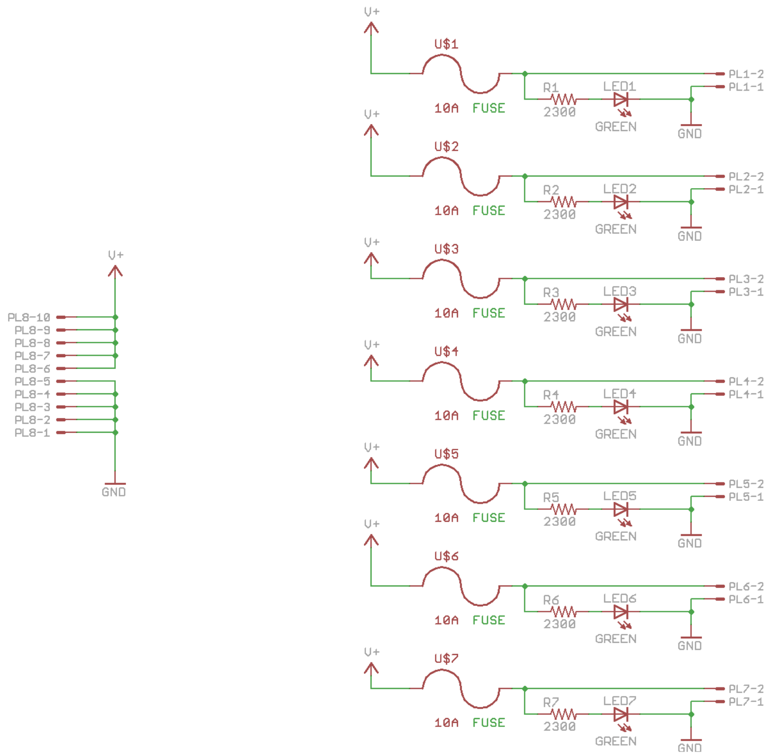
Appendix A - Electrical System Schematics

Motor Driver Mk 15b

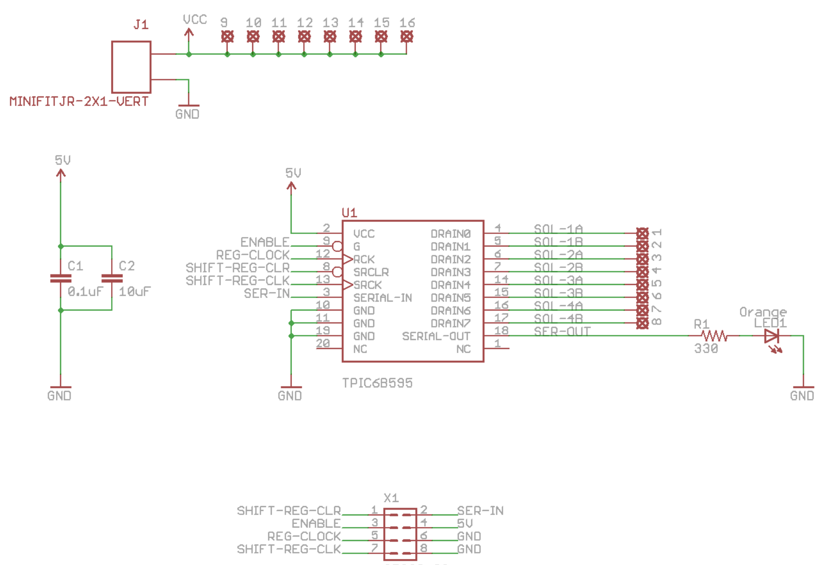


Appendix A - Electrical System Schematics

Power Breakout Mk1

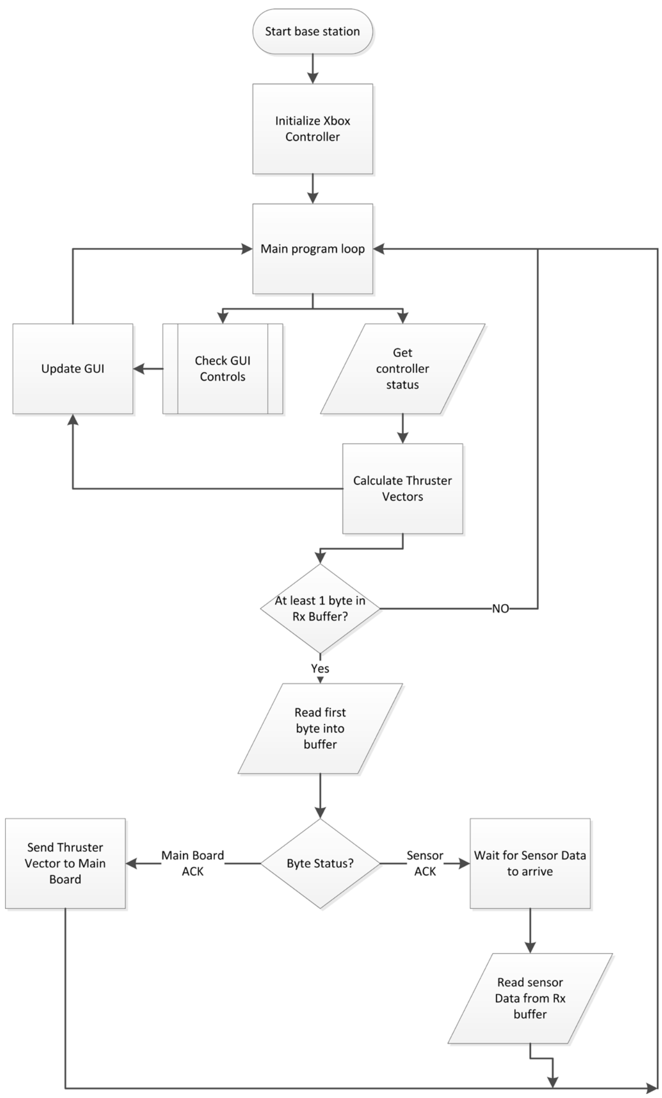


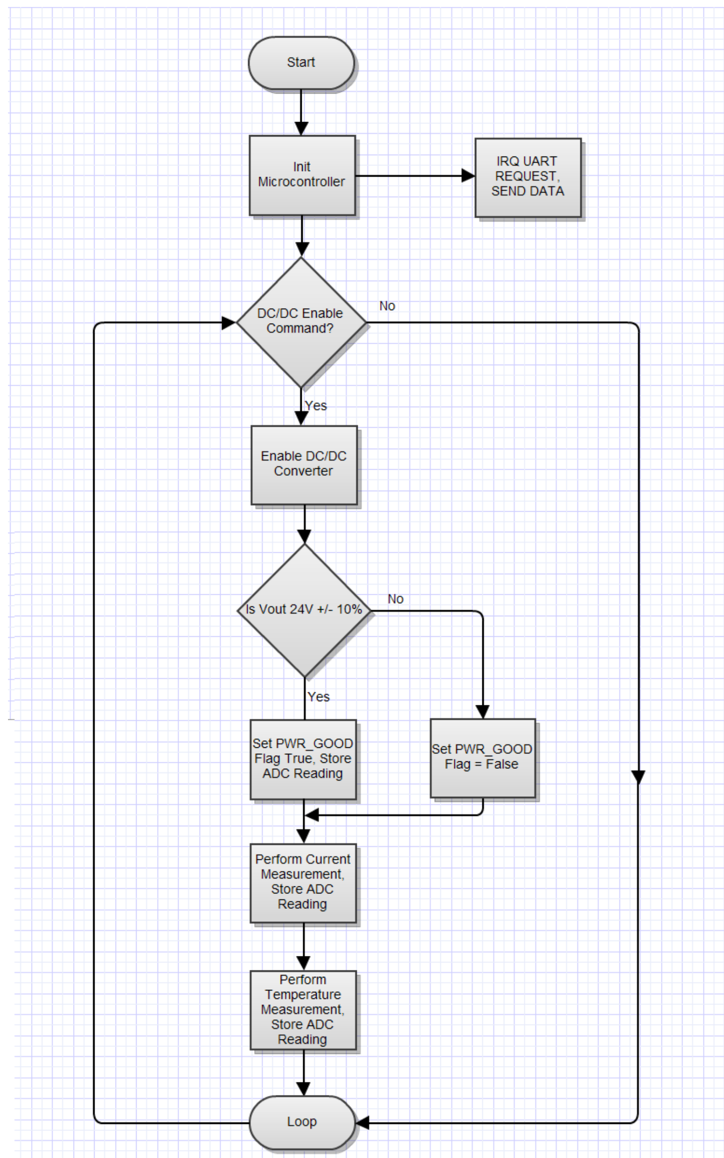
Solenoid Driver Mk1



Appendix B - Software Flowcharts

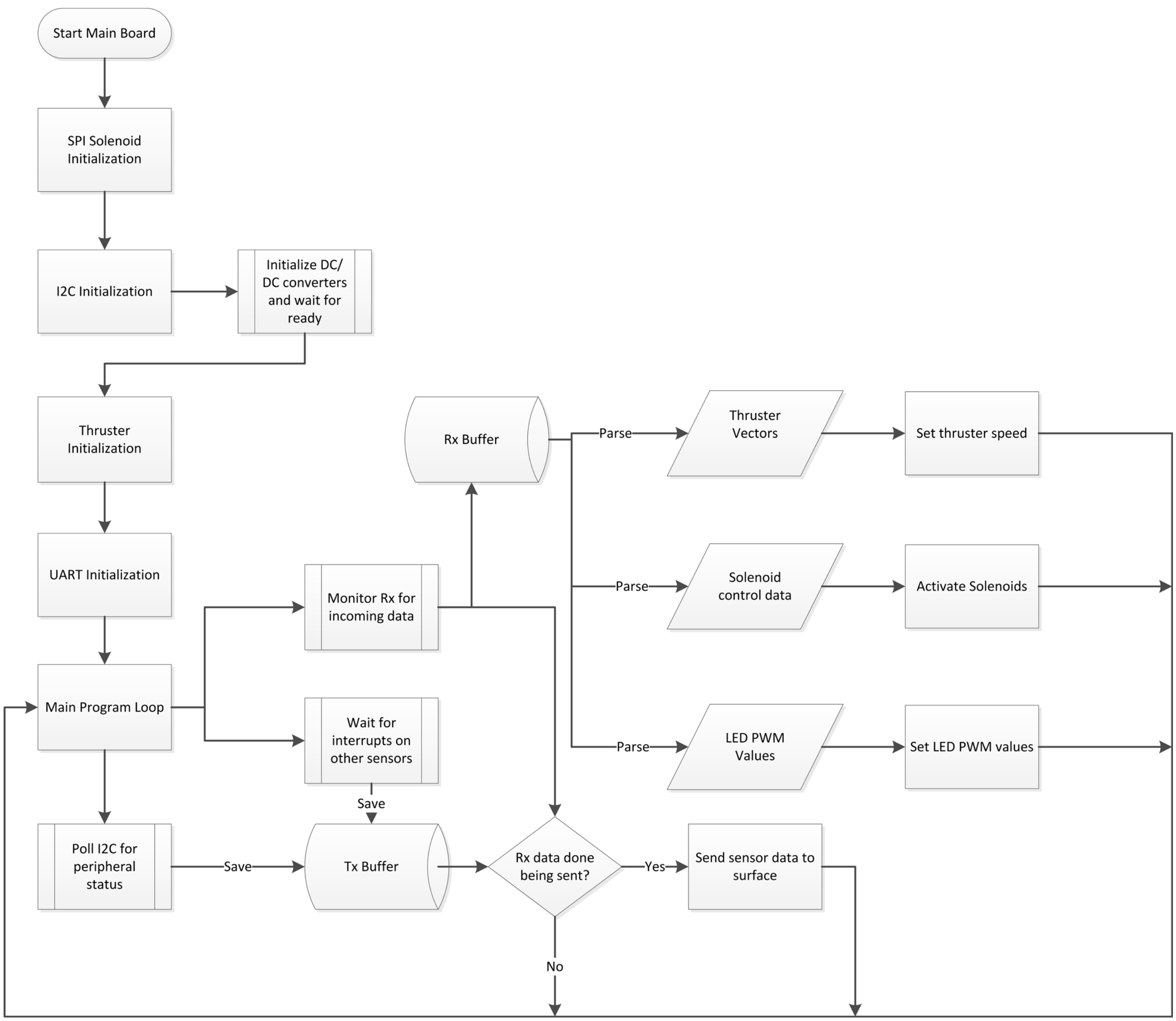
Basestation & DC/DC





Appendix B - Software Flowcharts

Main Board



Appendix C - Pneumatic System Diagram

Pneumatic System