NASA Space Grant Robotics
Koi 2.0 ROV

COMPANY NAME NASA Space Grant Robotics

INSTITUTION Arizona State University

LOCATION Tempe, AZ – United States

MATE SEASONS 2009 –2013

EMPLOYEE LIST				
Name	**Major**	**College Level**	**Team Position**	**First MATE Season**
Matthew Plank	Computer Systems Engineering	Junior	Chief Executive Officer	2012
Michael Przeslica	Materials Science & Engineering	Junior	Chief Electrical Engineer	2012
Jonathon Houda	Mechanical Engineering	Junior	Chief Mechanical Engineer	2010
Anthony Hallas	Computational Mathematical Sciences	Senior	Chief Programmer	2011
Josh Miklos	Computer Science	Sophomore	Senior Programmer	2013
Ben Mackowski	Electrical Engineering	Sophomore	Programmer, Historian	2012
Max Ruiz	Electrical Engineering	Freshman	Senior Electrical Engineer	2013
Joseph Mattern	Electrical Engineering	Freshman	Electrical Engineer	2013
Carl Stevenson	Electrical Engineering	Freshman	Electrical Engineer	2013
Peter Tueller	Electrical Engineering	Freshman	Electrical Engineer	2013
D. Benjamin Teoh	Accountancy	Senior	Mechanical Engineer, Chief Financial Officer	2012
Erick Yanez	Mechanical Engineering	Senior	Mechanical Engineer	2012
Drew Denike	Mechanical Engineering	Freshman	Mechanical Engineer	2013
VaibhavMenon	Aerospace Engineering	Sophomore	Mechanical Engineer	2013
Tyler Achey	Mechanical Engineering	Junior	Mechanical Engineer	2012
Jonathan Paul	Mechanical Engineering	Freshman	Mechanical Engineer	2013
Emily McBryan	Aerospace Engineering	Senior	Consultant	2009
Alex Kafka	Exploration Systems Design	Senior	Senior Consultant	2009
Mike Veto	Ph.D. Candidate Geological Sciences	Graduate	Senior Consultant	2009
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Abstract

In 2013, the ASU/NASA Space Grant Robotics Corporation has been upgrading the systems on our underwater vehicle Koi, from the previous year. Koi has an elegant design that integrates both remote operations and semi-autonomous controls for ease of use and precise movements. Koi moves smoothly through the water with five powerful custom thrusters capable of five degrees of freedom including tilt and strafe. To complete the mission objectives, Koi utilizes two custom claws and four cameras. Koi also comes equipped with an IMU (Inertia Measurement Unit) for directional aid and a depth sensor which is relayed on the operator's heads up display. The team is composed of a variety of undergraduate students attending Arizona State University. Fueled by challenges from the MATE competition, their application and innovation makes the NASA Space Grant Robotics team a strong force at ASU and a proud representation of the Space Grant Consortium.

Safety Features

Koi has several safety features to allow it to shut down in case of signal or power loss. The Arduino microcontrollers are programmed to shut down after 1.5 seconds without a signal from the surface. Both the Castle brushless motor speed controllers and the Sabertooth brushed motor speed controllers shut down and reset, cutting power to the motors if the signal line does not receive any data. The programming code is set up with an emergency stop feature, strategically placed within reach on the front of the Xbox controller, to quickly stop all commands and send a neutral pulse to all motors.

All of our electrical systems are individually fused to prevent any overloads or shorts from causing significant failures and damage to systems or persons. The tether is similarly fused closest to the surface power connection. Our company uses Anderson Powerpole connectors to insure a correct and proper electrical mating of components and wires. Koi is equipped with wet-mateable connectors on the exterior to prevent any water from seeping into the electrical enclosures or into the connectors themselves.

Our frame also included a few safety features. The most obvious is the handles that are embedded into the frame, giving the people who carry the robot a safe and comfortable place to grab, which was also important so as the robot would not be dropped. All sharp edges of the robot have also been smoothed out so that no one would cut himself or herself. Also, plastic skids have been placed on the bottom of the robot so that when it comes in contact with the floor, nothing will be damaged. Guards/housings have been placed around the propellers to prevent objects from coming in contact with the moving blades. Caution tape has also been placed on critical areas such as the propellers to warn of potential hazards.

Design Rationale – Mechanical

In order to create a robot that is both neutrally buoyant and hydrodynamic, our mechanical division chose a simple symmetric design with a bow and stern container for housing the electronics. This allows for easy assembly and disassembly of the robot and still maintains an even balance. Inside the electrical enclosures are cameras, which maximize the use of the enclosure space and thereby limiting points of failure on the ROV regarding water leaks. The camera systems inside the enclosures are mounted on a pivoting structure to provide a varied viewpoint, which drastically increases the visibility that Koi has.

Figure 1: Koi Design

The frame is composed of two separate parts, a top and a bottom. The top part contains all the bare requirements for the ROV to run: computer, cameras, and thrusters, while the bottom half is for the payload. This design provides modularity to Koi since the payload can be switched out for any given mission with just a few bolts and wire connectors. The location for the payload and manipulators offers ample accessibility for Koi to observe and manipulate the environment for mission. Koi is controlled with five thrusters providing five degrees of freedom including tilt and strafe.

To maintain neutral buoyancy of Koi, a block of syntactic foam is used along with the air inside the two large electronic enclosures. The design of Koi's structure puts all sources of buoyancy above the lines of the thrusters and symmetric about the frame and center of mass. This gives it stability in the water, which is necessary for maintaining its maneuverability.

Frame Design

In order to create a robot which is both neutrally buoyant and hydrodynamic, our mechanical division opted for a simple symmetric design with a bow and stern container housing the electronics. This allows for easy assembly and disassembly of the robot and maintains balance. Also inside the electrical enclosures are cameras, this maximizes the use of the enclosure space and limits points of failure on the ROV regarding water leaks. The camera systems inside the enclosures are also mounted on a pivoting structure to provide a varied view point; this drastically increases the visibility from ROV Koi.

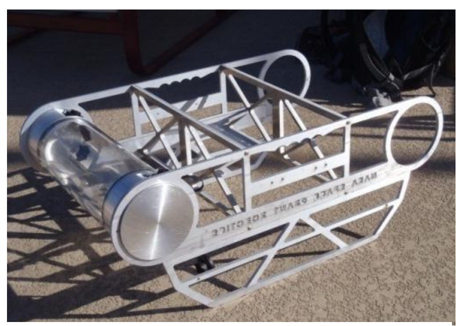


Figure 2: Koi Frame

The frame is composed of two separate parts; the top part contains all the bare requirements for the ROV to run: computer, cameras, and thrusters, while the bottom half is for the payload. This design provides modularity to Koi since the payload can be switched out for any given mission with just a few bolts and wire connectors. The location for the payload and manipulators offers ample accessibility for Koi to observe and manipulate the wreck site or any other mission. Koi is controlled with five thrusters providing five degrees of freedom including tilt and strafe.

To maintain buoyancy of Koi, a block of syntactic foam is used along with the air inside the two large electronic enclosures. The design of Koi's structure puts all sources of buoyancy above the lines of the thrusters and symmetric about the frame and center of mass.

Claw 1: Magneto Coupled Manipulator System (MCMS)

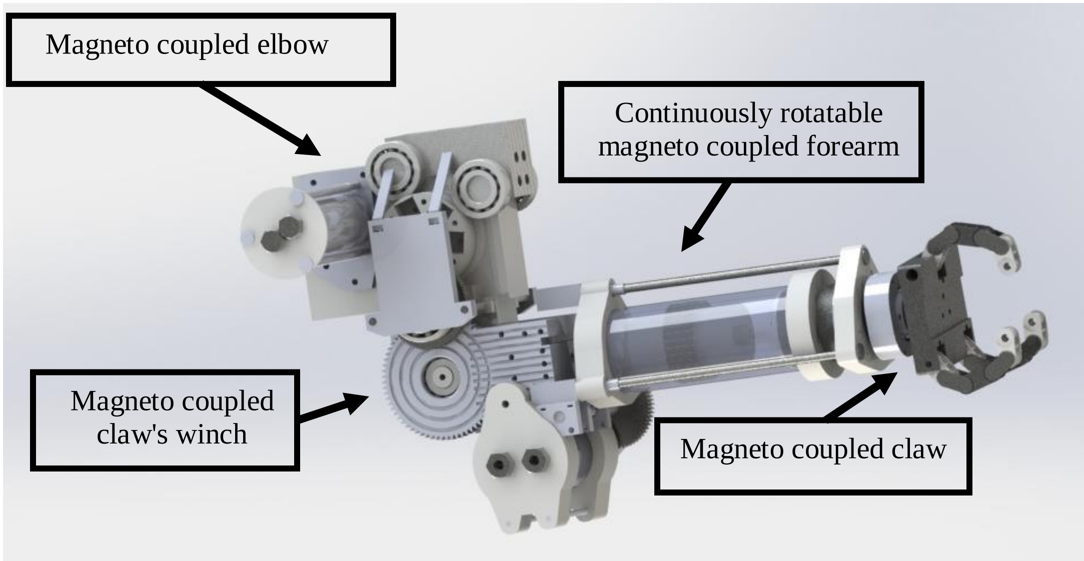


Figure 3: Magneto Coupled Manipulator System

In order to perform a variety of complex tasks with the minimal amount of manipulators and advanced underwater manipulator technologies, Koi features a custom magneto coupled manipulator arm and claw. The custom manipulator system overcomes complex tasks due to the dexterity and continuously rotatable forearm, allowing Koi to easily reposition the claw to grab different objects and easily rotate them to any degree. Furthermore, as NASA Space Grant Robotics is always trying to advance submersible vehicle technologies, the custom manipulator system utilizes magneto couplers to actuate all of its systems including the claw system which utilizes a magneto coupled winch system and custom built gyro to allow the claw to be continuously rotatable as mentioned earlier.

Claw 2: Modular Motor Claw (MMC)

Koi is equipped with a second redundant claw. Based off of already waterproof motors normally used in bilge pumps, this claw is a simple backup to the MCMS. Located on the stern of Koi, this manipulator also provides another point of contact for which it can interact with its environment. This claw features an opening and closing action, as well as a rotation, allowing multiple ways of grasping an object. The jaws of this claw are also specifically designed to hold onto the SIA and CTA and ensure that they will not be unintentionally lost in travel to the study site. Additionally, this claw is constructed of a clear polycarbonate. This helps prevent some of the loss of view on the cameras due to the claw. It also aids in positioning Koi as it is grasping an object to pick up.

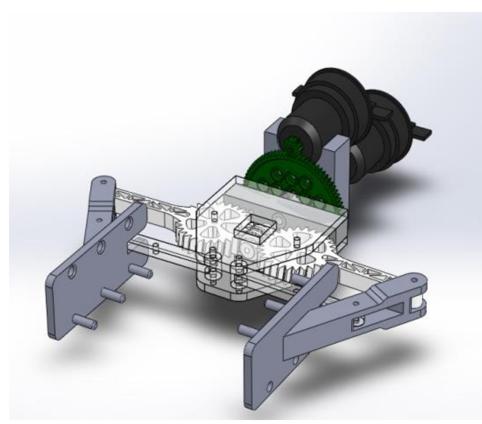


Figure 4: Secondary Claw installed on Koi

Side Camera Enclosure

Koi is equipped with another camera in addition to its bow and stern cameras. This camera is mounted on the side with a full pan-tilt mechanism. This allows for a much greater field of view and eliminates many of the blind spots on Koi. The increased field of view from this camera is necessary to help locate the various elements of mission task.

Design Rationale– Electrical

The electrical systems are divided between the two cylindrical enclosures. From its inception, the plan was to give this ROV extensive autonomous capability beyond what the company has attempted previously. Having two enclosures allow for easy replacement and upgradeability of the onboard computer and cameras without requiring the rearrangement and rewiring of more fundamental components.

Inside each enclosure is a polycarbonate sheet on which the electronics are mounted. Servicing the electronics has been made easier by routing wires leaving the enclosure through a DB-25 connector. Removing an end cap of the enclosure will automatically disconnect this connector. Sliding the enclosure back together will reconnect the DB-25, similar to installing PCI cards into a desktop personal computer.

Stern Electronics Enclosure

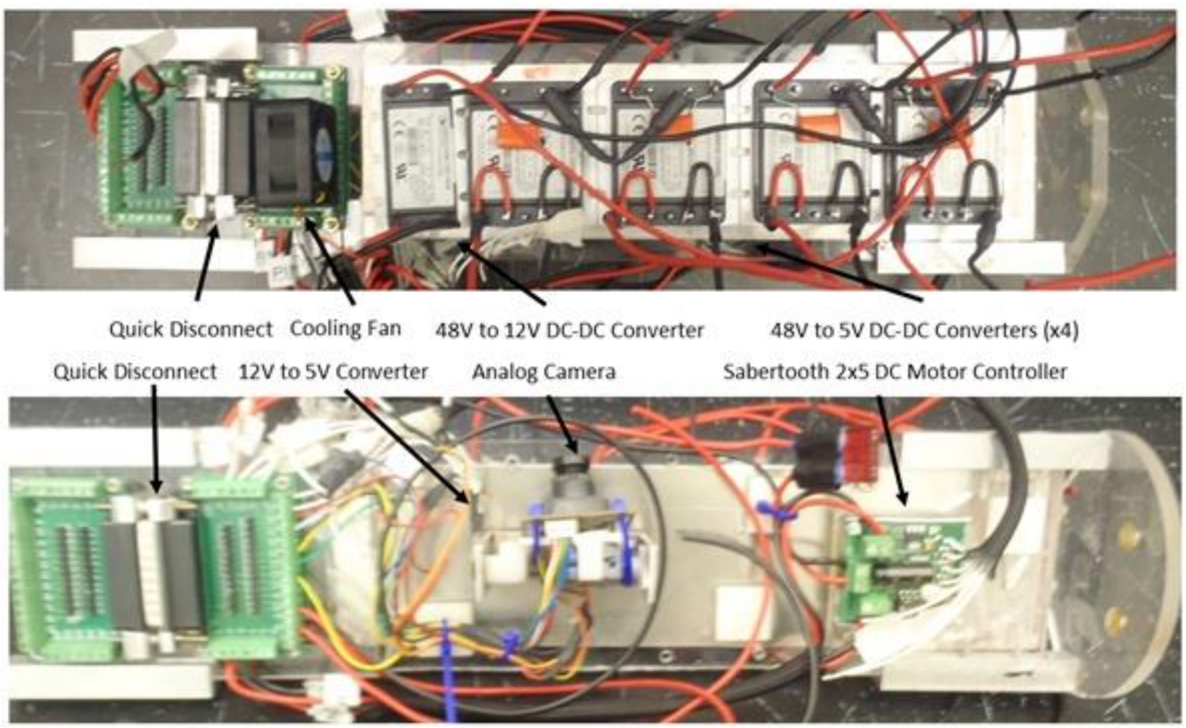


Figure 5: Stern Electronics Enclosure

The stern enclosure contains a reliable electrical system our team has perfected in previous ROVs (including thruster and motor control, sensors, and power management). The power tether brings fused 48VDC power from the surface into the stern enclosure. One Vicor DC-DC converter outputs 150 watts of 12VDC from supplied 48VDC. The 12VDC is used to power three Sabertooth 2X5 brushed DC motor controllers also located in the stern enclosure and an ATMEGA2560 microcontroller and PC located in the bow enclosure.

Four 48VDC to 5VDC Vicor DC-DC converters in the stern enclosure provide a total 800 watts of power for the thrusters on Koi. These converters are linked with a one-wire interface, allowing automatic load sharing and redundancy if one of the converters were to fail. The power is equally divided and separately fused between two circuits, one which powers the left, right, and strafe thrusters and another which powers the two vertical thrusters.

Koi's three dual-channel Sabertooth speed controllers in the stern enclosure can control two brushed DC motors each, saving a significant amount of space in the enclosure. The controller is capable of peak output current of 10 amps and (a normal output current of 5 amps to each motor) from 6 to 12 VDC. They also feature auto-centering code which automatically trims attached motors by assigning the zero output value to the first signal the microcontroller provides. Each Sabertooth speed controller is protected with a 10-amp auto-reset fuse. Two signal lines pass from each speed controller to the Arduino MEGA microcontroller. Providing three controllers on Koi allows us to operate two custom manipulators designed for this mission.

Bow Electronics Enclosure

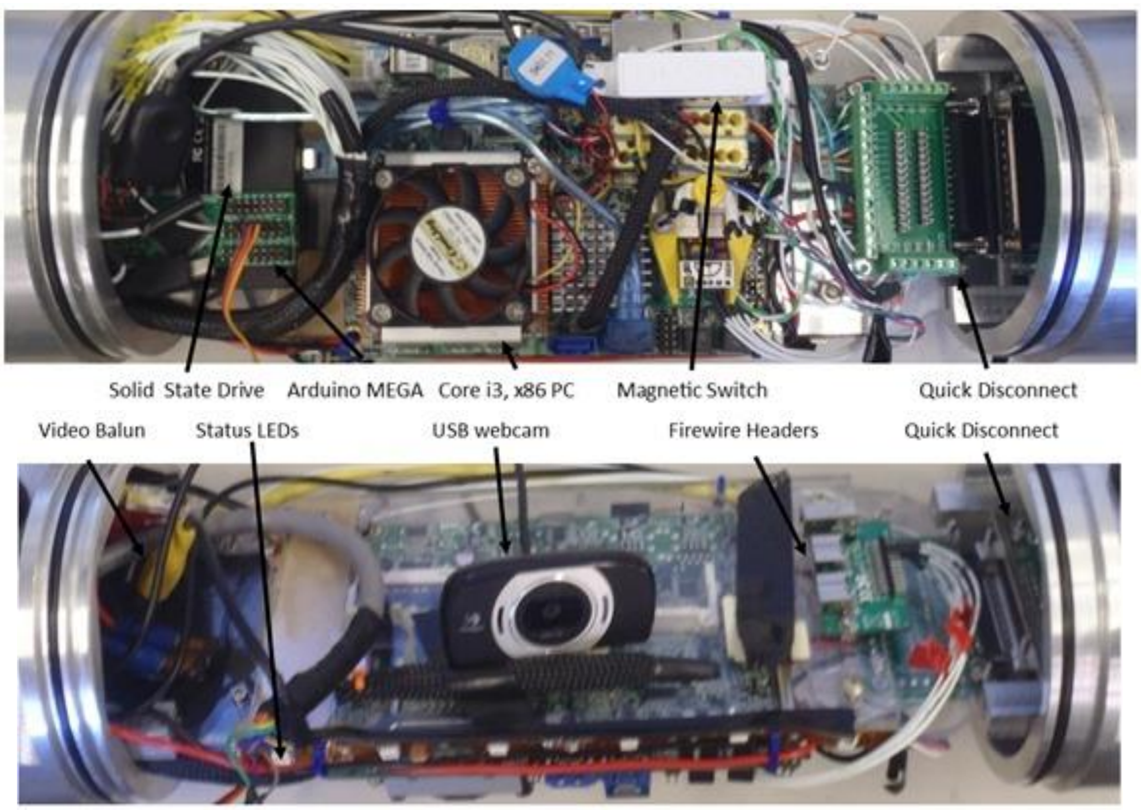


Figure 6: Bow Electronics Enclosure

The ATMEGA2560 serves as the hub for electromechanical robot functions. It is an Arduino compatible microcontroller, ideal for our ROV for because of its robust hardware, extensive public codebase and documentation. It controls motors through digital PWM (pulse width modulation) output and receives data from the IMU and other sensors. The IMU used is an ArduIMU3+, designed originally to convert RC (remote-controlled) planes into UAVs (Unmanned Aerial Vehicle). It contains an ATMEGA328 microcontroller (Arduino compatible) to manage a 6-axis gyroscope/accelerometer sensor and a 3-axis magnetometer. These sensors provide information to the main ATMEGA2560 for semiautonomous functions and transmitted to the surface for telemetry. The advantage of this IMU is that it offloads the sensor processing to the microcontroller on the IMU rather than sending raw data to the ATMEGA2560microcontroller. It has been reprogrammed to provide data in a format most convenient to the programming team. The IMU sends data over a serial connection to the main ATMEGA2560 and requires 5VDC from a linear regulator.

To monitor external pressure, a Honeywell industrial pressure sensor is bolted to the bow enclosure. This sensor provides a simple linear voltage response to water pressure. Our model, PX2EN1XX100PSAAX, is equipped with a cable harness type connection with a ¼" pipe length and 18 threads per inch. The sensor has a maximum pressure range of 100 psi and a ratiometric voltage output from 0 – 5 volts.

The bow enclosure contains a forward-facing cameras and an ECX form-factor, Intel PC. The ROV can be tele-operated using only the ATMEGA2650 microcontroller, but the addition of the PC and USB webcams allow for autonomous functionality through ROS (Robot Operating System) running on the PC. The on-board PC sends instructions and receives feedback from the robot systems through a serial link with the ATMEGA 2560 microcontroller. Surface communication is achieved using 10/100 Ethernet to the PC. Alternatively, the ATMEGA2560 can communicate with the surface using a serial connection. The PC, microcontroller, and sensors in the bow enclosure are powered with 12VDC supplied via the power cable linked to the stern enclosure.

Camera System

In addition to the webcams attached to the PC, up to 4 analog cameras can be implemented on the KOI ROV. Sony Super-CCD cameras are located in the stern enclosure and side-mounted pan/tilt module. These cameras have automated digital contract adjustment, which prevents the blinding of the camera by floodlights or refraction while simultaneously providing contrast between black mission props and shadows. These cameras feature 2.8mm wide-angle lenses, which allow improved field of view for the pilot. Servo motors in the stern enclosure allow the operator to gimbal the camera 90 degrees from parallel to the horizon to straight down. The side-mounted module contains two 180 degree servos and an analog camera. The analog camera signals are transmitted to the surface using a Black Box RCA to ethernet video balun.

Figure 7: Camera System

Cables & Connectors

A power link between the bow and stern provides 12VDC to the bow enclosure from the stern power tether connection. The bow enclosure contains the computer and microcontroller which control all ROV functions.

Seacon Wet-Con and All-Wet series wet-makeable connectors were chosen for all enclosure connections. These connectors are rated to 304.8m open-face and up to 6096m when mated. To prevent connecting the wrong cables together, labels are placed at each interface to make it easy for any team member to assemble the robot without a wiring diagram.

Thrusters

For thrusters, our ROV utilizes five brushless "Scorpion" brand motors. There are significant advantages to using brushless motors as thrusters compared to brushed DC motors. First, the design of a brushless motor makes it inherently waterproof because there is no electrical contact between the rotating and stationary portions of the motor. This reduces the complexity of the thruster design because waterproof housings and shaft seals are not required, unless working in hazardous environments that would lead to the degradation of the enamel coating on the brushless stators. Additionally, brushless motors provide significantly higher thrust and torque compared to an equally sized brushed DC motor. Extra care must be taken, however, to keep the motor coils and windings of the brushless thruster clean as part of regular scheduled maintenance. For safety reasons, our company conducted extensive underwater testing prior to implementing brushless thrusters on the ROV. Our company concluded that even after repeated water use, the brushless motors do not conduct through the water because the wrapping of motor windings is enamel coated and insulated from the water.

Five Castle Creations Mamba Max brand motor controllers are used to run the brushless thrusters. Although the brushless motors are "sensor-less", without a position sensor or encoder, the controllers sense motor position using feedback along the motor connections. Each controller requires a 5V power and ground line for power to the thruster, a second 5V line (about 200 mA) to power the onboard microcontroller, as well as a PWM signal. The electrical connections for the main power are routed to the stern enclosure. The PWM signals are routed to an 8-pin Seacon connector which interfaces with the bow electronics enclosure. Each motor controller can be tuned using a USB interface to allow for operation at any voltage down to 3.3V and to adjust motor timing for best water performance.

Design Rationale – Programming

Software

Koi is using a two code block system, implementing a surface side code along with a robot side Arduino microcontroller. Each side communicates transfer data through a serial port on Koi's tether. The surface side code is written in Java due to its cross-platform capabilities, compatible libraries, and employees' expertise. The Arduino microcontroller is coded in C/C++ and is used for its cross-platform capabilities, cost efficiency, and open source community.

Surface Side

Continuing on the past success of our easy to read and easy to modify code, updating the surface side code was simple and painless. The design of multiple packages containing smaller, documented classes allowed for quick modifications so Koi is up to date and mission ready.

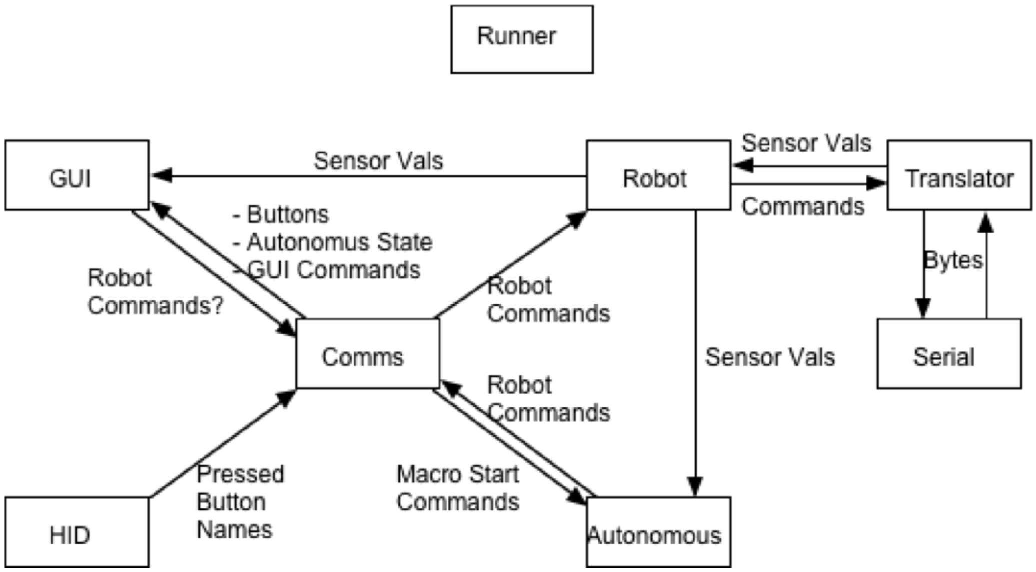


Figure 8: General design which served as the basis for our code

The Java code is broken up into the three main packages of HID, GUI, and CORE. The HID package contains classes and libraries for the use of a keyboard and Xbox 360 controller which is compatible with Linux, Mac OS, and Windows. The GUI package contains the necessary functions to handle incoming sensor data and properly display them on the custom-built GUI screen. The CORE package is responsible for taking all human input and Koi's input and return the appropriate responses.

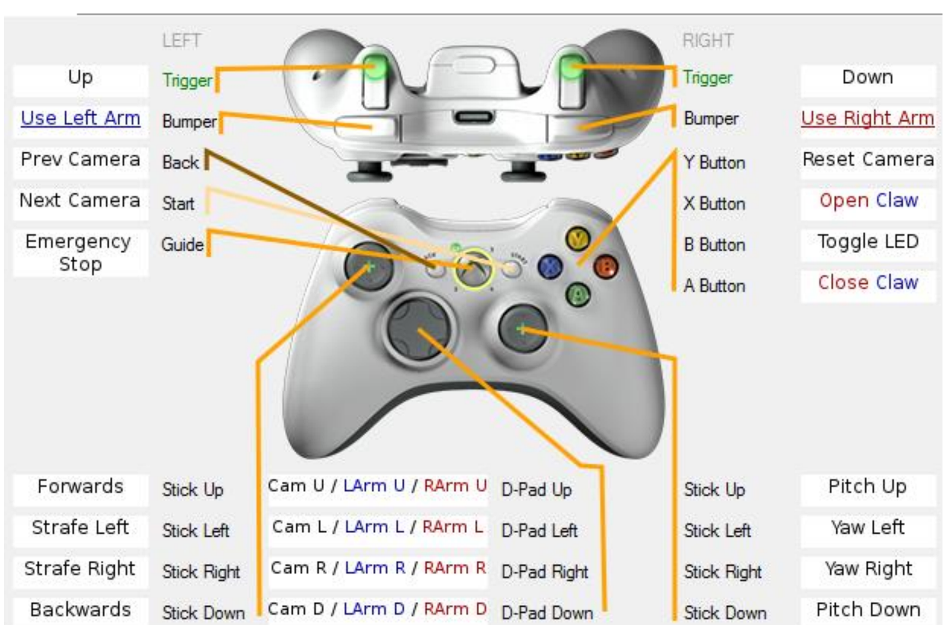


Figure 9: Controller Layout

The use of the Xbox 360 controller continues to provide excellent control for Koi. Continued use of this controller was chosen because of the ample range of input mechanisms and user friendly familiarity. Keyboard functionality for less-used functions is also present for semiautonomous commands.

Arduino

It was decided to continue using our Arduino microprocessor to handle all communications on Koi. The Arduino offers multiple connections to handle all incoming data separate from the PC. The open source nature of the Arduino provides an easy environment to maintain and create functional code for all peripherals.

The Arduino is responsible for receiving all high-level commands from the surface and processing them. It then sends the appropriate commands to each individual motor in accordance to the driver's command. In return, the Arduino gathers all raw data from the sensors and passes them back to the surface to be displayed for the driver.

Design Rationale – Transmissometer

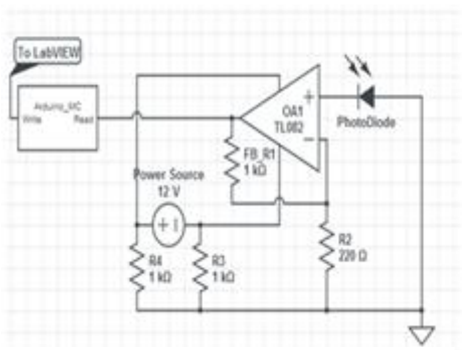


Figure 10: Transmissometer diagram

A transmissometer is sensor instrument that determines the opacity, or in some cases the turbidity, of a fluid or medium. The device includes a transmitter, such as a laser or LED, which permeates through some medium—like water—which will be directed at a close range receptor to measure the amount of radiation received from the transmitter that can then be compared to an expected value. A variance in detected light radiation from the transmitter will indicate a difference in the opacity as light will be diffracted due to an impurity in the medium it was shined through.

The design operates using a 3.3 volt, 20 mA blue LED which will be shined into a 0.5 x 0.5 cm photodiode, the intensity of the LED is controlled by PWM signals from the Arduino. A circuit implementation is used to amplify the signal received through the photodiode which is then read through an Arduino Microcontroller and displayed via the software LabVIEW. Figure 9 shows the circuit diagram of the amplification circuit and Figure 10 is a picture of the actual device.

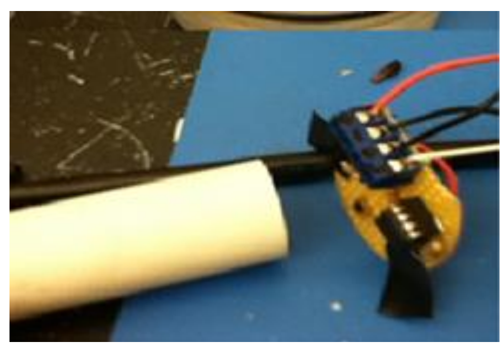


Figure 11: LED and receiving amplifier circuit

The typical output of the photodiode is 0.2 to 0.4 volts +/-0.05 volts. The non-inverting amplifier circuit, powered by a 12 volt battery, has a gain of 5 to 15 +/-0.2. The signal is sent through a 15.25 meter Ethernet cable, then through a pseudo FTDI connector head which connects to the computer via USB. The Ethernet is the medium for sending power to the Arduino and transmitting and receiving data.

Figure 12: LabVIEW

The LabVIEW interface allows the team and judges to visualize real-time variance in opacity by displaying a wave chart and the voltage being received from the photodiode. Figure 11 gives an image of what the interface looks like.

The housing of the receiver, amplifier circuit, and Arduino is a pre-used plastic, water sealed container that was originally used to house cameras on previous robots. The container is made out of plastic with steel end caps, secured by rubber gaskets to create a pressure lock. The wiring inside the enclosure is connected through a 6 conductor bulging connector which externally connects to an Ethernet cable to the surface. The LED housing is made of a PVC piping with optical epoxy shielding the front and is Scotch casted at the tail with the extruding wiring for connection to the Arduino.

The enclosure, Figure 12, is constructed out of galvanized sheet metal and was bent into an equilateral triangle in order to inscribe the housing of the circuit and Arduino. The top has a corner bracket securing the triangle shut via rivets and was drilled in the center to install a metal square handle for our robot carry to the drop off. The triangular enclose has a mid-section cut out to allow for a smooth landing and correct positioning of the device when being placed on the sea floor platform. Remaining on the opposite side of the receiver is a section that encloses the LED. Both the LED and the receiver are held in position by pool noodles. Figure 13 shows the enclosure and displays the dimensions in centimeters.

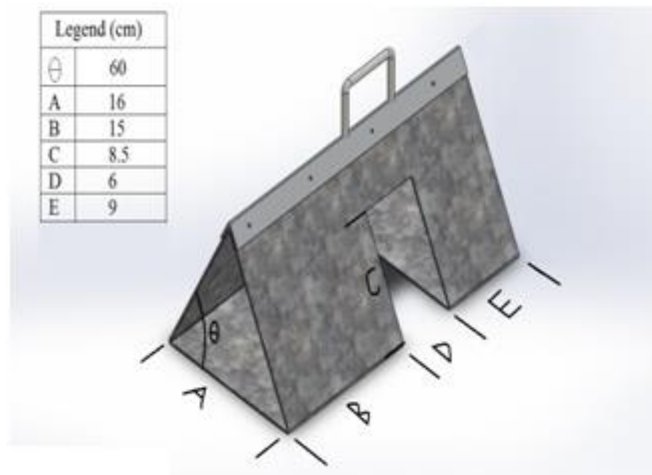


Figure 13: Transmissometer Enclosure

Future Improvements

SCUBa

For future use on our ROVs, the company has continued research and development of variable buoyancy devices. One such device named SCUBa (System for the Control of Underwater Buoyancy) uses rigid walled containers that allow air to be pumped in or let out, with one end open to the water. This will cause a change in volume of air inside the containers and thus change our buoyancy. We believe such a device that would allow us to control our buoyancy would be a great asset in the control of our robots. It will enable us to remain neutrally buoyant in environments of different densities, which

Figure 14: SCUBA

would be helpful when switching between salt and freshwater environments. It will also allow the neutral buoyancy to adjust when mass changes, in cases where an object is being picked up. This consequently allows the lift of heavier objects underwater as well. Furthermore, it will provide the ability to ascend very rapidly by setting the system to maximum buoyancy, working in tandem with the already existing thrusters. All these things in combination will make having precise control over our buoyancy much more beneficial system than the traditional static buoyancy found in most UROVs.

Stereovision

Our company lost our lead autonomous and stereovision programmer and had to take a step back from realizing stereovision this year. However a new programmer has recently taken the reigns and looks to take on the challenge of implementing stereovision on Koi this upcoming year.

Stereovision would add another dimension to what the ROV perceives and extended functionality without impeding on current onboard systems. The left figure is a screen capture of the left and right images captured by the Bumblebee®2 camera from Point Grey Research. The figure to the right demonstrates a depth-view image indicated by the color of the surface – the darker the color the further that surface is from the camera and the brighter the color towards red indicates a closer surface. Now back to the left figure, the hallway extends approximately 26 meters according to rough measurements. The darkest blue pixel on the right image (near center) measured 25.837 meters long according to the vision software. Koi will use this same technology to measure the lengths and gain depth perception for both tele-operated and autonomous competitions.

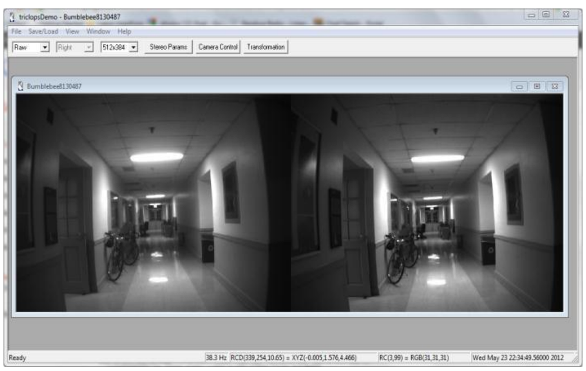


Figure 15: Hallway Test

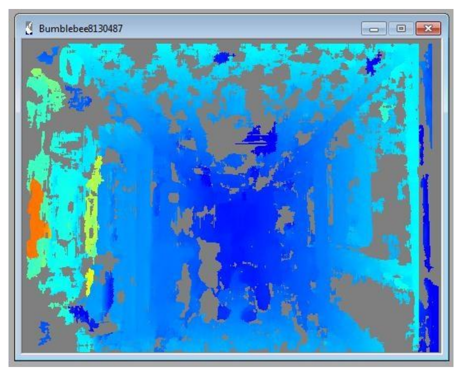


Figure 16: Camera Data

Challenges

Technical

One of the biggest technical challenges faced on the mechanical department was how to adapt or redesign the complex waterproof end caps for the electronics enclosure so that they would fit the new waterproof connectors. The new connectors required material to thread into, and the previous end caps did not have adequate thickness. This meant that entirely new end caps were required. To maintain a hydrodynamic shape, the waterproof connectors had to come out along the circumference of the end caps instead of the flat end in order for the wires to maintain in the ROV frame perimeter. An easier way to remove the electronic enclosures was also desired. Thus, the new end caps were D-shaped in design. This allowed a new and much simpler method to attach the end caps to the robot frame. All of these design requirements resulted in a design that was very complex to machine. As such, we opted to have our end caps professionally machined. Weighing all of these factors was a large technical challenge.

Programming

One main challenge of the programming team this year was adjusting the existing ArduIMU code. While the actual ArduIMU was outputting the correct compass and accelerometer data, the intra communication between it and the Arduino was not correct. Finding the root of this error was more involved than initially planned and the entire sensor code had to be reworked. This in turn required an overhaul of a few surface side classes as well.

Lessons Learned / Skills Gained

Programming

With the problem with the ArduIMU was that the open source code actually didn't work correctly. After rooting out the problems and completely overhauling the code one of the last problems to overcome was that read and write function in the Arduino only handle one byte at a time. By doing some research, the programming team found a solution using the Union class type. The write function was modified to send chunks of 8 bites at a time, read into an array that was part of the Union class. Then the data can be accessed as a double that is connected to the array. This is an easy way to get around the limitations of single byte communication when you want to send larger information.

Reflections

This robot redesign has taught me many valuable skills that I did not have before. Adapting an already existing system for a new set of design criteria was a real challenge. The new waterproof connectors also required many mechanical details as well, such as surface finishes, which have never been considered to this extent in the past. Making the new end caps fit onto the existing frame was also a learning process, as they had to be mounted on in a specific way that was easier to remove for repairs. In the end, I gained knowledge from overcoming these engineering challenges.

- Jonathon Houda

Acknowledgements

Arizona State University Fulton Schools of Engineering
Arizona NASA Space Grant Consortium
Marine Advanced Technology Education (MATE)
Advisors – Rob Wagner & Mike Veto
ASU Mars Space Flight Facility – Dr. Phil Christensen

Expense Report

Item	Qty	2012 -13 Expense	Prior Year Expenses	Donation	2012-13 Income
ROV Construction					
Waterjet Aluminum Frame (SW Waterjet Service Donation)	1		$100.00	$300.00	
Aluminum Machined Endcaps	4	$105.00			
Polycarbonate (Electronics Enclosures)	2		$70.00		
Polycarbonate Endcaps	10	$80.00			
O-rings (10 small, 4 large)	14		$10.00		
Aluminum Tubing (Speed Control Enclosures)	5	$24.00			
Various other materials (metals, plastics)			$75.00		
Claw 1 (MCMS - Claw Assembly)	1	$230.68			
Claw 1 (MCMS - Arm Assembly)	1		$360.50		
Claw 2 (Open/Close, Rotation, Elbow)	1	$85.00			
Propellers	5			$65.40	
Seacon Wet-Mateable Connectors (50% discount)	37	$1,477.61		$1,464.39	
Data Tether (AlphaWire 100ft)	1			$812.50	
Power Tether (100ft)	1	$35.00			
Ethernet (100ft)	1		$15.00		
Data Connection Box	1				
Logitech C620 Webcam	1		$50.00		
Sony CCD Cameras	2	$109.98			
Arduino Mega Mini	1		$53.00		
Onboard Computer (Motherboard and I3 processor)	1		$329.00		
ArduIMU (9 axis Inertia Measurement Unit)	1		$84.56		
DB25 Breakout Boards (Electrical Container Disconnects)	6		$59.45		
Brushless Speed Controllers (Castle Creations 30% discount)	5	$534.65		$225.00	
Vicor DC-DC Power Converters	6			$724.00	
Scorpion Brushless Motors	5		$550.00		
Pressure Sensor	1	$105.34			
2x5 Speed Controllers (Dimension Engineering 50% discount)	3	$90.00		$90.00	
Various Wire			$50.00		
Electrical Connectors & Parts (Bulgin, spades, capacitors, resistors)			$70.00		
Transmissometer (Arduino, LED, photo diode, op-amp, housing)	1	$40.62	$40.50		
Black Box Video Balun IC564A (RCA - Ethernet)	2		$129.90		
Servo's (Camera Positioning)	3		$37.12		
Batteries (12V LiPo - Testing, Practice, Transmissometer)	5	$161.25			
Auto Reset Fuses			$68.04		
Robot Cost Totals		$3,079.13	$2,152.07	$3,681.29	
Travel / Competition					
Hotel - Seattle (3 Rooms)		$1,652.19			
Rental Vehicles (2 Vans)		$784.40			
Vehicle Fuel		$200.00			
Competition Registration		$100.00			
Total		$2,736.59	$0.00	$0.00	
Other					
SolidWorks Licenses	12			$1,200.00	

Mission Props		$180.00			
Total		$180.00	$0.00	$1,200.00	
Donations					
NASA Space Grant (Materials)					$1,600.00
NASA Space Grant (Travel)					$3,000.00
ASU Fulton Schools of Engineering					$3,250.00
Total					$7,850.00
Grand Totals		$5,995.72	$4,304.14	$4,881.29	$7,850.00
Cost of Koi ROV		$8,912.49			

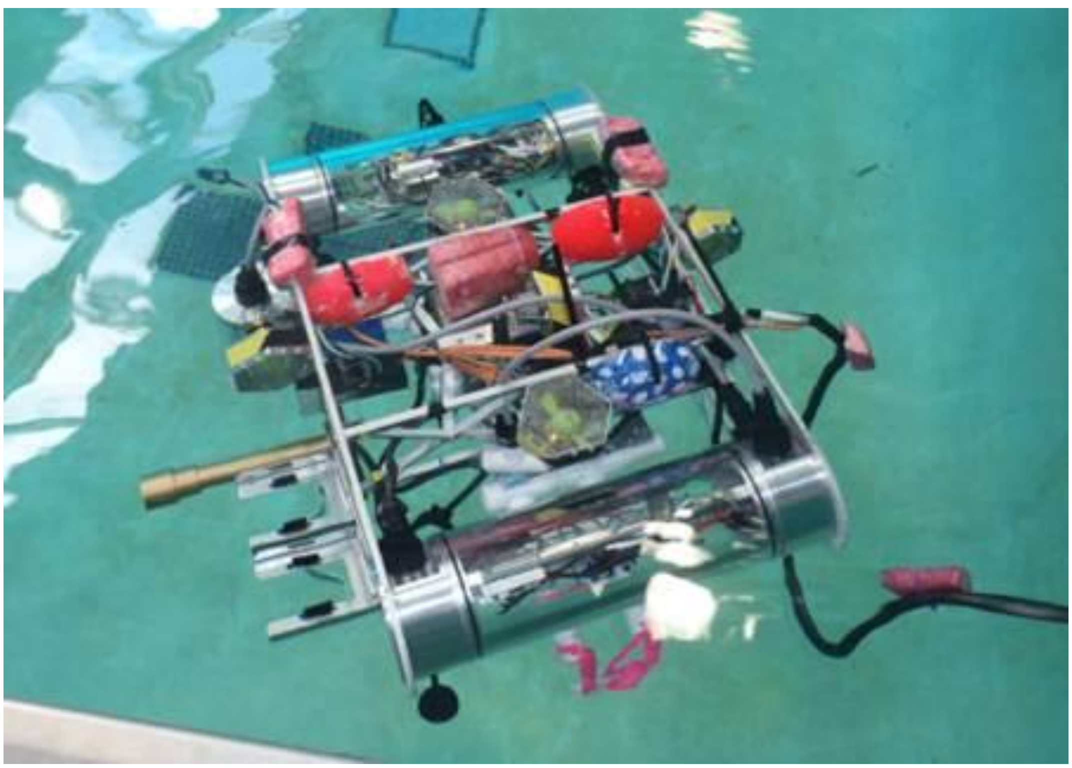
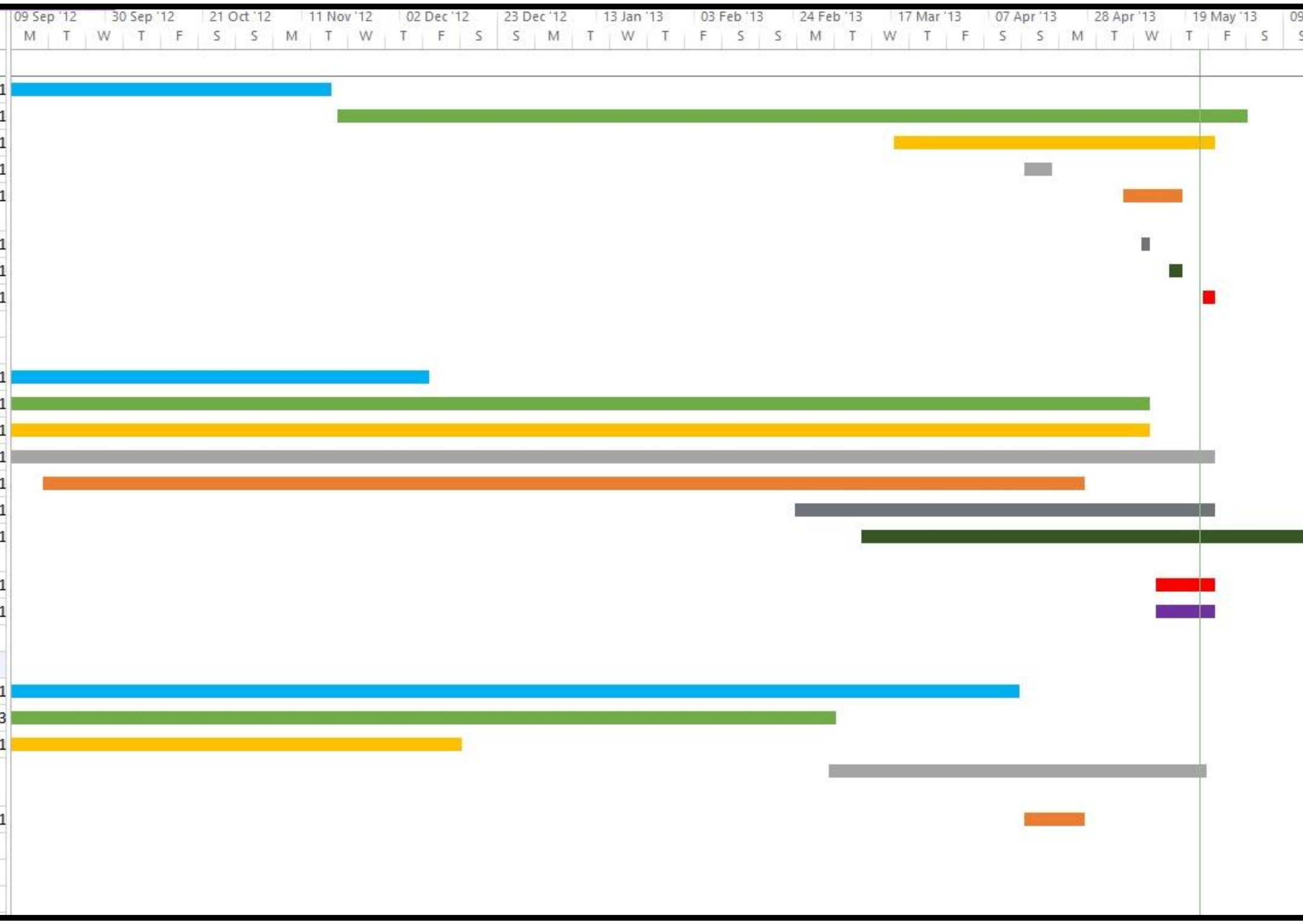


Figure 17: Koi ROV

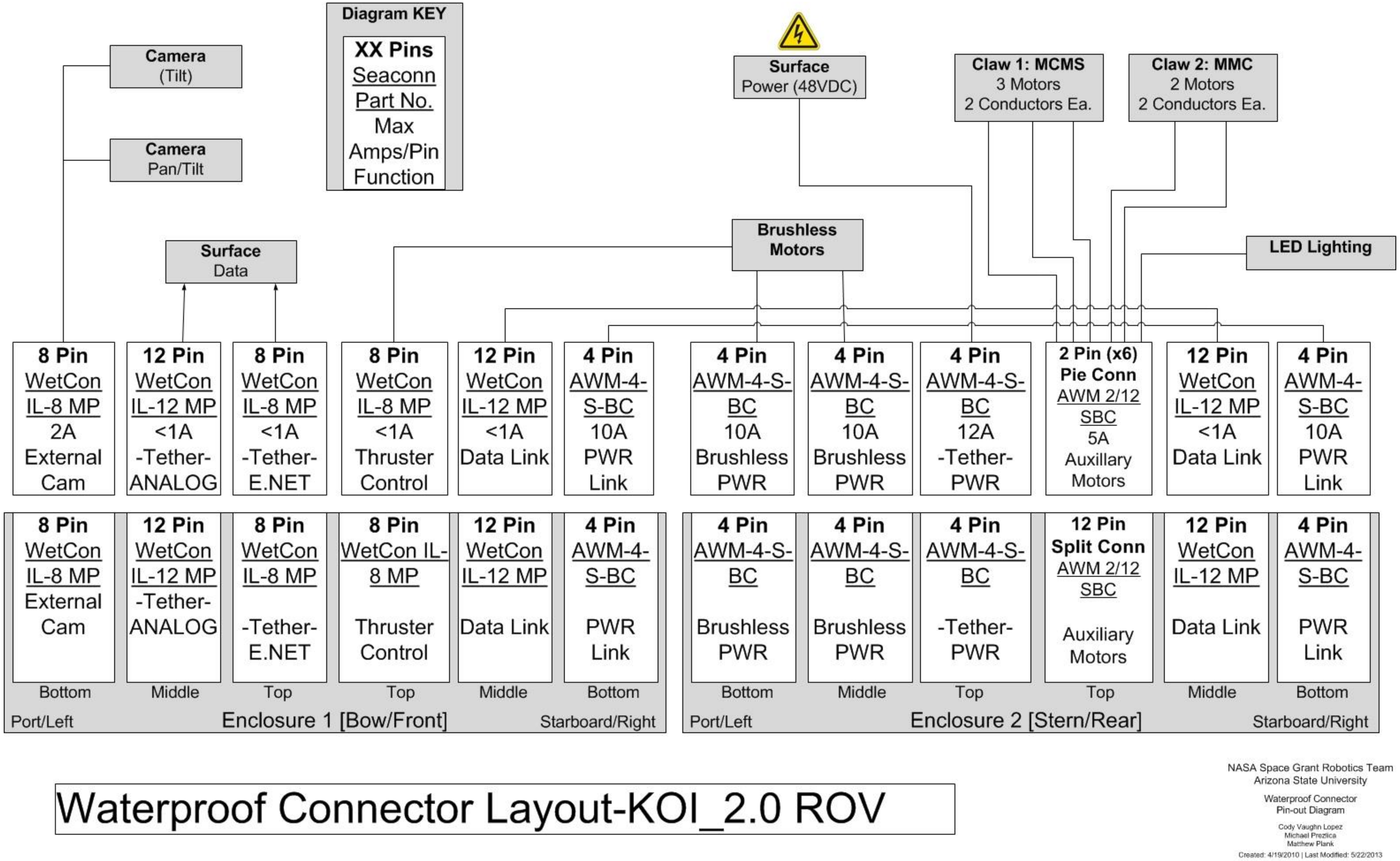
Gantt chart

Task Name	Duration	Start	Finish
Electrical			
Training new electrical hires	3 mons	Mon 27-08-12	Fri 16-11-1
Speed controller enclosure	7 mons	Mon 19-11-12	Fri 31-05-1
Transmissometer	2.5 mons	Mon 18-03-13	Fri 24-05-1
Internal wiring	5 days	Mon 15-04-13	Fri 19-04-1
Vicor Power converter replacement	2 wks	Mon 06-05-13	Fri 17-05-1
Install new cameras	1 day	Fri 10-05-13	Fri 10-05-1
Remap wiring diagram	2 days	Thu 16-05-13	Fri 17-05-1
Lighting installation	2 days	Thu 23-05-13	Fri 24-05-1
Mechanical			
Training new Mechanical Hires	77 days	Thu 23-08-12	Fri 07-12-1
End Cap Redesign	187 days	Thu 23-08-12	Fri 10-05-1
Frame Redesign	187 days	Thu 23-08-12	Fri 10-05-1
Main Claw	197 days	Thu 23-08-12	Fri 24-05-1
Speed controller housing	160 days	Mon 17-09-12	Fri 26-04-1
Secondary Claw	65 days	Mon 25-02-13	Fri 24-05-1
Discrete component Waterproof Testing	70 days	Mon 11-03-13	Fri 14-06-1
End cap Machining	10 days	Mon 13-05-13	Fri 24-05-1
Frame Machining	10 days	Mon 13-05-13	Fri 24-05-1
Programming			
IMU	167 days	Thu 23-08-12	Fri 12-04-1
Cleaning ROV code	138 days	Thu 23-08-12	Mon 04-03
Ethernet Communication	82 days	Thu 23-08-12	Fri 14-12-1
Updating New ROV components code	58 days	Mon 04-03-13	Wed 22-05-13
Semi_Autonomous	10 days	Mon 15-04-13	Fri 26-04-1

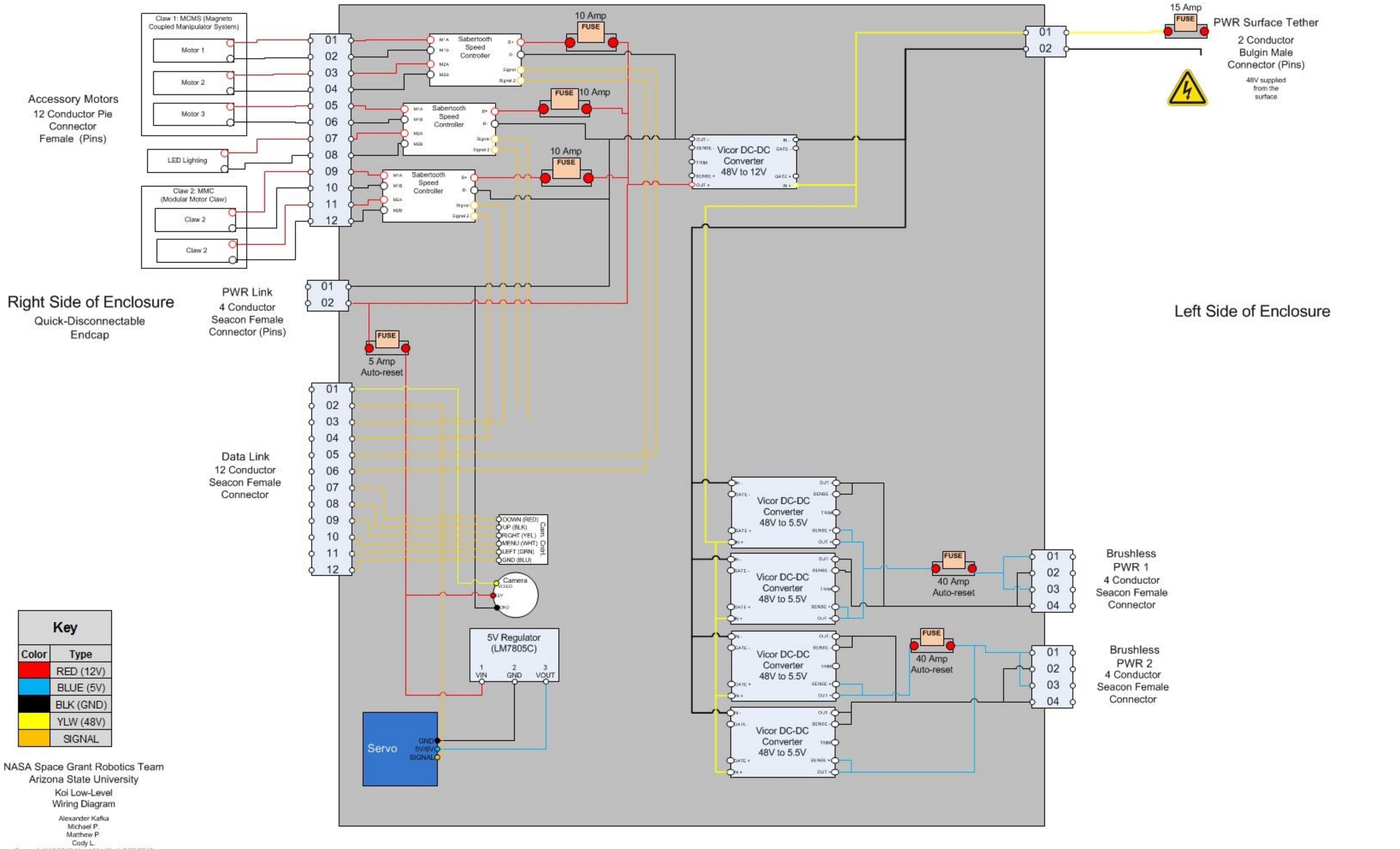


Electrical Schematics

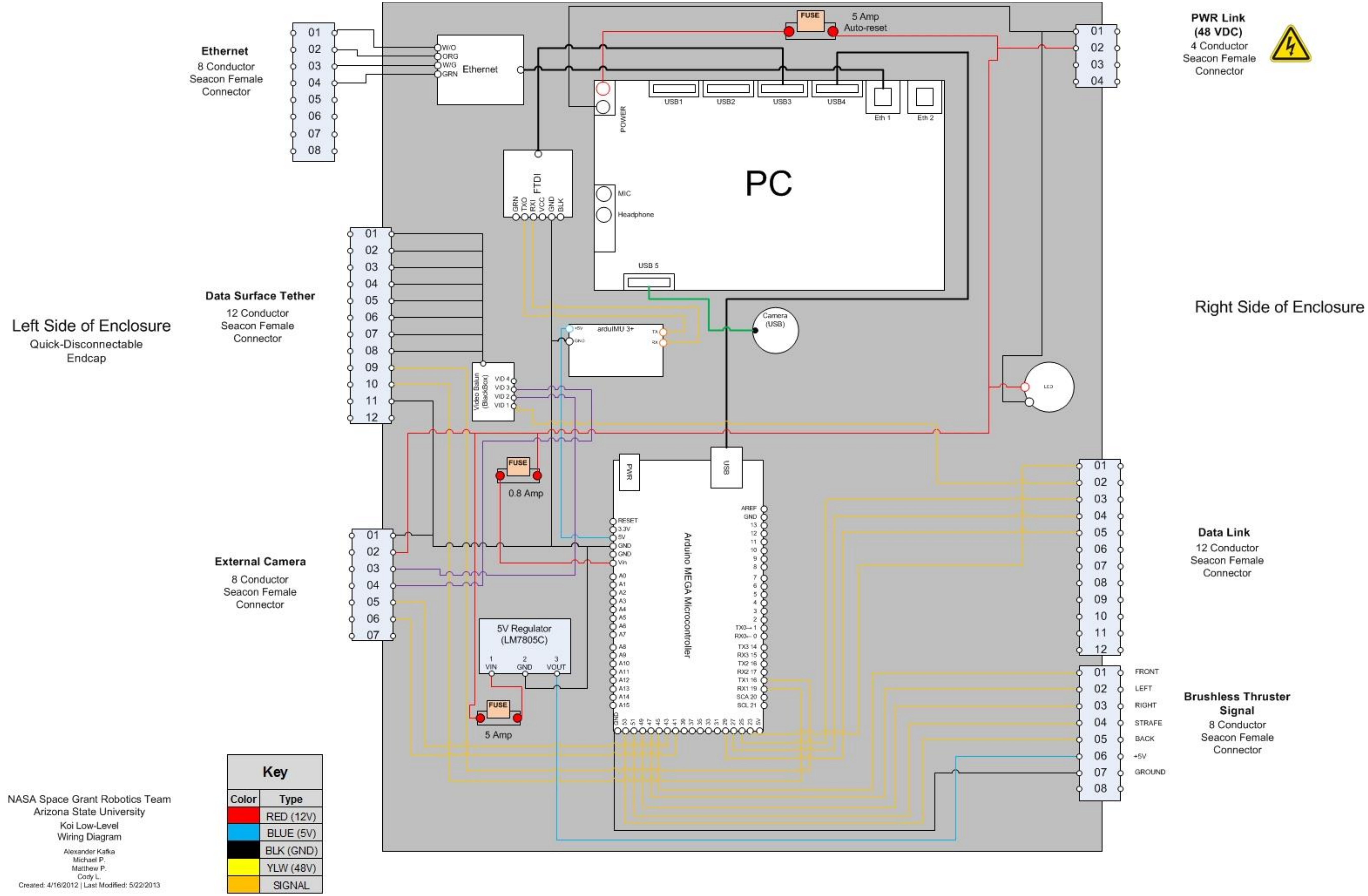
Waterproof Connector Layout



Stern Enclosure



Bow Enclosure



Enclosure Quick Disconnects

Enclosure Quick-Disconnects

Stern/Rear Enclosure

12 Pin "Pie" Seaconn		Pin	Pin Use	DB 25 External Pin #	DB-25 Internal Pin #
"AUX Motors"		1	M2B	F13	M1
		2	M2A	F12	M2
		3	M1B	F11	M3
		4	M1A	F10	M4
		5	M4B	F7	M7
		6	M4A	F6	M8
		7	M3B	F5	M9
		8	M3A	F4	M10

12 Pin Seaconn		Pin	Pin Use	DB 25 External Pin #	DB-25 Internal Pin #
"Data Link"	Green	1	Video	F1	M13
	Blue	2	Cntrl. GRN	F25	M14
	Purple	3	Cntrl. YEL	F24	M15
	Gray	4	Cntrl. BLK	F23	M16
	White	5	Cntrl. WHT	F22	M17
	W/Black	6	Cntrl. RED	F21	M18
	W/Brown	7	M1Sig	F20	M19
	Orange	8	M2 Sig	F19	M20
	Yellow	9	GND	F18	M21
	Red	10	M3 Sig	F17	M22
	Black	11	M4 Sig	F16	M23
	Brown	12	Servo	F15	M24

4 Pin Seaconn	Pin	Pin Use	DB 25 External Pin #	DB-25 Internal Pin #
"PWR Link"	1	12VDC	M13, M11	F1, F3
	2	GND	M10, M8	F4, F6

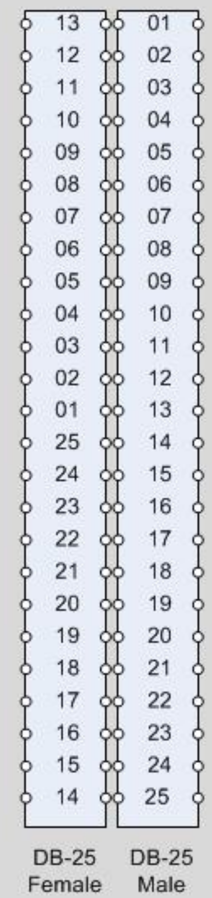
Bow/Front Enclosure

25-Pin DB-25	5A per pin				25 Pin DB-25
6 Pin Bulgin			**Pin Use**	**DB 25 External Pin #**	**DB-25 Internal Pin #**
"Ethernet"	WHT/ORG	1	M1A	M13	F1
	ORG	2	M1B	M12	F2
	WHT/GRN	3	M2A	M15	F24
	GRN	4	M2B	M16	F23
		5			
		6			

12 Pin Bulgin		Pin	Pin Use	DB 25 External Pin #	DB-25 Internal Pin #
"Data Tether"		1	WORG	M1	F13
		2	ORG	M2	F12
		3	WGRN	M3	F11
		4	BLU	M4	F10
		5	WBLU	M5	F9
		6	GRN	M6	F8
		7	WBRN	M7	F7
		8	BRN	M8	F6
		9	GND	M9	F5
		10	Tether TX	M10	F4
		11	Tether RX	M11	F3
		12	NC	M14	F25

7 Pin Bulgin		Pin Use	DB 25 External Pin #	DB-25 Internal Pin #
"Camera"	Green 1	GND	M21	F18
	Blue 2	12V	M22	F17
	Purple 3	ID PAN/TL	M23	F16
	Grey 4	VID STATIC	M17	F22
	White 5	ERVO1 pin	M18	F21
	Orange 6	ERVO2 pin	M19	F20
	Yellow 7	NC	M20	F19

M1



Pin-to-Pin Reference

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Enclosure Quick-Disconnects

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Enclosure Interconnects

Interconnects

Supply Connector				Appliance Connector		
12 Pin Seacon	5A per pin		Cable	Bow Enclosure	Use	Stern Enc.
Data Link	Pin	Color	Connector Pin			
	1	PUR	1	GRN	CAM SERVO	GRN
	2	BLU	2	BLU	VIDEO	BLU
	3	GRN	3	PUR	M1SIG	PUR
	4	YEL	4	GRY	M1DIR	GRY
	5	WBRN	5	WHT (NC)	M2 SIG	M3 SIG
	6	GRY	6	WBLK (NC)	M2 DIR	
	7	WBLK	7	WBRN (NC)		
	8	WHT	8	ORG (NC)		
GND/SHIELD	9	BLK	9	YEL	GND/SHIELD	GND/SHIELD
	10	BRN	10	BLK (NC)		
	11	ORG	11	RED (NC)		
	12	RED	12	BRN (NC)		

Power Link			
4 Pin Seacon	12A per pin		4 Pin Seacon
12V Power	Pin	Label	Connector Pin
	1	GND	1
	2	12V	2

Key

Color	Type
	RED (12V)
	BLUE (5V)
	BLK (GND)
	GRN (3.3V)
	YEL (48 V)
	ORG (SIG)

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Interconnects

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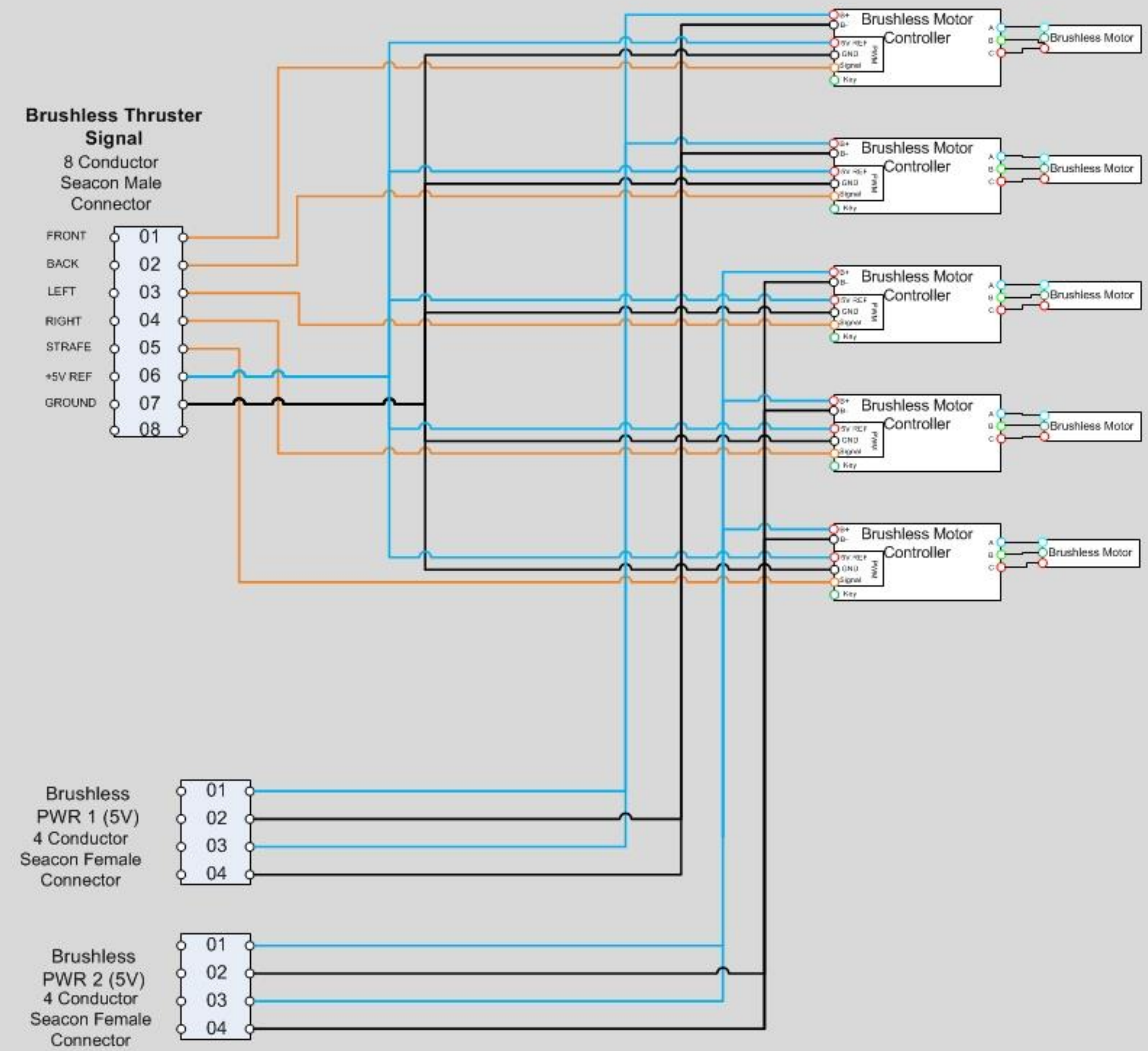
Brushless Thruster Connector Wiring

Supply Connector			DATA	POWER 1	POWER 2
8 Pin Seacon	1A per pin		8 Pin Seacon	4 Pin Seacon	4 Pin Seacon
FRONT	**Pin**	**Wire Color**	**Pin Number**	**Pin Number**	**Pin Number**
	5V	RED		1& 3	
	GND	BLACK		2 & 4	
	SIG	BLACK	1		
	5V REF	BLUE	6		
BACK	**Pin**	**Wire Color**	**Pin Number**	**Pin Number**	**Pin Number**
	5V	RED		1& 3	
	GND	BLACK		2 & 4	
	SIG	WHITE	2		
	5V REF	BLUE	6		
LEFT	**Pin**	**Wire Color**	**Pin Number**	**Pin Number**	**Pin Number**
	5V	RED			1& 3
	GND	BLACK			2 & 4
	SIG	RED	3		
	5V REF	BLUE	16		
RIGHT	**Pin**	**Wire Color**	**Pin Number**	**Pin Number**	**Pin Number**
	5V	RED			1& 3
	GND	BLACK			2 & 4
	SIG	GREEN	4		
	5V REF	BLUE	15		
STRAFE	**Pin**	**Wire Color**	**Pin Number**	**Pin Number**	**Pin Number**
	5V	RED			1& 3
	GND	BLACK			2 & 4
	SIG	ORANGE	5		
	5V REF	BLUE	8		

Key

Color	Type
	RED (12V)
	BLUE (5V)
	BLK (GND)
	GRN (3.3V)
	YEL (48 V)
	ORG (SIG)

Brushless Connector Wiring



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Brushless Connector Wiring

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12-Conductor Aux Motors

12-Conductor Aux Motors

Supply Connector				Appliance Connector	
12 Pin Seacon	5A per pin		Supply	Appliance	Type
Claw 1: MCMS	Pin	Label	Connector Pin	Splice Pin	Cable Splice
Motor 1	1	PWR	1	WHT	
	2	GND	2	BLK	
Motor 2	1	PWR	3	WHT	
	2	GND	4	BLK	
Motor 3	1	PWR	5	WHT	
	2	GND	6	BLK	
LED	Pin	LABEL	Connector Pin	Splice Pin	Cable Splice
		PWR	7		
		GND	8		
Claw 2: MMC	Pin	Label	Connector Pin	Splice Pin	Cable Splice
Motor 1	1	PWR	9	WHT	
	2	GND	10	BLK	
Motor 2	1	PWR	11	WHT	
	2	GND	12	BLK	

Key

Color	Type
(red)	RED (12V)
(black)	BLK (GND)

Accessory Motors
12 Conductor Pie
Connector
Female (Pins)

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12-Conductor Aux Motors

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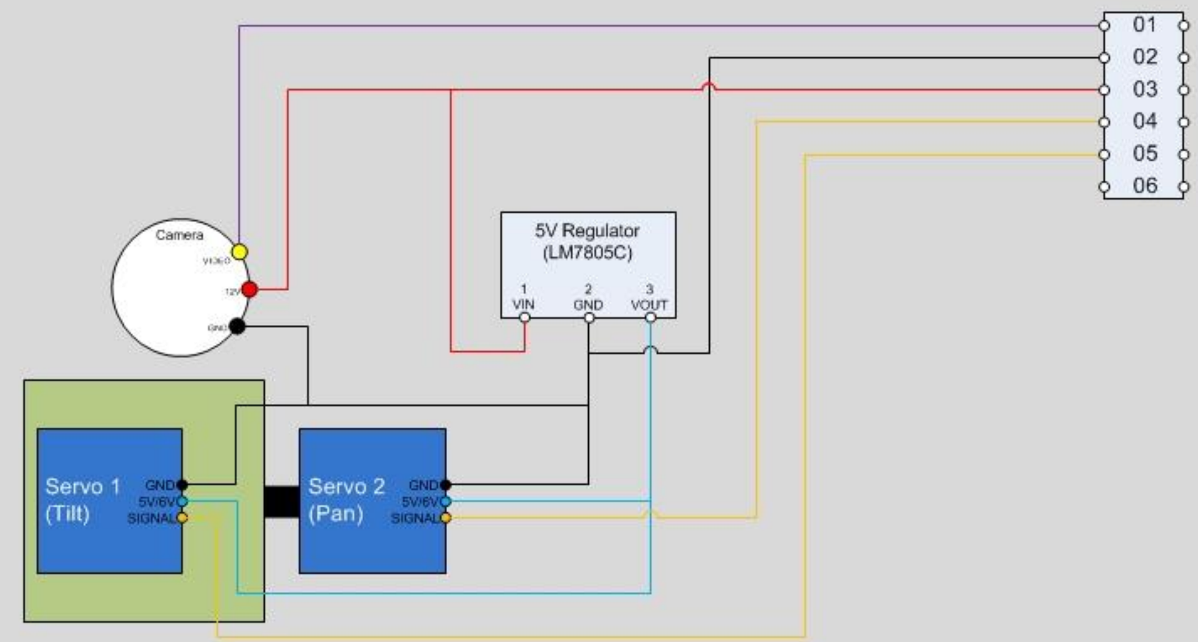
Internal Camera Wiring

Internal Camera Wiring

12 Pin Bulgin	5A per pin		Supply	Appliance	Type
Camera1 (Servo)	Pin	Label	Connector Pin	Splice Pin	Cable Splice
	1	VID1	1		
	2	GND1	2		
	3	PWR1	3		
	4	PAN1	4		
	5	TILT1	5		

Key	
Color	Type
(red)	RED (12V)
(blue)	BLUE (5V)
(black)	BLK (GND)
(yellow)	VIDEO
(orange)	SIGNAL



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Internal Camera Wiring

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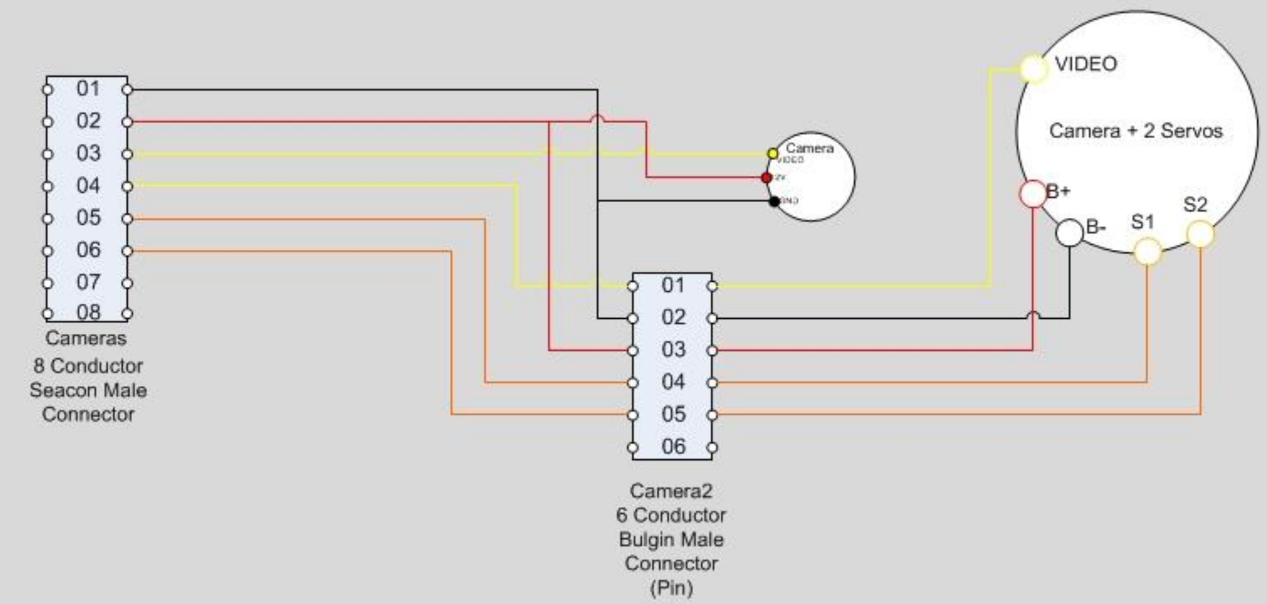
Camera Cable Diagram

Camera Cable Diagram

7 Pin Bulgin	5A per pin		Supply	
Camera1 (Pan+Tilt)	Pin	Label	Enclosure Pin	Wire Color
	1	VID	3	
	2	GND	1	GRN
	3	12V	2	
	4	SIG1	5	
	5	SIG2	6	Splice Pin
	6	NC		
Camera2 (Stationary)	1	GND	1	GRN
	2	VCC	2	
	3	VID2	4	

Key	
Color	Type
(red)	RED (12V)
(blue)	BLUE (5V)
(black)	BLK (GND)
(yellow)	YLW (VID)
(orange)	ORG (SIG)



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Camera Cable Diagram

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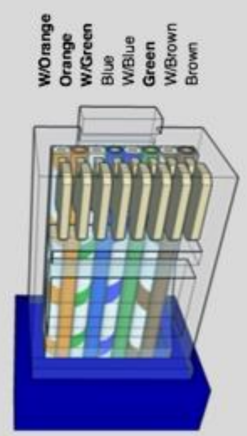
Tether

Tether

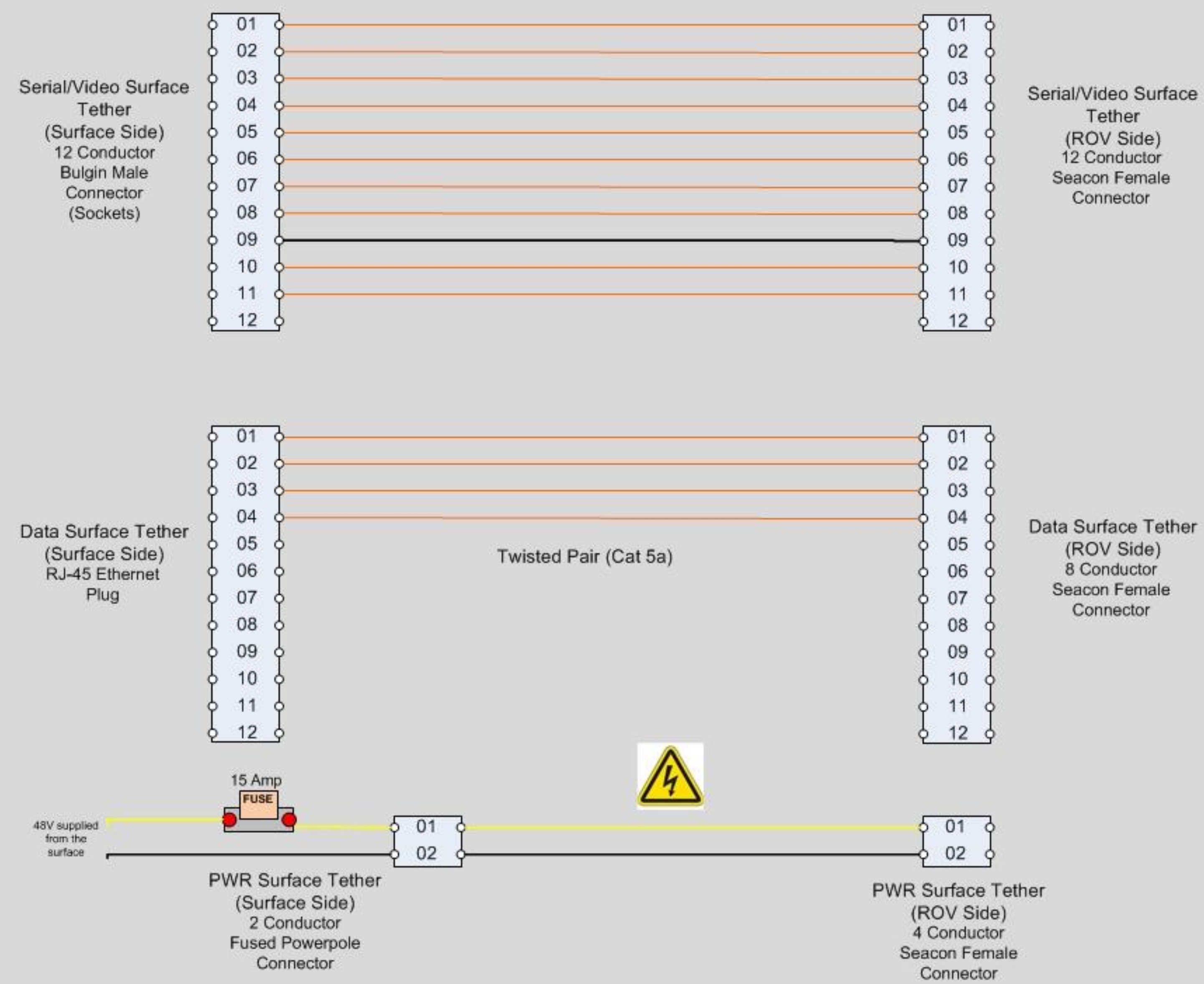
Serial/Video Tether			
12 Pin Seacon	5A per pin		Supply
Video Balun	Pin	Label	Connector Pin
	1	WORG	1
	2	ORG	2
	3	WGRN	3
	4	BLU	4
	5	WBLU	5
	6	GRN	6
	7	WBRN	7
	8	BRN	8
Serial Com	Pin	Label	Connector Pin
	9	WORG	9
	10	ORG	10
	11	WGRY	11

Key	
Color	Type
Red	RED (12V)
Blue	BLUE (5V)
Black	BLK (GND)
Green	GRN (3.3V)
Yellow	YEL 48 V

Ethernet Tether			
8 Pin Seacon	5A per pin		6 Pin Bulgin
10/100 Elthernet	Pin	Label	Connector Pin
	1	WORG	1
	2	ORG	2
	3	WGRN	3
	4	GRN	4



T568-B (Optional)



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Tether

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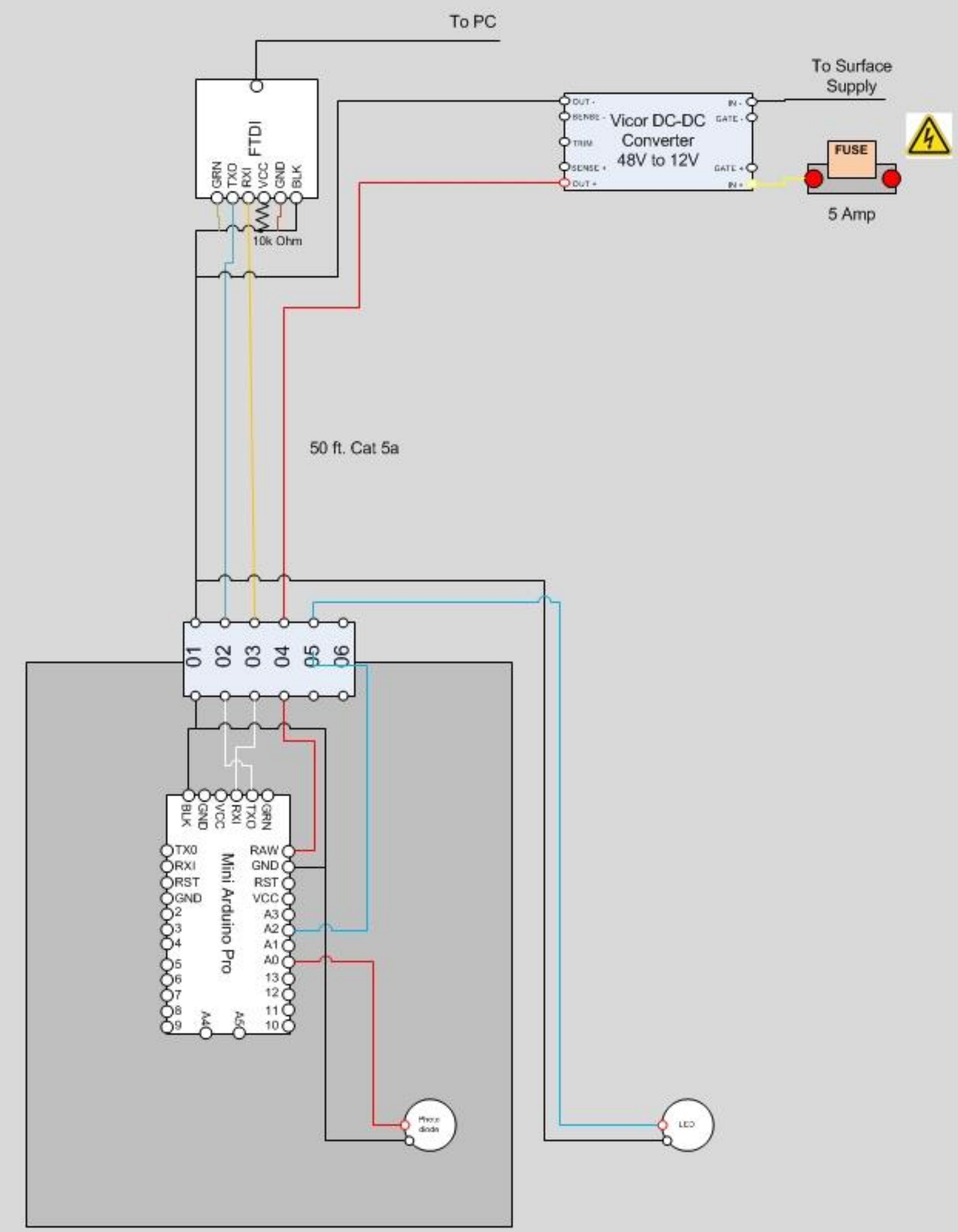
Transmissometer

Transmissometer

Supply Connector				Appliance Connector	
6 Pin Bulgin	5A per pin		Ethernet	AlphaWire	Wiring
Arduino/photodetector	Pin	Label	Outside	Outside	Inside
	1	GND	BROWN	BROWN	BLACK
	2	TX	ORANGE	ORANGE	GREEN
	3	RX	BLUE	YELLOW	WHITE
	4	12V	GREEN	GREEN	RED
	5	LED PWR		BLUE	GREEN
	6	NC			
			Ethernet	AlphaWire	Wiring
	#	Label	Outside	Outside	Outside
LED	1	LED PWR		BLUE	RED
	2	GND	BROWN	BROWN	BLACK

Key

Color	Type
(red)	RED (12V)
(blue)	BLUE (5V)
(black)	BLK (GND)
(green)	GRN (3.3V)
(yellow)	YEL (48 V)
(orange)	ORG (SIG)



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Transmissometer

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Seacon Connector Reference