NASA Space Grant Robotics

Arizona State University - Tempe, Arizona

MATE 2015 International ROV Competition

Technical Report

Member List:

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Christine Langevin – Chief Financial Officer

Carl Stevenson – Chief Electrical Engineer

Ben Mackowski – Historian

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1 Abstract:

NASA Space Grant Robotics, founded in 2009, is an organization at Arizona State University under the NASA Space Grant Consortium and is dedicated to building and competing with underwater robots. Its members are primarily mechanical, electrical, and computer engineering undergraduate students that are all dedicated to developing a robot that can operate in extreme environments.

This year, in 2015, the NASA Space Grant Robotics Corporation is revealing their reinvented underwater vehicle Koi 3.0. Koi has an elegant design that integrates both remote operations and semi-autonomous controls for ease of use and precise movements. The primary emphasis of Koi is modularity, so that the single robot can effectively compete in the three different extreme environments without significant modifications. Koi moves smoothly through the water with powerful custom thrusters capable of five degrees of freedom including tilt and strafe. To complete the mission objectives, Koi utilizes complete on-board computation and a brand-new Small Diameter Claw. Koi also comes equipped with a series of sensors for directional aid, a depth guide, and data from the surrounding environment all of which is relayed to the operator’s piloting software.

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.

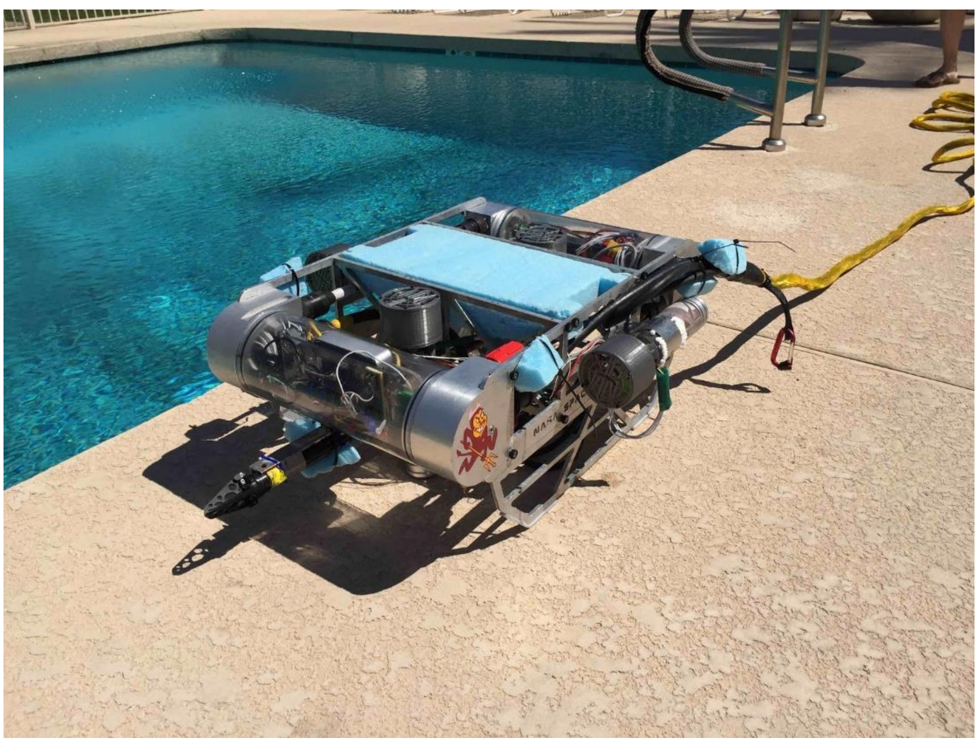

Fig. 1 Koi

2 Project Management:

The project lead for Koi was our CEO, Joseph Mattern, who coordinated with the mechanical, electrical, and programming team leads about the overall goals for Koi and the timeline for completely components of the robot. He would also consult with our CTO, Peter Tueller, who would coordinate resources for each team and would lead the overall integration of components into a fully-fledged underwater robotic vehicle. Each of the team leads would then organize each of their team members and assign tasks, establish due dates, and keep up on the progress of each task. Generally, there would be informal communication between all members, leadership and general alike, as we all work in the same area, but at the very least information would propagate through the established leadership system.

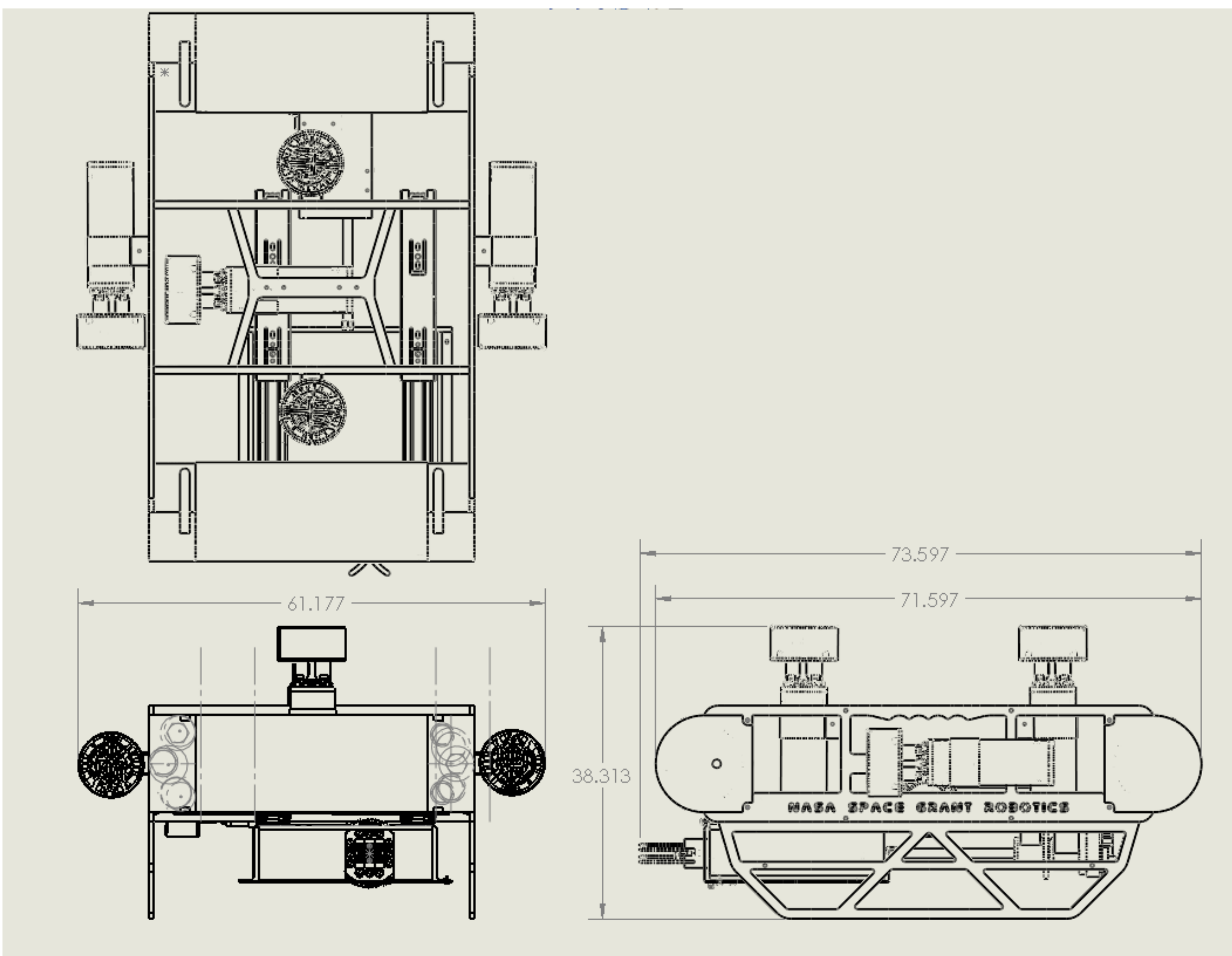

Fig. 2 Koi Design Drawings

2.1 Gantt Chart:

Number		Prereq	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	New Recruit Training												
2	Mechanical Large System Design	None											
3	Mechanical Large System Build	2											
4	Electrical Large System Design	None											
5	Electrical Large System Fabrication	4											
6	Software Architecture Design	5											
7	Software Implementation	6											
8	Mechanical Subsystem Design	2											
9	Mechanical Subsystem Fabrication	8											
10	Electrical Subsystem Design	5											
11	Electrical Subsystem Fabrication	10											
12	Assembly and Testing	3,5,7,9,11											

3 DESIGN RATIONALE:

3.1 MECHANICAL:

Materials: Throughout Koi's design, 6061 aluminum alloy was used for its high strength-to-weight ratio and relatively low cost compared to other metal alloys. To further keep weight down, many parts were 3D-printed from polylactic acid (PLA), an inexpensive rapid-prototyping material. Other parts were made from polycarbonate (PC) for its excellent impact resistance; transparent PC tubing is used when the visibility of internal components is desired

Frame Design: The frame design was kept the same as it has for the last two years. The mission for this year did not necessitate major modifications, so we decided to focus efforts elsewhere. The frame is small enough to fit through the 75 cm square ice opening and has ideal placement of cameras directly over claws and other peripherals. The biggest design change was our four new endcaps. These may superficially look the same as last year's endcaps, however, the new SeaCon connectors that we are using required different holes to be drilled. The new SeaCon connectors allow for more interconnecting wires between the two enclosures as well as more modular sensors and motors. Some of the new Seacon connectors are 'pie' connectors, which means that they have multiple male connectors (slices of the pie) going into a single female connector. Because of the size and complexity of the design, we ended up outsourcing most of the machining to ProtoLabs and drilling and tapping the holes ourselves. The frame is water-jetted 6061 aluminum alloy (waterjet work and material graciously donated by Southwest Waterjet). The end caps are machined 6061-T6 aluminum alloy. (Endcap Project Engineer/Machinist: Drew Denike)

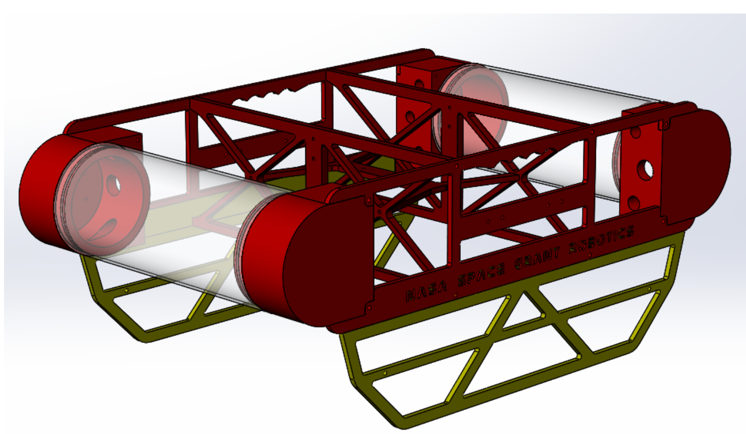

Fig. 3 SolidWorks rendering of Koi's frame

Claw 1 - Small Diameter Claw (SDC): This claw was designed and built in-house to satisfy Koi's specific needs. Claws used in past season have been found to be too wide when open to allow for full rotation and articulation when the ROV is resting on the floor, limiting her operational envelope. The SDC is fully articulable with 360+ degree wrist rotation. It can pick up objects up to 65 mm wide (approximately) and is retractable to allow the ROV to fit in tight spaces such as the 75 cm square ice opening. We found this design to have the most flexibility when it came to manipulating objects over a simple claw like the Seabotix claw due to the inclusion of a wrist and its ability to retract. We no longer need to reposition the robot to grab an object, which can be a imprecise and cumbersome process. The claw operates using two 12-volt bilge pump motors with speed-reducing gear trains, and is manufactured using machined 6061-T6511 aluminum alloy, bent and punched 6061-T6511 aluminum alloy sheet, and 3D-printed PLA (polylactic acid) plastic, as well as commercially available parts (such as bearings, threaded rod, and sliders). (Project Lead Engineer: Drew Denike; Project Engineers: Jeremiah Dwight, Annie Martin)

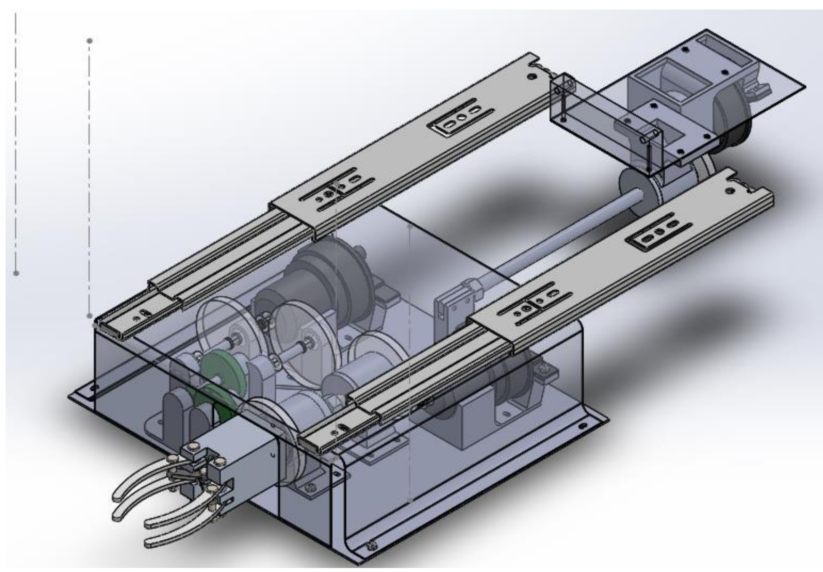

Fig. 4 SolidWorks rendering of the Small Diameter Claw

Claw 2 - Seabotix Grabber: The Seabotix Grabber is a commercially available claw that has been used by the company for a number of years now. It takes a simple voltage as input and uses that to turn a screw, which then opens and closes the claw. The claw mounts on the bow of Koi using a custom-built adapter and connects to one of the speed controllers in the stern enclosure via a pie connector. Because this claw is so simple, it will be used for simple tasks like delivering items from the shore to the mission area or vice versa. We decided to use this commercially available part in addition to designing our own because it allows us to perform general manipulation tasks where a more custom claw design is not needed.

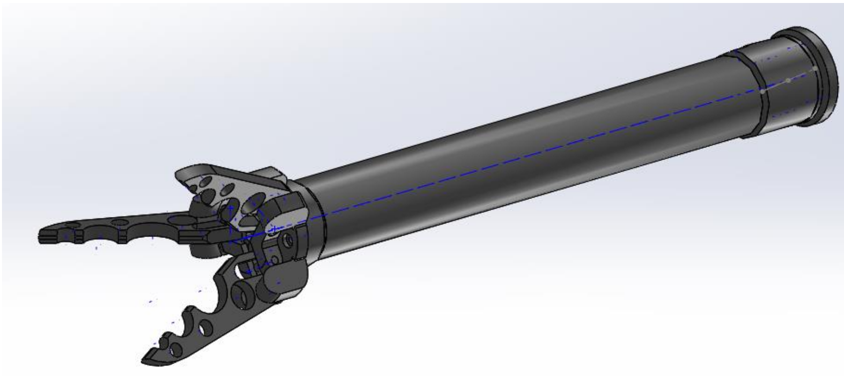

Fig. 5 Seabotix Grabber

Motor Enclosures: This year's motor enclosures are an update to the previous model. In the past, an aluminum tube with polycarbonate end caps had been used; however, impact damage compromised some of the seals and the enclosures flooded. In the current rendition, the enclosure comprises of a PC tube with one PC endcap on the motor side and one aluminum endcap with a sealable pressure relief hole on the other. The aluminum cap serves as a heat sink for the electrical components inside, as PC is a poor thermal conductor. The pressure relief hole is a tapped hole in the endcap that allows for easy installation and removal of the endcaps for service, but is sealable with a rubber seal and screw. (Project Lead Engineer: Drew Denike)

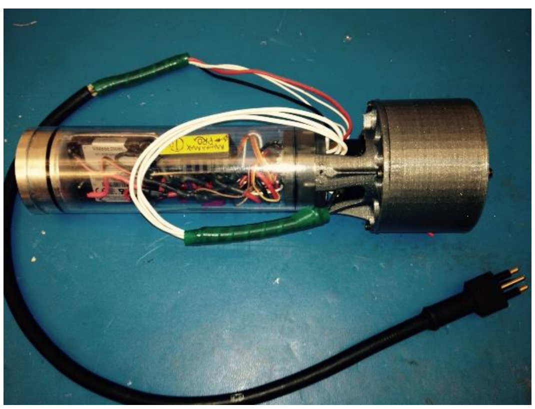

Fig 6: Motor Enclosure with Propeller Cowling on the front

Propeller Cowlings: The propeller cowlings used in past years functioned as intended, but broke in transit and melted in the hot Arizona sun during outreach and recruitment events. An update to the cowlings was designed to improve impact strength and structural integrity. Due to cost it was not found to be advisable to change materials to prevent further melting; however, the design is more modular than before and parts which show signs of degradation can be easily replaced. The cowlings are made from 3D-printed PLA plastic to accommodate the complex design. (Project Engineer: Jeremiah Dwight)

Side Camera Enclosure: The side camera consists of a webcam mounted to a servo array inside a PC tube with an optically clear acrylic base to allow maximum camera visibility. The servos allow for pan-tilt capability so the operator may point the camera independently of the rest of the robot. In previous years we have found that simply having a forward and rear facing camera does not give us enough visibility in the water, and this side-camera enclosure allows us to scan the entire mission field, depending on where it is placed. This design is also very modular, which has been the primary goal of development this season. We can very easily move the enclosure to a different part of the robot depending on what kind of mission needs to be run. The signal and power goes through a Bulgin connector on one end of the tube to SeaCon connector on the bow enclosure. This part was reused from previous years, though the internal camera was updated from analog to digital.

3.2 ELECTRICAL:

Stern Electronics Enclosure: The stern electronics enclosure houses Koi's power converters, a camera, and an Arduino microcontroller. The power converters take 48V from the surface and convert it to lower levels for use by all onboard systems, except the motors, which have their own converters. The Arduino controls the claw, the tilt servo for the camera, along with all five motors. It, along with the camera, are connected to the Intel NUC in the bow enclosure via a 12-pin SeaCon cable. (Project Lead Engineer: Carl Stevenson; Project Engineers: Sayed Serhan, Saeed Amirchaghmaghi)

Bow Electronics Enclosure: The bow enclosure contains the onboard computer (an Intel NUC), a pressure sensor, IMU, another Arduino, and the forward camera. The NUC is connected to the surface via an Ethernet line, which allows the pilot to establish a remote desktop session with it and bring up the control interface for Koi's systems and the camera displays. The Arduino (a Mega Mini) reads data from the IMU and pressure sensor and sends it to the NUC. (Project Lead Engineer: Joseph Mattern; Project Engineers: Brittany Nez, Saeed Amirchaghmaghi)

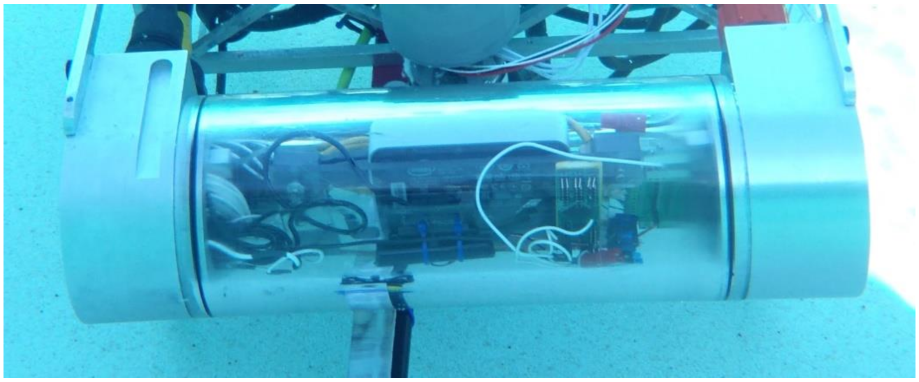

Fig. 7: Bow electronics enclosure

Flow Rate Sensor: The flow rate sensor consists of an LED, photodiode, and a propellor that will interrupt the LED's light as it spins. Based on how often the light is interrupted, a computer program will determine the number of rotations per minute the propellor is making. That will in turn determine the how fast the water is moving in meters per second. We decided to measure the interruption of light rather than measuring the current generated by a motor that is being turned by the water flow because we believe that a motor would not be sensitive enough to give us precise measurements or that the motor would not be able to accommodate many different flow rates. Our members also have more experience with detecting and amplifying light variations from similar projects. (Project Engineer: Max Ruiz)

Camera System: Koi uses three digital webcams to observe its environment. There is one in the stern enclosure, one in the bow enclosure, and a third one that can be mounted externally. Each of these simply plugs into the NUC with a USB line. From there, they are routed to the surface via the remote desktop connection and displayed on the video monitors. In previous years we have used analog cameras and transferred their display to the surface through Black Box and Ethernet technology, but this year we wanted to develop stereovision and general image processing software, which requires the NUC to receive the video feeds. (Project Engineer: Carl Stevenson)

Cables and Connectors: The tether contains a 48V power line and two ethernet lines. The 48V line connects to the stern enclosure, while other two connect to the bow enclosure. One ethernet line carries data back and forth between Koi and a laptop on the surface. The other ethernet line used a 12-pin connection (only eight of which were active) on either end for the old camera interface, but is now no longer in use.

The stern enclosure has four additional connectors: a 4-pin SeaCon, a 12-pin SeaCon, a 12-pin pie connector, and a 24-pin pie connector. The 4-pin connector carries power from the convertors in the stern enclosure to the bow enclosure. The 12-pin pie connector connects to the Small Diameter Claw and other auxiliary systems. The 24-pin pie connector sends signal and power to each of the five motors (see Fig. 7). This setup allows motors to be easily and individually removed and placed back in, which is in line with the philosophy of modularity that drives development of Koi. The 12-pin SeaCon is used to run a USB line between the stern and bow enclosures. The bow enclosure has an 8-pin SeaCon connector for the external webcam. The extra pins allow for the possibility of future expansion. (Project Lead Engineer: Carl Stevenson; Project Engineer: Sayed Serhan)

Thrusters: Koi contains five onboard motors, two facing forward, two facing upward, and a strafe motor. The thrusters are each composed of a Scorpion brushless motor, 3D-printed propeller housing, and an attached enclosure. Each enclosure contains a power convertor and a speed controller. The converter takes in 48V and sends 5V to the speed controller. The speed controller takes in data from the Arduino Mega in the stern enclosure and tells the motor how fast and in what direction to spin. (Project Lead Engineer: Joseph Mattern; Project Engineer: Carl Stevenson)

Fig. 8: The 24-pin pie connector, with multiple male connectors feeding into a single female connector. This allows for rapid swapping of motors and a more intuitive design.

Secondary Control Box: As Koi becomes more complicated, the number of functions the pilots need to be able to control increases, and we found that we quickly ran out of space on our Xbox controller to fulfill all those functions. This inspired the design of the Secondary Control Box, which has a variety of switches, knobs, and displays to allow another pilot to control aspects of the robot during the mission. The box was designed to be generic, so that it can fulfill a variety of functions, and for this year we anticipate it will be used to control the voltage sensor used in Demo 3 and the Seabotix Claw. (Project Engineer: Brittany Nez).

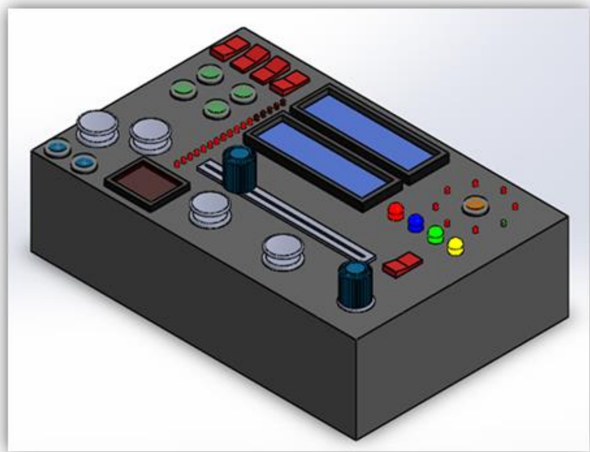

Fig. 9: Secondary Controller SolidWorks Design

3.3 Programming:

Software: Koi is controlled by two Arduino microcontrollers that both communicate serially with the onboard NUC. Koi utilizes ROS's subscription and publishing features to coordinate data transfer between the microcontroller's and the NUC, as well as cameras that connect directly the NUC. On the surface, a laptop is connected directly to the NUC through an Ethernet cable in the tether and the pilot initiates a remote desktop session and all the software is run directly on Koi. An Xbox controller is ported through the remote desktop session and serves as the pilot's primary interface to Koi. The pilot additionally runs a C++ Graphical User Interface designed in Qt Creator that can display the sensor data from the robot, such as the flow rate sensor or the camera feeds. We chose to use ROS because of its elegant design that promotes modularity, which has been a primary emphasis for our team this season. (Project Lead Engineer: Josh Miklos; Project Engineer: Peter Tueller)

ROS: This season was the first time the programming team attempted to implement the Robot Operating System, or ROS, as the primary software design for Koi. ROS operates under the idea that everything connected to it is a 'node' that is a part of a larger communication network, and certain nodes can publish messages or subscribe to other messages. We have implemented nodes inside the Arduino code that publish sensor values or can control motors based on received messages from the user's input to the NUC. We could additionally use the digital cameras as a node that publishes their video feed and the user subscribes to it in the Qt application, but due to the relative inexperience of team members with this software and time constraints, we were unable to implement it this season. (Project Lead Engineer: Josh Miklos; Project Engineer: Chris Harn)

Surface Side: The Graphical User Interface, or GUI, is an important feature of the surface side code. The design was focuses on being simplistic and effective. All data passed from the Arduino is sent to the GUI to be displayed for the driver to see. Critical information such as depth and current direction are present to guide the driver through any environment. Other relevant information as the mission timer and data from sensor probes are presented in a clear manor that our drivers need for completing missing tasks in a timely manner. On the simulated screen are other useful notifications that the driver will encounter. A notification will pop up in the middle of the screen if communication with the robot is broken during the run time. An message box at is also present to give any relevant information to the driver, such as when semi-autonomous functions like hold depth and tilt lock are activated. (Project Lead Engineer: Josh Miklos; Project Engineer: Peter Tueller)

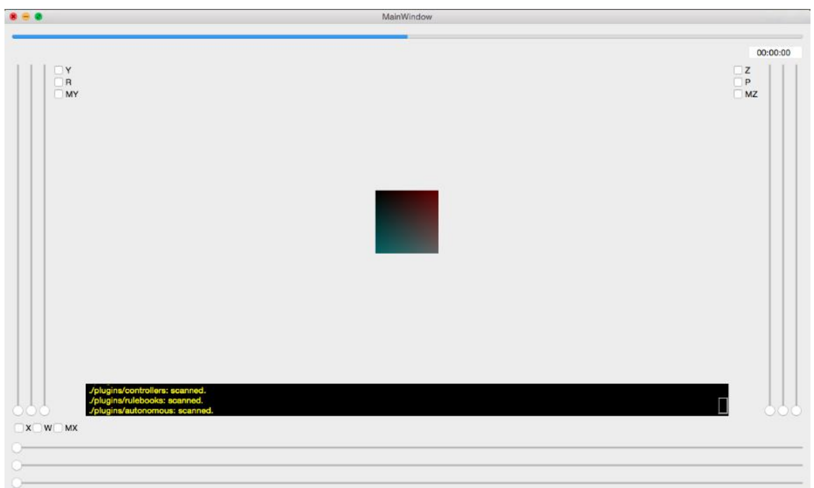

Fig. 10: GUI without Koi connected. Not pictured are the additional windows that display sensor values and coordinate access to plugins

Arduino: The Arduinos offer multiple connectors that handle data separate from the PC. Due to the Arduino's open source nature it comes with well documented example code from other users. This means our programming team can use the Arduino for each and every situation and I/O device required by the application. The Arduino is responsible for receiving all the high-level commands from the surface side code and interpreting them. It then sends appropriate commands to each individual motor to simulate what the driver wanted Koi to do. In return, the Arduino gathers all raw data from our sensors and passes them back to the surface side code to be displayed to the driver. (Project Engineer: Peter Tueller)

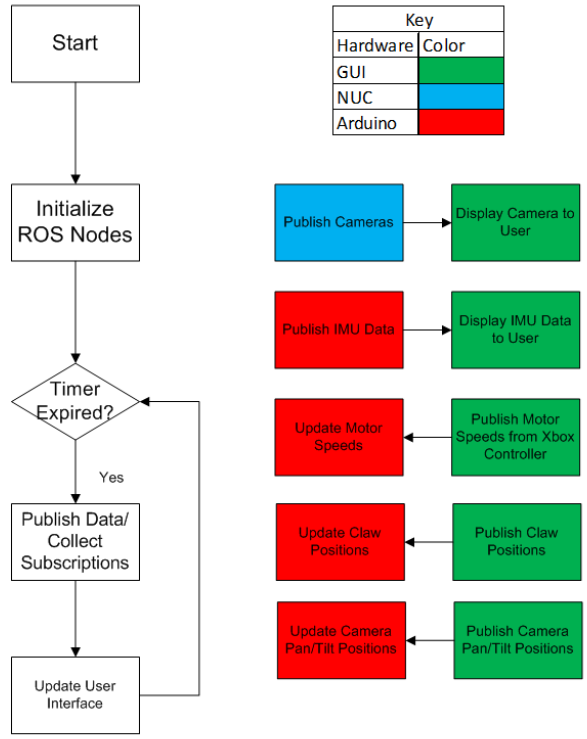

Fig. 11: Programming Flow Chart

4 Troubleshooting:

One issue on Koi that we had to adjust after construction was the buoyancy. Koi is designed to have a high center of buoyancy, while remaining roughly neutrally buoyant. The marine foam we used this year for central buoyancy turned out to be more buoyant than we expected. As a result, we spent the better part of an hour carving away at the foam with a hacksaw in order to reduce buoyancy. We tested it several times in the pool, carving away bits, before putting the block back on and putting the robot in the water momentarily. Eventually, we got Koi down from positively buoyant to roughly neutral. We also had to make sure it was slightly more buoyant on the bow side to compensate for the weight of the claw.

On the electrical side, very often things wouldn't work the way we expected. One particularly hard issue was that we could not get USB communication working between the NUC in the bow enclosure and the Arduino in the stern enclosure. To determine what the problem was, we isolated each individual piece of the communication line: we plugged the Arduino directly into the NUC, we tested continuity across the SeaCon that connected the two enclosures, we checked the appropriate voltages to make sure both the NUC and the Arduino received adequate power, etc. In the end, we found that our quick disconnect that connected the

SeaCon in the stern enclosure to the electronics in the stern enclosure was misaligned, and proper contact was not being made. This problem was quickly rectified and communication began working as expected. The entire electrical and software portions of the robot were tested in this manner: each component was isolated and verified, and then each component was added incrementally until the entire robot was built.

5 Safety Features:

NASA Space Grant Robotics is fully committed to safety and integrates it into our designing, manufacturing, and testing workflows, not to mention in our general use of the robot. Whenever performing mechanical work on the robot, students are required to wear protective clothing and shoes, as well as safety goggles. Each student that performs machine work in Arizona State University's machine shops are expected to become a certified machinist, which is a 20-30 hour interactive safety and instructional course offered by ASU. Every student who performs electrical work on the robot is given an instructional course on soldering and is required to wear a grounding strap when working with sensitive components. There are checks in place to determine that there is no power to the area that is being worked on.

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. The Vicor power converters also are able to shut down when they detect a short circuit in the system. In the event that one of our enclosures floods, the power converters would shut off very quickly and preserve the electronics from being destroyed. Additionally, each significant component of the robot is fused appropriately so that if a portion of the robot starts drawing enough current to indicate that it is malfunctioning, the wire connecting the power source to that component is physically destroyed.

All electrical connections that can be disconnected are terminated with Anderson Power Pole connectors, as seen in Fig. 12, and are color-coded with the appropriate voltage so that we do not accidentally wire components in such a way that shorts them or applies a reverse voltage.

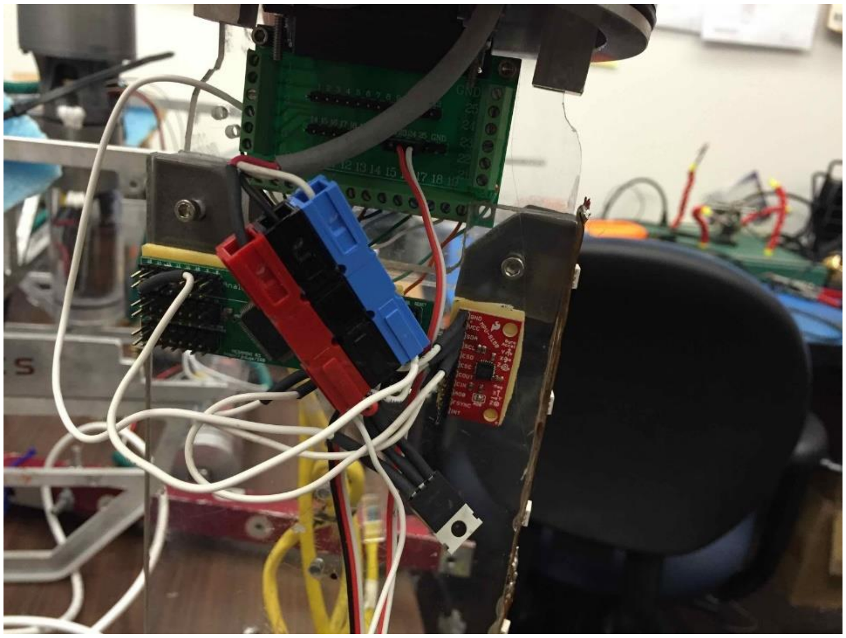

Fig. 12: Anderson Power Pole Quick-Disconnect between Pressure Sensor and Arduino

Our frame also included a few safety features. The most obvious is the handles that are embedded into the frame (see Fig. 11), 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 themselves. Every thruster has a propeller cowling shielding it so that no one can be injured by the rapidly rotating propellers. 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.

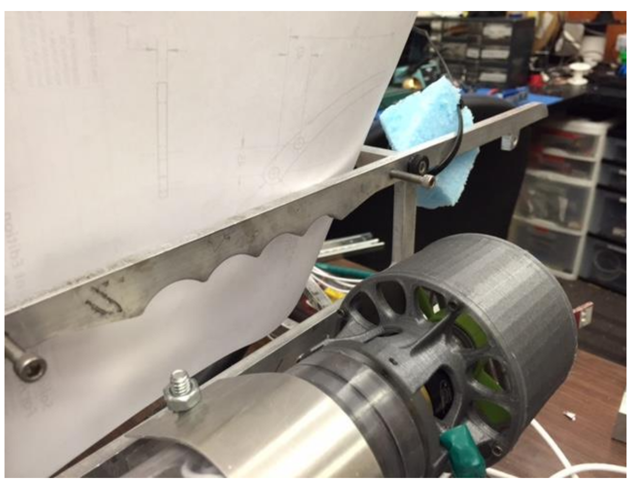

Fig. 13: An ergonomic handle embedded in Koi's frame

6 Challenges:

The primary challenge this season was the integration of the Small Diameter Claw (SDC) to the frame of Koi. The design of the claw itself was fundamentally straightforward, but when it came to controlling the SDC's movement and choosing the motors we should use to power the SDC, the engineering design became more difficult. After much debate between the SDC designer and the integration team, large and cheap motors were used and a gear box was designed to reduce the RPM. The SDC also had to have significant additions to it so that it could be feasibly mounted on the frame of Koi, and it was these portions of the SDC design that took up the greatest amount of time and resources.

The largest non-technical challenge facing the organization was organizing space and time to test Koi and validate the system. In order to fully test the robot, we needed a lot of space for electrical and software debugging, and we did not want to be very far from our facilities. In the end, we thought outside of the box and decided not to conduct testing through ASU's facilities, and instead created our own testing center around a swimming pool in a local apartment complex. We had to give a presentation to the property owner about our safety procedures and what exactly we intended to use the pool for, but in the end we had a great amount of control over how and when we tested Koi, which allowed us to progress quickly and easily.

7 Lessons Learned / Skills Gained:

One of the lessons we learned this year was how to properly design the thruster endcaps in preparation for Scotchcasting. Scotchcast is a brand of two-part epoxy we use to seal waterproof connections. Last year, our thrusters leaked because the Scotchcast did not properly bind to the wires. We learned that rather than making the holes just big enough for the wires, we had to gouge out a large groove in the endcap and fill it up with epoxy. Because the Scotchcast is very viscous, it will not flow into the gaps between the wires and the edges of a small hole. By making a very big hole and being careful to evenly distribute the epoxy around the wires, we were able to ensure a complete seal.

The largest interpersonal lesson that NASA Space Grant Robotics learned was in the organization of the team members. Many members wished to join simply to put the club on their resume, and did not last past the first two months of build season, which is valuable time lost. As a team we promote inclusion and have very low entry requirements to create a good learning environment, but this does have negative consequences for our productivity. We solved this problem by having a small meeting where each team member discusses what the progress of their assigned task and figures out what they are going to do that week to continue progressing. Member retention did not reach 100%, but it did increase and the entire team felt more cohesive and coordinated.

8 Future Improvements:

For future use on our ROVs we anticipate the need for a ranging mechanism. In running the missions our pilots have noticed that it is very difficult to determine how far away an object is, or even how far away the walls are. In some testing areas we have been unable to tell whether we are in the middle of the pool or looking right at a wall without moving the robot significantly and looking for landmarks. There has been discussion about creating some device that can determine the distance between an acoustic or LASER source and the object directly in front of it based on how long it takes for the source to return, much like how bats use echolocation or how submarines use SONAR. This additional sensor could be seamlessly integrated into our navigational interface and would make it easier for the pilots to navigate through the mission field.

9 BUDGET:

Expense	Cost [USD]
Intel NUC Compact PC	500
Endcap Machining Work	270
Power Conversion Systems	100
Microcontrollers	100
USB and Analog Cameras	60
Brushless Motors	600
Stock Materials and PVC	700
Miscellaneous Electronics	50
Complimentary Controller	100
Testing Systems	60
Tools and Drill Bits	160
Epoxy	100
Flight Cost	3,280
Room Cost	2,350
Total cost [USD]	8,630

Fig. 14: Planned Budget and Expenses for 2015 season

9.1 Project Costing:

Item	Quantity	Donation/Discount	Re-Used	Purchased	Total Cost [US$]
Aluminum Frame	1	300	100		400
Aluminum Enclosure Endcaps	4	2000	105		2105
Polycarbonate Motor End Caps	5			80	80
Aluminum Motor End Caps	5			70	70
Endcap Finishing Work	1			270	270
Intel NUC Compact PC	1			350	350
Hard Drive and Ram	1			147	147
Arduino Mega	2		21	42	63
Arduino Mega Mini	1		53		53
Brushless Motors	6			599	599
Propellers	5		65		65
DC - DC Power Converters	8	1200			1200
DC Speed Controllers	3	80	205		285
Three Phase Speed Controllers	5	225	540		765
Creative USB Camera	2			28	28
Sony CCD Camera	2		110		110
I2C IMU	2			20	20
DB25 Breakout Board	6		60		60
SeaCon Wet-Mate Connectors	25	1600		1600	3200
Pressure Sensor	1		105		105
Data Tether		813			813
Power Tether			35		35
Bilge Pump Motors	4		240		240
Black Box Video	1		130		130
Bearings	16			94	94
Gears				27	27
Servos	4		44		44
Wire and Connectors			50	30	80
Surface Side Controller Components				160	160
Epoxy				110	110
Paint				30	30
Marine Foam			150		150
Prop Materials			100	230	330
Stock Materials and Hardware			490	1060	1550
Total cost [US$]		6218	2603	4947	13768
Item	Quantity	Donation/Discount	Re-Used	Purchased	Total Cost [US$]
Flights				3280	3280
Hotel Cost		2000		350	2350
Rental Car				700	700
Total cost [US$]		2000	0	4330	6330

10: REFLECTIONS:

After my first year with NASA Space Grant Robotics and robotics in general, I learned that your input is always welcome, regardless of how much experience you have. Robotics, especially underwater robotics, can be an intimidating subject for freshmen and others who have no prior experience. Realizing that my opinion mattered made me more confident in exploring with ideas for improving Koi, the features of SolidWorks, and asking questions. I feel that my first year experience can inspire others to join and stay with the team next year and the years to come. -Annie Martin

NASA Space Grant Robotics gave me a great opportunity as a freshman to dive into hands-on engineering projects. Thanks to the club, I got a head start on learning how to use SolidWorks and its many capabilities. It also helped a lot to be able to see and hold the printed parts that I had designed so that I could improve my designs. Our organization was also very accessible to newer members in that my questions and design input were also answered and considered. I also look forward to next school year where I hope to learn and contribute more. -Trevor Falls

11: ACKNOWLEDGMENTS:

We would like to thank the Arizona Space Grant Consortium, the Ira A. Fulton Schools of Engineering, and the ASU Undergraduate Student Government for funding us. The Mars Space Flight Center has graciously lent us two rooms and use of their facilities as well. We would also like to thank the following organizations for their generous donations: UON Technologies for a cash donation, Vicor for power converter donations, Castle Creations for their discount, Dimension Engineering for their discount, Alpha wire for their donation, SeaCon for their discount, and Protolabs for machining work done on the electronic enclosure endcaps. Finally, we thank the MATE Center for providing us with this opportunity.

12: REFERENCES

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13: Appendix 1: Safety Checklist

Before putting Koi in the water:

1. Are all cables connected to Koi in their correct location?
2. Is the tether fastened to Koi?
3. Is the Ethernet cable connected to the piloting computer?
4. Is the main 48V fuse connected?
5. Is no one touching the robot?
6. Connect 48V to the tether and make sure the Castle Creations speed controllers make the appropriate start up noise (this means that the 5V Vicors are functioning properly).
7. Check the LEDs on the Arduinos and the Sabertooth speed controllers to make sure they have power (this means that the 12V Vicor is functioning properly).
8. Send a Wakeonlan magic packet from the piloting computer to the NUC and check the NUC's LED to make sure it is turning on (this means that electrically, all power systems are safely started up).
9. Make sure two people are putting Koi in the water: one on each handle.

Before pulling Koi out of the water:

1. Is the ROV completely shut off?
2. Are two people handling the robot to pull it out?

Before beginning general work on Koi:

1. Is the power off?
2. If the enclosures are closed, is there any water present?
3. If performing mechanical work, is the component you are machining detached from Koi and from other sensitive components?
4. If performing mechanical work, do you have safety glasses, protective clothing, and appropriate shoes?
5. If performing electrical work, are you sitting down at the solder station with a grounding strap?

14: Appendix 2: System Interconnection Diagram

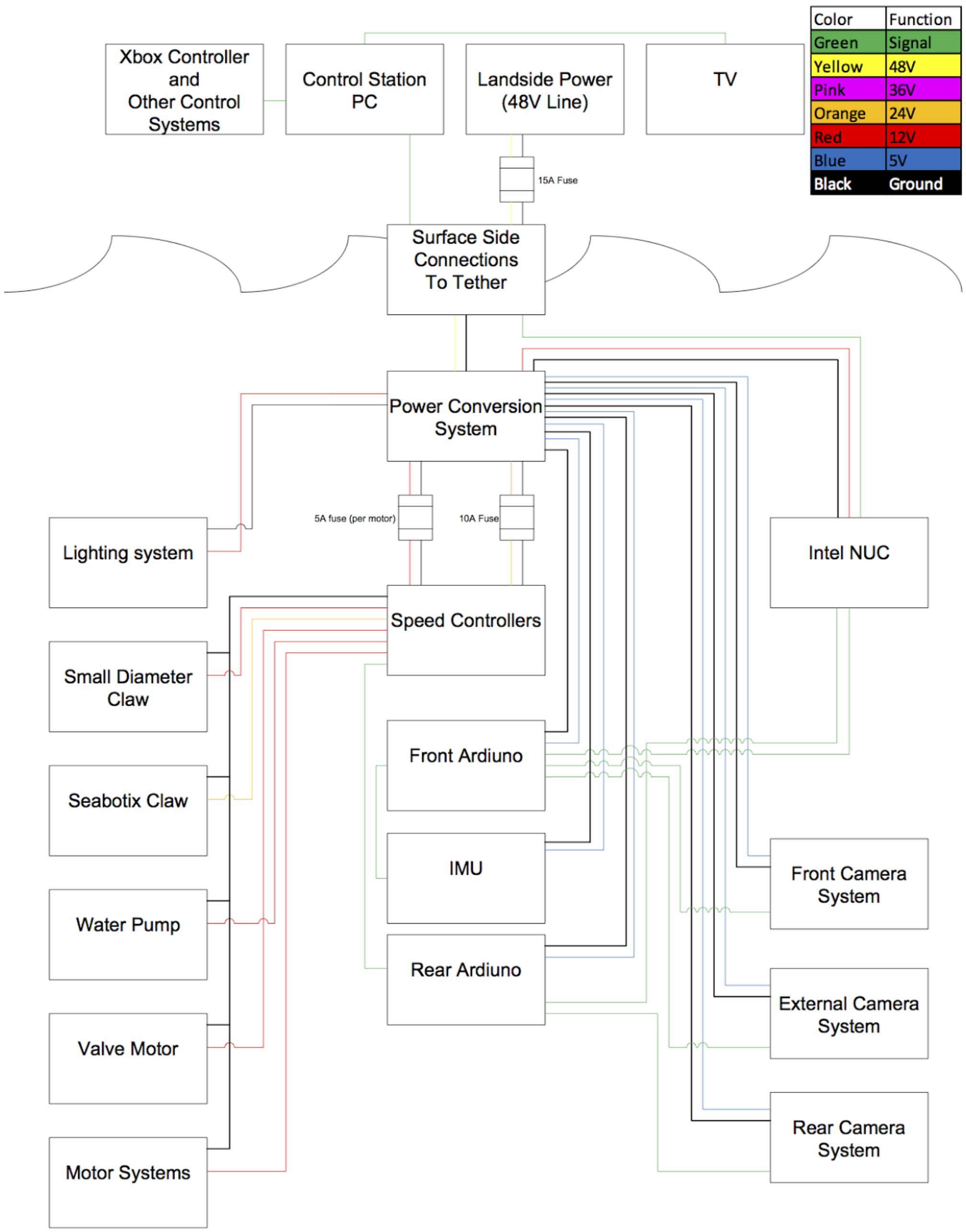
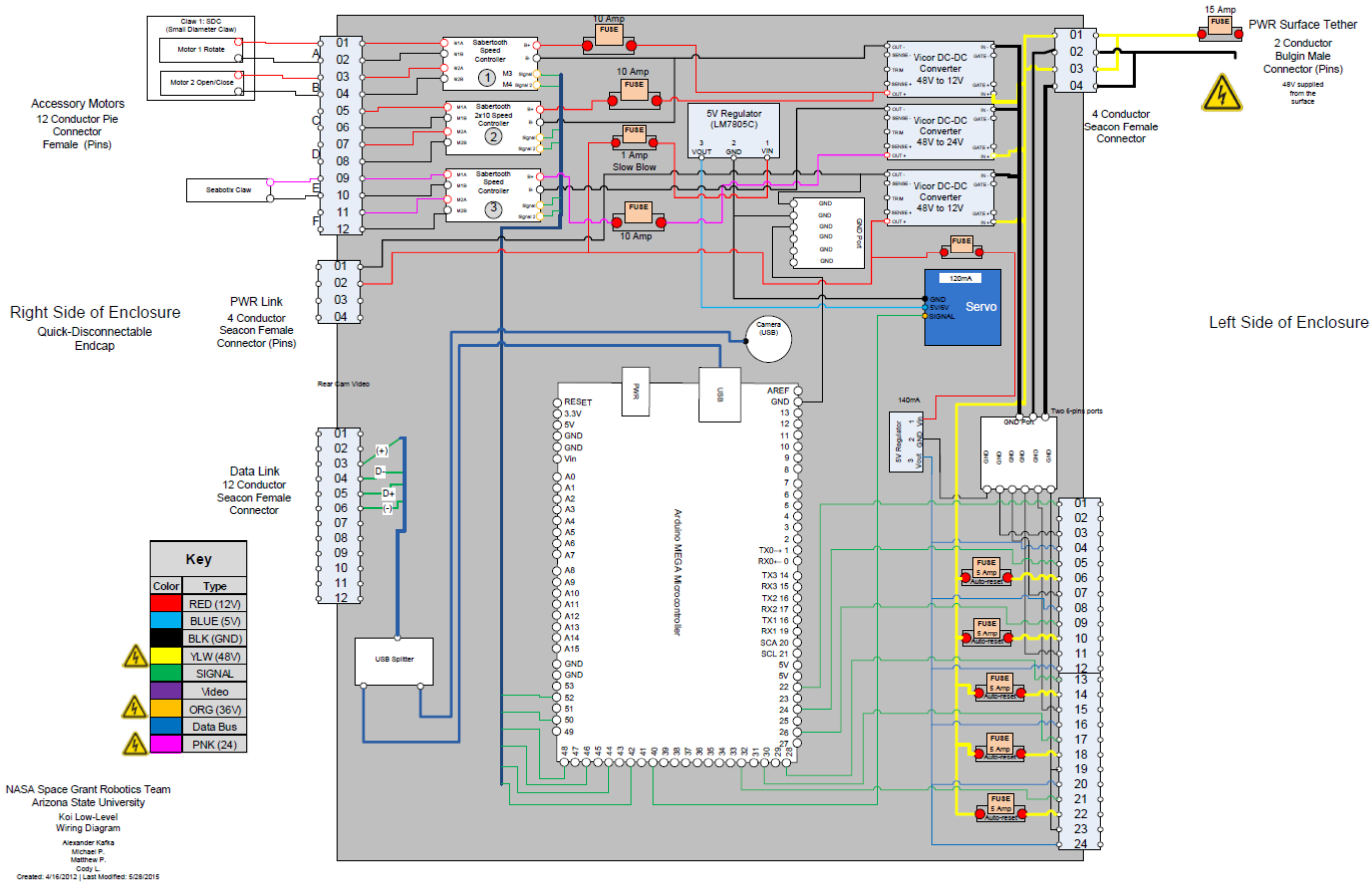


Fig. 15: System Interconnect Block Diagram

15: Appendix 3: Electrical Schematic



Color	Type
	RED (12V)
	BLUE (5V)
	BLK (GND)
	YLW (48V)
	SIGNAL
	Video
	ORG (36V)
	Data Bus
	PNK (24)

Fig. 16: Stern Enclosure Wiring Diagram

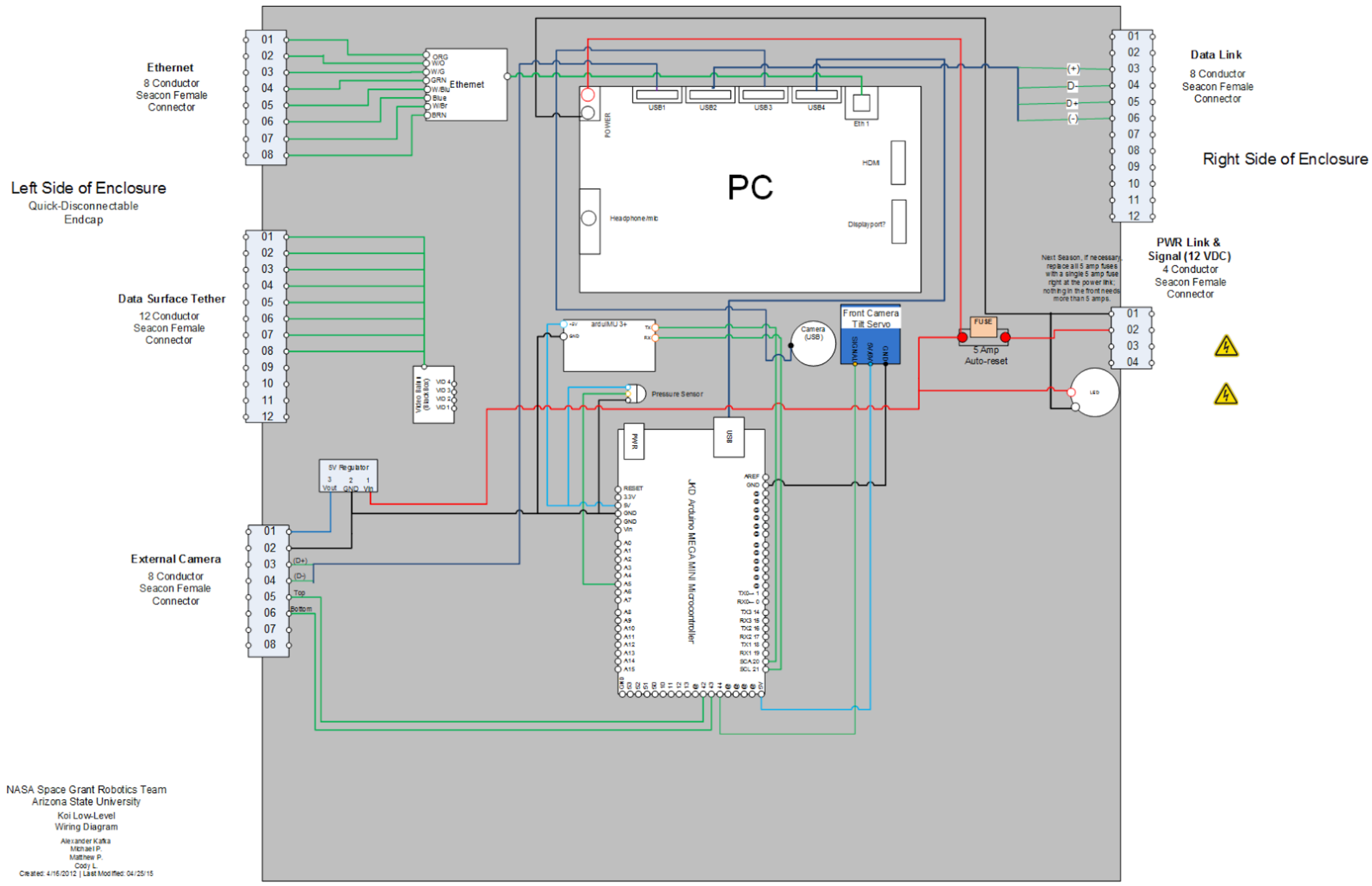


Fig. 17: Front Enclosure Wiring Diagram

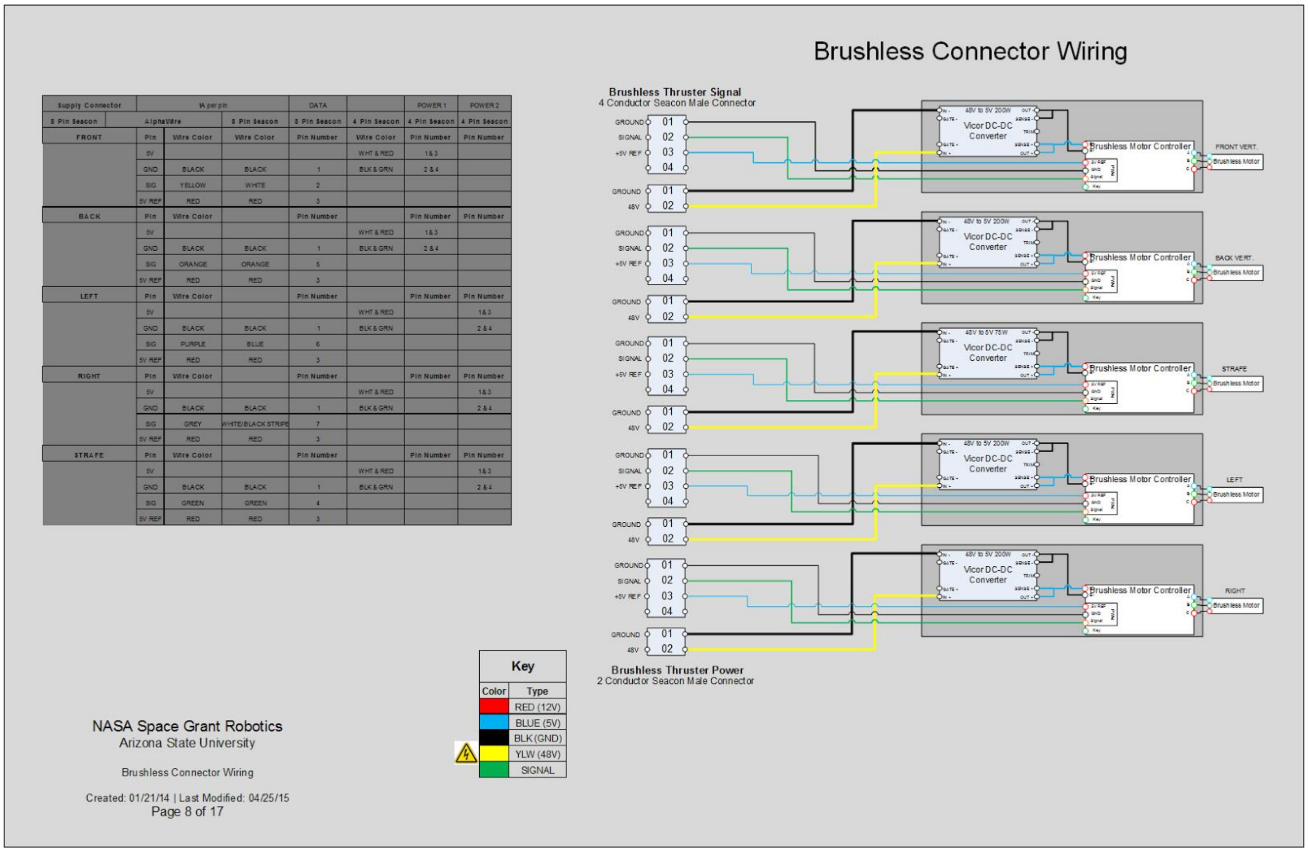


Fig. 18: Motor Enclosure Wiring Diagram