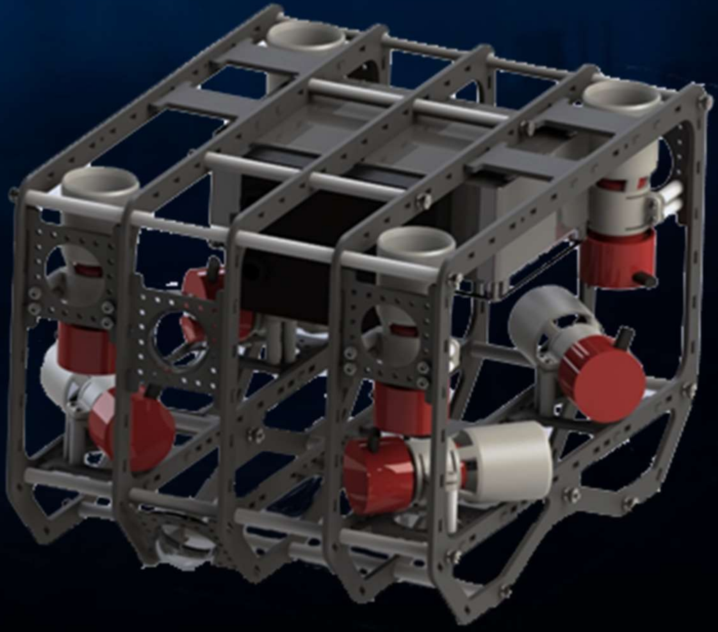
Remotely Operated Vehicle

Northern Illinois University - DeKalb IL, United States
MATE Explorer Class 2016
Technical Report



Staff:

Tim Olson – Mechanical Lead, Programmer, Pilot
Andrew Widmar – Electrical Lead, CEO, CFO, Pilot
Steffen Kist – Electrical Engineer, Artist
Charles Fortner – Mechanical Engineer, Logistics
Joel Rushton – Programmer, Operations Manager

Advisor: Dan Petschow

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Abstract

NIU Robotics ROV approaches the MATE International ROV Competition for the first time with a fully custom underwater remotely operated vehicle. The system utilizes a patterned and standardized tab and slot design that allows for easy reconfiguration and high modularity. A vectored thrust design provides maneuverability at a small cost of efficiency and acceleration. Custom electronics power all facets of the machine from a singular PCB assembly with liquid cooled voltage regulators. A pneumatic enclosure and manifold operate proportional and binary actuators to control a two-axis multi-function gripper. The wirelessly programmable onboard software offers both attitude and depth stabilization so that operators can focus on manipulation and measurement tasks. It also protects both personnel and equipment from damage by implementing monitoring of electronics as well as system status. With two video feed lines, tied into an Ethernet tether, up to four selectable cameras can be toggled and displayed two at a time. A graphical user interface allows for status observation, option controls, and camera selection. This new-to-us project was a challenge for NIU Robotics, a team of seasoned application engineers and robot builders. Our approach fit our resources and style, culminating in a robust system that we look forward to showing off at the Nasa Neutral Buoyancy Laboratory.

Design Philosophy

Modular

The NIU Robotics ROV is designed such that the end user may re-configure the ROV with minimal effort and tools. The ROV may be assembled to fit new applications or restrictions encountered on the job without having to wait for a new application-specific design. A tiered component system allows the ROV to be assembled using modules that fit the user's budget needs and application needs simultaneously. The modular design facilitates upgrades to components as they become available, without needing to replace the entire platform.

Custom

Custom fabrication of components allows the ROV to meet unprecedented user needs and expectations. The ability to design new singular modules to meet specific customer needs instead of redesigning entire platforms gives end users confidence that prior investments in the system do not go to waste, and have a long life-cycle. Custom components can be used with their existing systems to avoid waste and reduce costs.

At the heart of the ROV is a singular custom electronics assembly that serves as the electrical and communications hub of the robot. This all-inclusive system packs power and thermal management, Ethernet communication, motor control, camera management, and safety checking into a single package to be as small, lightweight, and efficient as possible.

Economic

The modular design of the NIU Robotics ROV allows it to take full advantage of economies of scale. Each module may be mass manufactured for sale as individual components to be assembled, cutting production costs. Dictated by user demand for components, product manufacturing lines may be adjusted per component instead of on an entire platform basis. This allows Lean "just-in-time" production values to extend to the end user, while manufacturing components in-house instead of outsourcing gives us control over the entire production process, culminating in reduced costs.

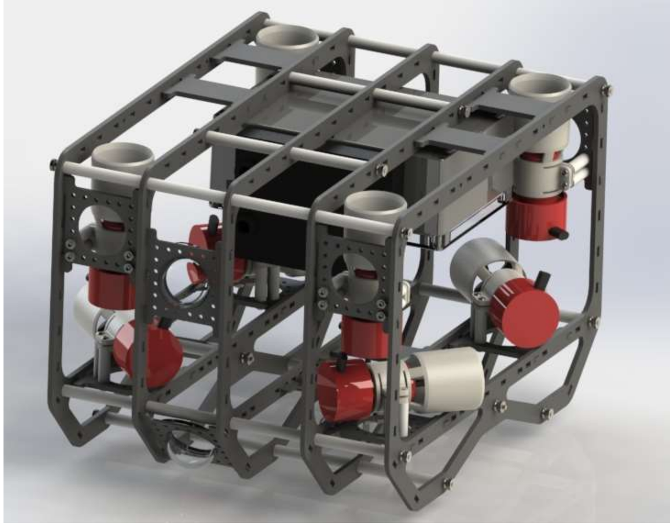


Figure 1: Rendered ROV Chassis

ROV System

Mechanical

Chassis

The NIU Robotics ROV chassis system is highly modular, slightly buoyant, and easily re-configurable. The 3/16 inch rigid high density polyethylene (HDPE) chassis plates provide positive buoyancy, impact absorption, and easy machinability. A total of four plate designs allows for custom systems as well as a variety of configurations. Each module plate can accept several types of attachments, including straight or angled motor mounts at varying positions or camera domes. The plates may also be used for mounting generic hardware.

The Main Chassis Panels serve as guides for placement of modules, supports, and hardware. Around the periphery, modules of 81.3 mm (3.2 in.) typical mounting length can be mounted in intervals of 35.6 mm (1.4 in.) along the front, back or top edges and, with some exceptions, along the bottom edge. At either end of the base, modules can be mounted at 45°. The panels are symmetric and have protrusions to serve as landing surfaces and holes for the chassis structural fasteners. The ROV is configured for the 2016 mission with five panels making up four lengthwise sections of 81.3 mm (3.2 in.) in width. When we discovered how the ROV dimensions were to be measured, the chassis system was placed within 58 cm circles on each plane to ensure this dimensional limit was kept in mind at all times.

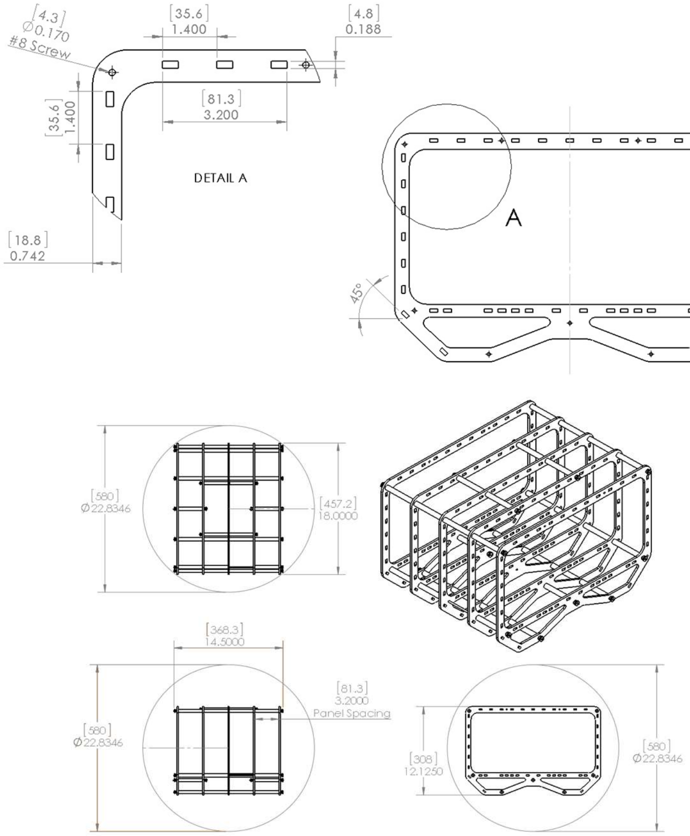


Figure 2: Chassis Dimensions and Modularity

The Straight Thruster Module mounts a motor parallel to the plate surface and two of its sides. The motor is elevated by spacers to allow clearance of propeller shrouds around other chassis components. The motors can be mounted at five positions forward and back along either primary direction of the plate. Additionally, this module's plate design doubles as the camera dome mount.

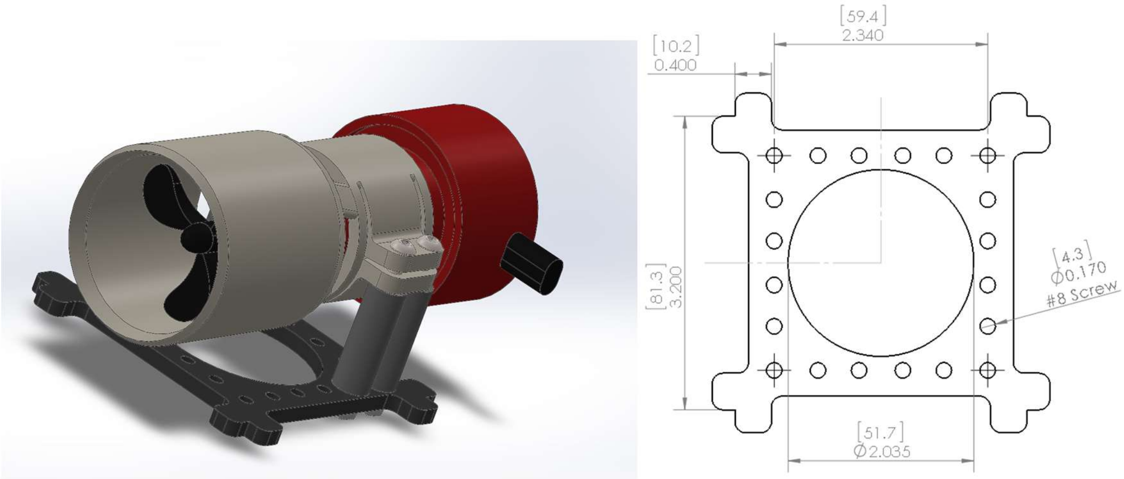


Figure 3: Straight Thruster Module

The Angled Thruster Module functions just as the straight thruster module, with adjustability being of the motor's angle. Our configuration places the angled thrusters at 45°, but the plate allows for increments of 22.5°.

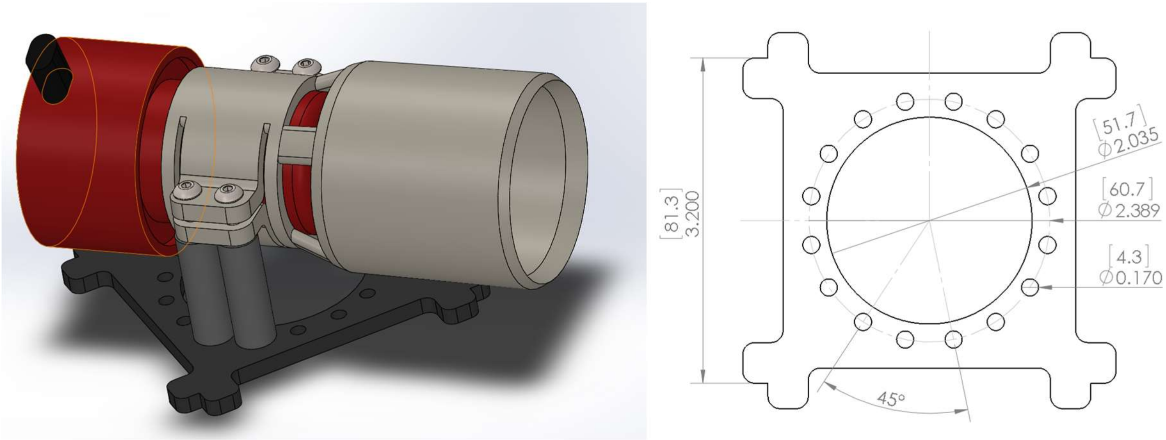


Figure 4: Angled Thruster Module

The Camera Module utilizes the Straight Thruster Module plate design, and mounts a camera inside a water sealed dome. An aluminum mounting plate on the back compresses a large silicon rubber gasket that seals against the dome's outer perimeter. The camera is hot-glued in position, centered on the backing plate. The wiring is run through a hole in the back plate that is sealed with epoxy that also structurally supports the cable. In the camera modules, extra rigidity is preferred to prevent plates from bowing, so the same plate profiles are available in ¼ inch aluminum as well as the HDPE. An additional plate design accounts for the case where modules may otherwise overlap mounting slots.

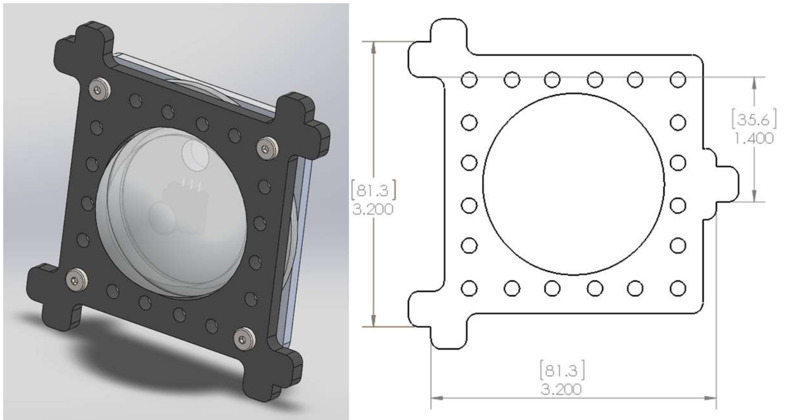


Figure 5: Camera Module and Special Case Plate

The chassis is fastened together by long #8 threaded rod that passes laterally through the main chassis panels. Depending on configuration, some fasteners pass completely across the ROV, while some only include two sections of panels versus the full four. At one end of the rods are brass thumb nuts for easy disassembly and reconfiguration by hand, with acorn nuts secured to the other end enabling sturdy fastening. Surrounding the rods are polypropylene spacers that maintain chassis panel dimensions, while adding significant structural rigidity to the overall system. Due to the flexibility of the HDPE, some areas may need extra support not available from the threaded rod or installed modules. In these cases, generic mounting plates can be added that provide strength and, due to the material's high machinability, additional hardware mounting points.

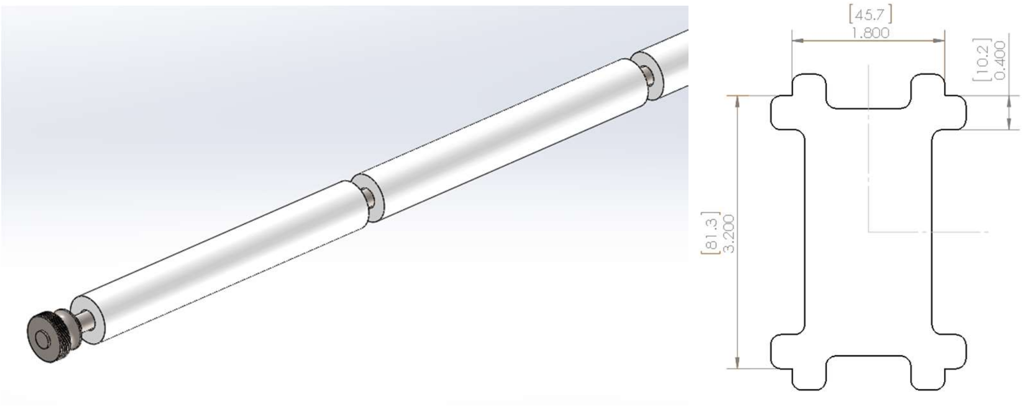


Figure 6: Chassis Fastening Rod and Spacers, Generic Mounting Plate

Propulsion

Rule 28D Bilge Pump Motors were outfitted with 3 blade, 50 mm (1.97 in.) propellers. The motors were selected for ease of use, as they were already waterproofed and required minimal modification. The propellers, Graupner G2308.50 and G2308.50L, thread onto M4 rods and into custom brass couplers. Each coupler uses a flat tip set screw that sits against the flat of the motor shaft, and a cone tip set screw pointing into the lip of the shaft. The former transfers torsion to the propeller, and the latter retains the attached hardware to the motor.

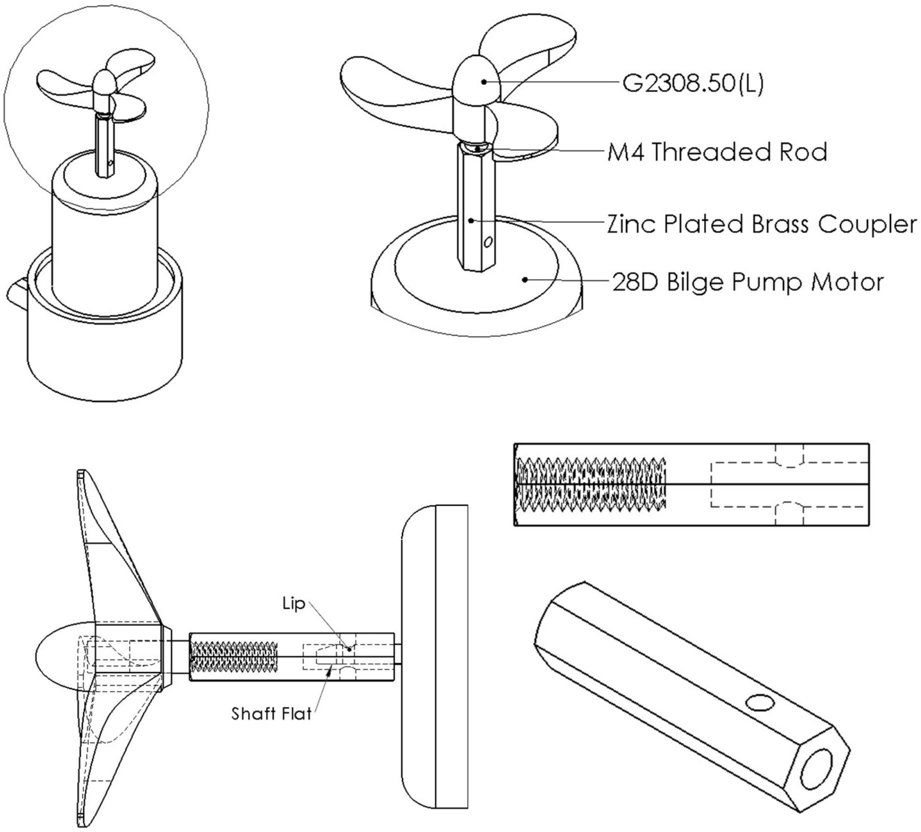


Figure 7: Propeller Couplers

Rapid-Prototyped Shrouds enclose each propeller, preventing injury or equipment damage. The shrouds extend in front of, and behind, the propellers by a minimum of 2 cm (0.79 in.). The shrouds utilize a friction clamping system, that worked well as a prototype and had minimal changes made for the final product. Specifically, the clamping ability is governed by the unstrained separation angle of the clamp, which was increased from 2° to 5° in the finalizing process. The casing that encircles the propellers has an approximate 2° draft, so that variance in propeller diameter can be adjusted for by shifting a motor forward or backward inside the clamp. At the back end, four small arms link the ducting to the clamping section, leaving the majority of the cross section open for water flow.

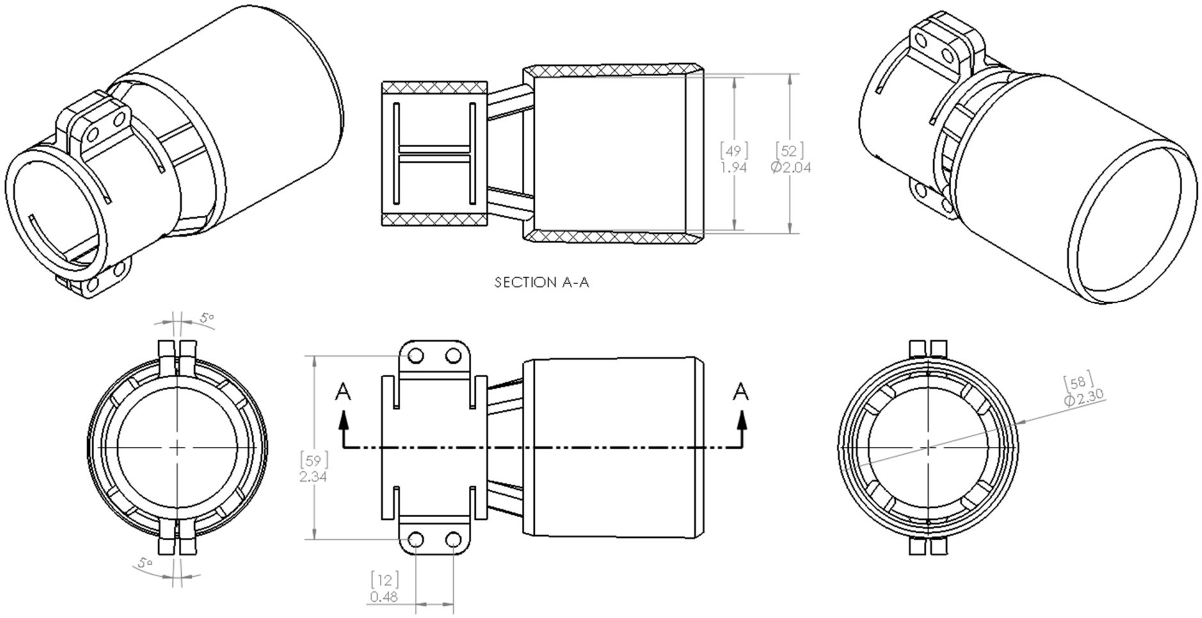


Figure 8: Rapid-Prototyped Propeller Shrouds

The Vectored Thrust System works, in principle, by resolving the thrust of each differently angled motor such that the summation results in a certain speed and direction of translation, as well as rotational velocity. This omni-directional control is possible by ensuring the vectors scale relative to one another, since the thrusters have a maximum operating speed. This means that, without rotation, translation in any cardinal direction will maximize thrust on all motors, while any other combination requires less than full thrust from some motors. While this system is less efficient than alternatives, it allows for great maneuverability and control. Other propulsion and chassis configurations are possible by relocating and re-orienting the modules, allowing the ROV to accommodate vastly different subsystems, manipulators, and tasks.

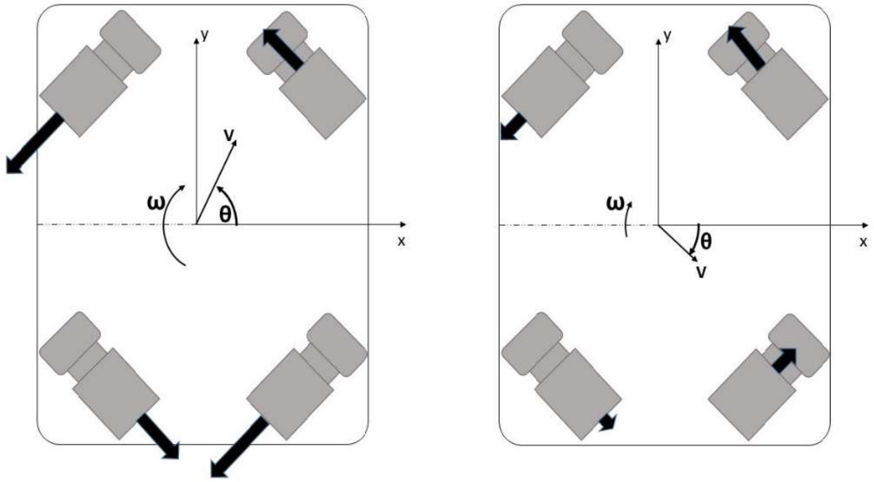


Figure 9: Vectored Thrust Example

Manipulator

The manipulator system is operated by cylinders on a four axis pneumatic circuit. Two of the axes are run on a standard two-way system and two are run proportionally. The two-way axes are controlled with three-way valves that either allow air into the cylinder or vent the cylinder to allow it to retract. For the proportional axes, an electronically controlled proportional valve controls the speed of airflow into the cylinder and a three-way valve allows air to either enter or leave the cylinder. The metered speed control and controllable exhaust allows the cylinder to hold multiple positions between the fully extended and fully retracted states. The entire control circuit is built into a single manifold that manages driving pressure distribution and vents into a box connected via tether to surface atmospheric pressure.

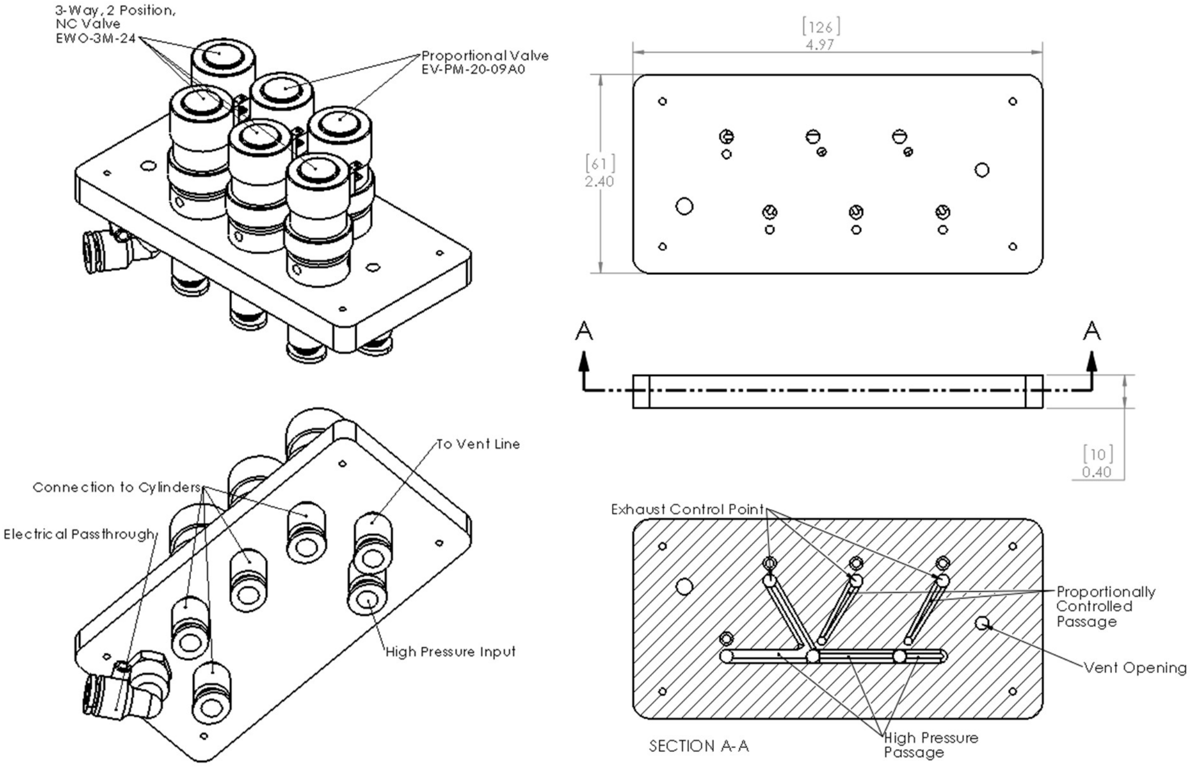


Figure 10: Pneumatic Manifold

The cylinders vent back through the manifold and into the pneumatics box. This reduces size, weight, and complexity of the circuit by removing several connections and replacing them with a venting reservoir that has one connection to the tether vent line. The opposite side of each cylinder is permanently connected to the atmosphere through unions onto the tether vent line. To reduce the number of operating valves, and thus the air circuit's size, the cylinders have external spring biasing that returns them to one end of their stroke.

Connecting the cylinders to the manipulator is accomplished by Kevlar fishing line that acts as belting in a pulley system. The three degrees of freedom achieved are a tilting elbow, rotating wrist, and binary gripping. The proportional tilt control sweeps through an approximately 160° range, while the wrist rotates up to 180° each direction.

The gripper is designed to enable manipulation of the 2016 mission Oil Samples, Wellhead Flange, Cap, and Bolts, as well as the Environmental Sample Processor cable connector. Additionally, the gripper is able to control the Mission Critical Equipment to be identified and recovered. The manipulator-gripper combination folds into the chassis almost completely during operation or for transit purposes.

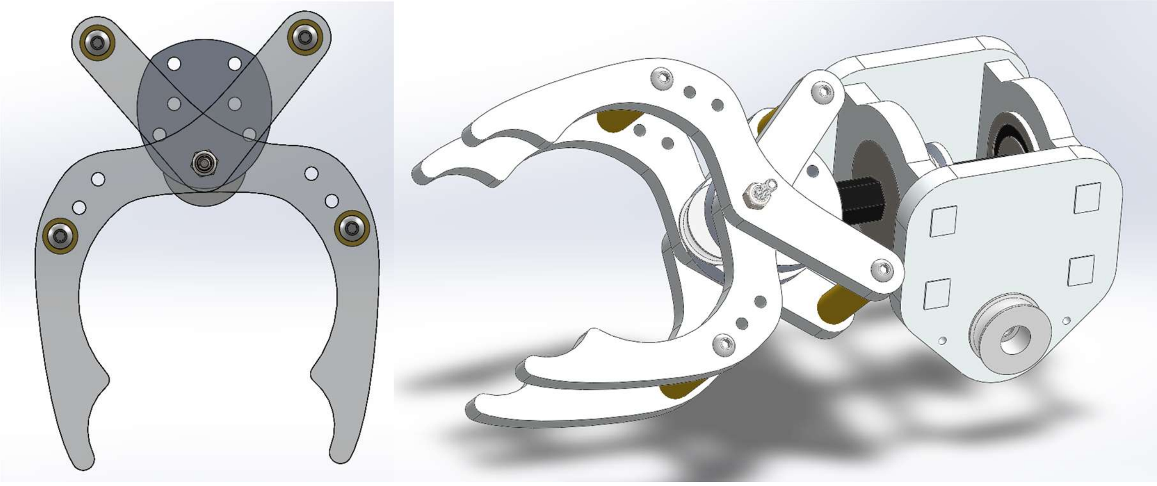


Figure 11: Gripper and Manipulator Assembly

A fixed position rod serves as a simple catch for the ESP Cable Connector hook. The rod captures the connector by catching underneath the top hook of the assembly and lightly snapping into the loop, retaining the connector. The rod is also magnetic, adding to the stability of the connector.

Electrical Enclosure

The electronics system for the ROV is contained in a Polycase WC-40 waterproof enclosure. The box is made out of polycarbonate, which allows us to easily add holes for wire glands. Nine holes were added to the box: three for motor wires; two for the liquid cooling system; two for cameras, sensors, and pneumatics; and one each for power and Ethernet from the tether. The lid has a silicone rubber seal to keep out water once it is secured on the box.

To support the electronics and cooling system within the box, a mounting platform was designed and printed using a Selective Laser Sintering (SLS) 3D printer. The platform was designed to support the cooling pump, waterblock and electronics within the box to both organize components and prevent damage during operation. The waterblock is supported on a set of springs that allows for shock absorption while applying pressure to the thermal interface. The electronics are held in place between the waterblock and snaps printed into the design. The cooling pump is also held in position by a similar snapping system.

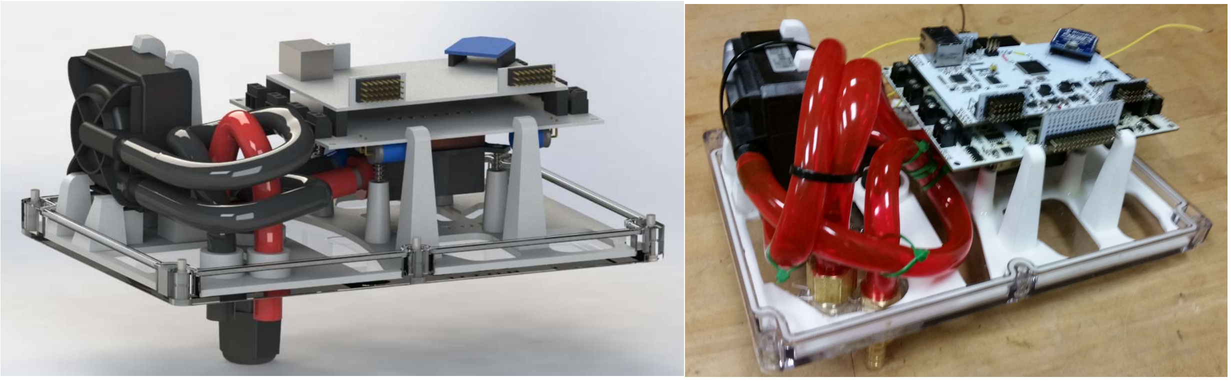


Figure 12: Cooling System and Electrical Mount

Cooling System

The cooling system is built to prevent overheating of the electronics, a potential hazard to operators, the environment, and equipment. The cross-flow heat exchanger system uses distilled water as the cooling fluid and is pumped by a 12-volt EK-DDC 3.2 PWM centrifugal pump. The water is pumped through an EK-VGA Supremacy waterblock, coupled to the high voltage regulators using thermal paste. The heated water is then pumped through an EK-CoolStream SE 120 radiator, located externally, which allows the heat to pass into the surrounding water. A Bitspower Water Tank Z-Multi 40 Inline Reservoir, attached between the radiator and pump allows for easy filling of the system.

The entire cooling loop is not specifically pressure rated. The pump manufacturer states a maximum working pressure head of 5.2 m, equivalent to 51 kPa (7.4 psig). As this pressure is low, even for very small liquid or gas systems, damage or injury risk related to the loop is negligible.

Sensors

The external water Temperature Sensor is a pre-wired, waterproof DS18B20. The sensor is mounted to the chassis within a 3D printed protective casing.

To measure submersion depth for the 2016 mission, a fluid Pressure Sensor is mounted external of the electrical box. The sensor measures pressure experienced on a gel membrane exposed directly to the surrounding fluid, while the remaining PCB board is entirely water sealed with epoxy and silicone sealant.

Cameras Modules are discussed previously in the Chassis section.

Electrical

Overview

The electrical system on the ROV is designed to be as robust and professionally designed as possible. As a result, almost all electrical subsystems are completely custom designed at the printed circuit board (PCB) level, and almost all major components have been researched and selected from major integrated circuit (IC) manufacturers. This approach allows for unparalleled control over the mechanical and economical aspects of the electrical system design, which creates a significantly more size efficient and cost effective system. The electrical system is divided into seven subsystems: voltage regulation circuitry, microcontroller circuitry, thruster control circuitry, actuator control circuitry, communication circuitry, vision circuitry, and sensor circuitry. In the following section of this document, the electrical subsystems and resulting PCBs are described in moderate detail with emphasis placed on each subsystems' advantages over commercially available alternatives.

Printed Circuit Boards

The ROV electrical system is comprised of 8 custom designed printed circuit boards: control board, power board, camera connector board, sensor connector board, tether connector board, actuator connector board, pressure sensor board, and inertial measurement (IMU) board. The main electronics assembly contains the control, power, and connector boards. The control board is mounted on top of the power board using header pins as stand offs. The camera, sensor, and tether connection boards are mounted perpendicularly to the control board using right angled headers. The actuator connector board is mounted to the power board in the same manner. The pressure sensor and IMU boards are located external to main electronics assembly and are connected to the sensor connector board using jumper wires. The control board is home to part of the voltage regulation circuitry, all of the microcontroller circuitry, all of the communication circuitry, and all of the vision circuitry. The power board contains the rest of voltage regulation circuitry, all of the thruster control circuitry, and all of the actuator control circuitry. The camera, sensor, tether, and actuator connection boards are where the onboard cameras, sensors, video portion of the tether, and actuators attach to respectively. The pressure sensor and IMU boards simply house the pressure sensor and IMU respectively. The design of the PCBs was completed using EAGLE CAD software and the fabrication of the PCBS was completed by Seeed Fusion PCB fabrication service.

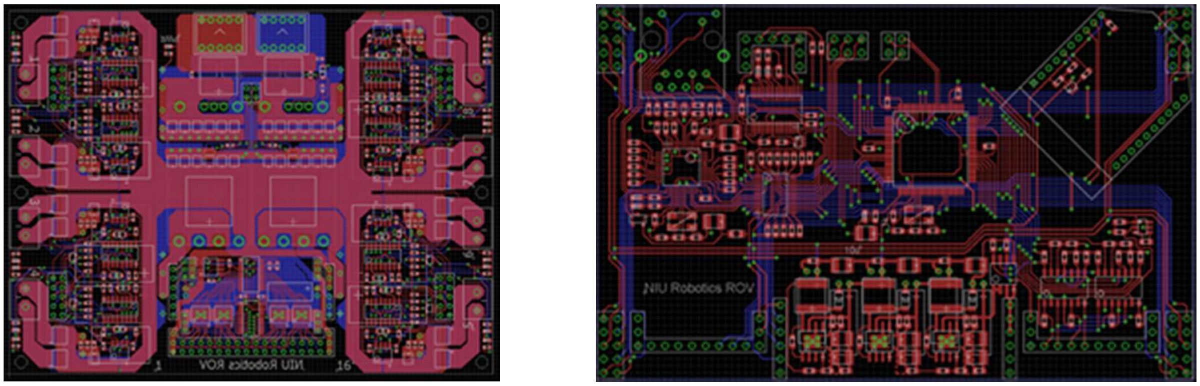


Figure 13: Power Board (L) and Control Board (R)

Voltage Regulation Circuitry

The voltage regulation circuitry consists of four reverse polarity protection mosfets, two 48V to 24V VICOR regulators, one 24V to 12V regulator, one 12V to 5V regulator, one 5V to 3.3V regulator, two ratiometric temperature sensors, one Hall Effect current sensor IC, and various other supporting components. This circuitry is capable of providing all necessary voltages for use by other subsystems in addition to providing protection against incorrect power hookup. The two 48V to 24V VICOR regulators are connected in parallel and are capable of providing approximately 22 amps of current for use by any other part of the electrical system. These regulators produce a significant amount of heat, and as a result, are monitored by a pair of ratiometric temperature sensors that produce an analog signal proportional to their measured temperature. The 24V to 12V, 12V to 5V, and 5V to 3.3V are capable of providing one amp of current each for use by lower power consuming parts of the electrical system. The Hall Effect current sensor is located in line with the input of the 24V to 12V regulator and outputs an analog signal proportional to its measured current. This is used to help monitor the total current consumption of the ROV such that it does not go over the 22 amp limit. Developing a solution for regulating 48V down to lower voltages with large current sourcing capability was one of the most challenging aspects of designing the electrical system. Various methods were considered such as using external regulators or simply not using regulators for high current applications at all, but ultimately using VICOR regulators was determined to be the most optimal solution. This approach allowed for a very compact design, provided a high efficient and easily cooled power system, and reduced cost significantly since the regulators were generously donated.

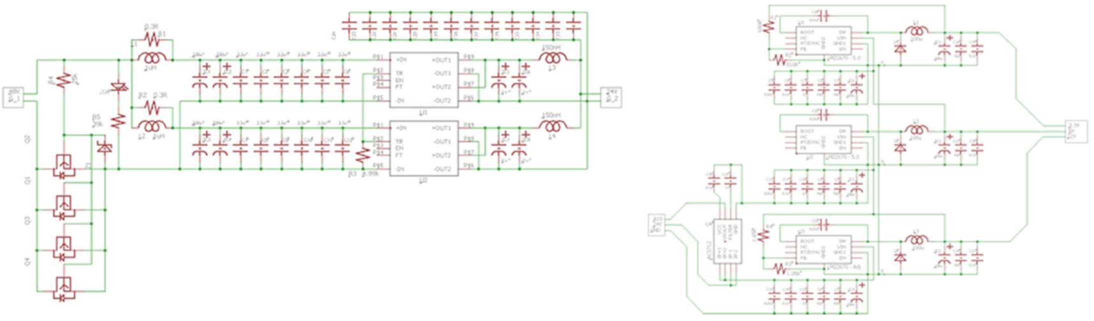


Figure 14: Voltage Regulators

Microcontroller Circuitry

The microcontroller circuitry consists of one system microcontroller, one 10-channel 5V to 3.3V level shifter, one USB to serial converter IC, one Bluetooth module, and various other supporting components. This circuitry is capable of performing all necessary microcontroller programming and is responsible for controlling all other ROV subsystems. The main system microcontroller is powered from 5V and communicates with all other systems using various methods of communication including SPI, I2C, Serial, PWM, digital, and analog. The system microcontroller was initially flashed with a bootloader using a programmer and broken out ICSP pins. After this initial programming, all additional programming occurs using either USB or Bluetooth. The USB to serial converter IC and Bluetooth module act as interfaces between the programming computer and the system microcontroller, converting incoming USB or

Bluetooth data into serial data. The 10-channel 5V to 3.3V level shifter acts as an interface between the system microcontroller and any system it needs to communicate with that requires 3.3V signal levels. This IC takes in 5V versions of SPI, I2C, serial, and a reset signal and converts them into 3.3V versions. The system microcontroller that was used, was selected because of its large availability of communication methods as well as for its relative ease of use in terms of programming, being compatible will all Arduino based programming libraries and the Arduino IDE.

Thruster Control Circuitry

The thruster control circuitry consists of eight identical circuits each containing: four n-channel power MOSFETs, one h-bridge driver IC, one 2-channel de-multiplexer IC, one Hall Effect current sensor, and various other supporting components. This circuitry is capable of controlling the direction and speed of up to eight 24V DC brushed motors. Each circuit is capable of supporting at least 5 amps of current. Hall effect current sensors are used to monitor the current running to each motor in order to prevent overcurrent situations as well as monitor overall current consumption. The four n-channel MOSFETs are arranged in an h-bridge configuration and are responsible for switching power on and off to the motor. A single digital pin controls the direction of the motor, while a single PWM signal controls the speed of the motor. The h-bridge driver IC acts as the interface between these signals coming from the system microcontroller and the n-channel power MOSFETs. This IC is responsible for performing level shifting, gate driving, and shoot through prevention. A de-multiplexer IC is used to reduce the number of PWM signals needed from two to one, and replaces one of the PWM signals with a digital signal. This results in a total reduction of PWM signals needed from 16 to 8. Two signal LEDs indicate which direction and what speed the motor is turning depending on which of the two is on and how bright it is illuminated. A single screw terminal block is used for attaching the motors to the circuit. Using this circuitry as an approach to thruster control not only provides us with a compact and robust thruster control mechanism this year, but provides flexibility in terms of being able to upgrade to higher power custom or Seabotix thrusters in future years.

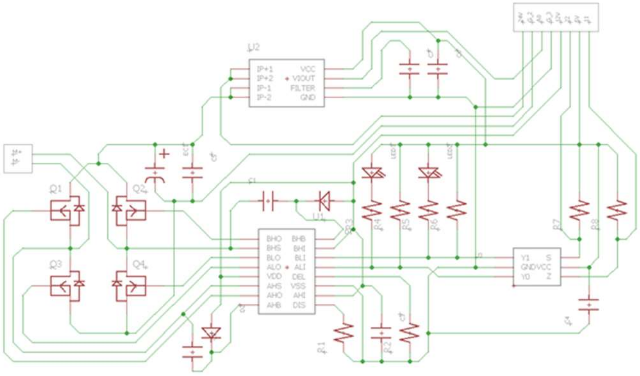


Figure 15: Thruster Controller

Actuator Control Circuitry

The actuator control circuitry consists of four 4-channel low side driver ICs, two 16-channel PWM expander ICs, two Hall Effect current sensor ICs, one 24V to 12V regulator, one 24V to 6V regulator, and various other supporting components. This circuitry is capable of controlling a combination of up to 16 pneumatic valves, servos, and/or other loads as needed. The four low side driver ICs are each capable of supporting up to an amp of current in each of their four channels. In order to prevent over current situations and to monitor current consumption through the actuators, two additional Hall Effect current sensors are used. The first is used for monitoring current on the 24V line going to solenoids and other loads, and the second is used for monitoring current going through a 24V to 6V regulator used for powering servos. The first of the two PWM expander ICs is used to provide control signals to any servos. The second of the two PWM expander ICs is used to provide PWM signal lines to the low side driver ICs. Both PWM expander ICs communicate with the system microcontroller over a 5V I2C bus. The 24V to 12V regulator is an external Castle Creations CC BEC Pro and is used to power the pump used for the cooling system. Pneumatic valves, servos, and/or other loads are connected to the circuit through the actuator connector board. This connection board consists of 16 connection points, providing 24V, 6V, a 5V PWM signal, and a common return line through a low side driver channel. Additionally, signal LEDs at the top of the actuator connector board provide an indication of which low side drivers are turned on and to what duty cycle percentage if they are receiving a PWM signal. Commercial alternatives used for controlling pneumatics are generally costly, large, and more complicated than the custom solution implemented. This circuitry is unique in that it provides the ability to control various types of actuators, which provides a lot of flexibility in the mechanical design of the manipulators.

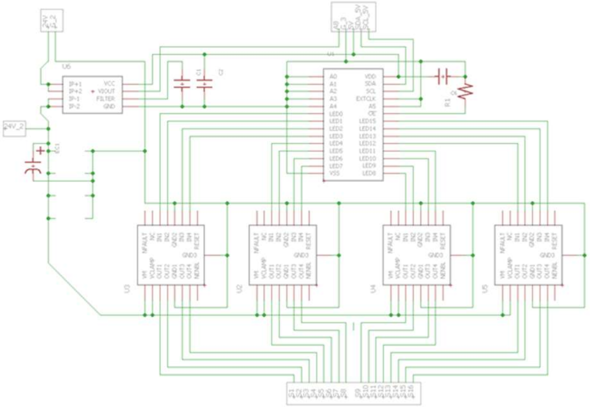


Figure 16: Actuator Controller

Communication Circuitry

The communication circuitry consists of one Ethernet controller IC and various other supporting components. This circuitry is capable of providing a 100M bit/s Ethernet connection between the control station and the ROV. The Ethernet controller IC facilitates this communication as well as communication with the system microcontroller over SPI. An Ethernet cord connects to the circuit through an RJ45 connector. Ethernet was chosen as the communication method due to its ability to provide reliable communication over moderately long distances such as over the approximately 80 foot distance from the control station to the ROV. Alternative solutions would have required additional investment and development time, and would have likely been more complicated. The particular Ethernet controller IC was chosen due to its compatibility with prewritten software libraries that handle the majority of the intricacies of facilitating the Ethernet communication.

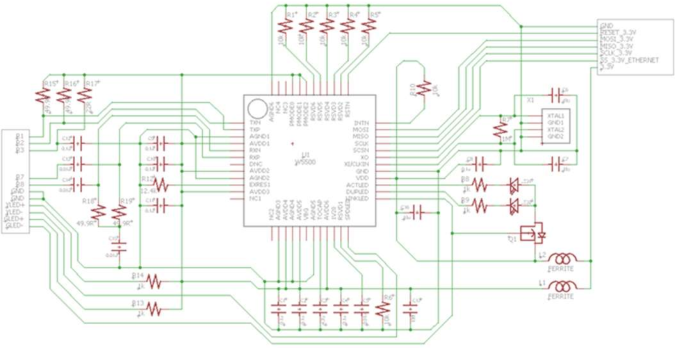


Figure 17: Communication Circuit

Vision Circuitry

The vision circuitry consists of four analog video cameras, two 4-channel analog video multiplexer ICs, one 5V to -5V regulator, and various other supporting components. This circuitry is capable of providing two independent video feeds from the ROV to the control station, where the active video feeds are selected from one of the four onboard cameras. The analog video cameras provide moderate resolution and minimal latency video feeds using an NTSC communication protocol. The output signals from the cameras are run into the video multiplexer ICs which select which of the four feeds to output on their respective tether lines. The IC selects its chosen feed based on the binary value of two digital input selection signals. The video signals are connected to the circuit using the camera and tether connection boards. The particular cameras used, were chosen primarily because of their cost, size, and relative simplicity when compared with digitally based alternatives.

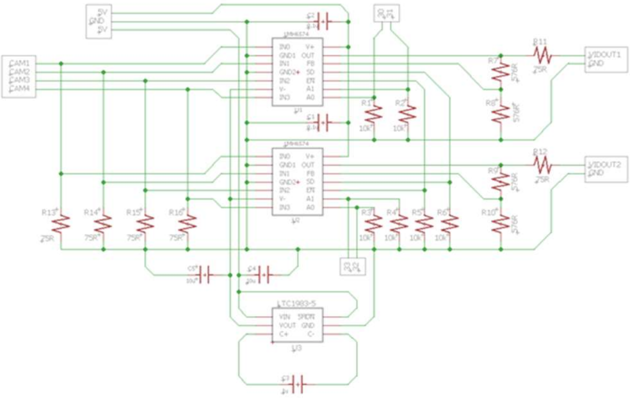


Figure 18: Vision Circuitry

Sensor Circuitry

The sensor circuitry on the ROV consists of a temperature sensor, a 9 degree of freedom inertial measurement unit (IMU), and a pressure sensor. The temperature sensor is located external to the main electronics enclosure and provides a temperature reading over a one wire communication protocol. The pressure sensor is also located external to the main electronics enclosure and is mounted on the pressure sensor board. This sensor provides a pressure reading which can subsequently be converted into a depth reading. This sensor communicates with the system microcontroller using 3.3V I2C. Lastly, the 9 degree of freedom IMU is located inside the main electronics box and provides accelerometer, gyroscope, and magnetometer data which is used as feedback for controlling the ROV's orientation. It also communicates with the system microcontroller using 3.3V I2C. The temperature sensor was primarily selected due to it being pre waterproofed. The IMU and pressure sensors were selected and implemented in the way they were because it was considerably cheaper than commercial alternatives.

Software

Overview

The NIU Robotics ROV's software is written in C/C++/Arduino C. The overall structure organizes several objects within an ROV class that manages most sensors, inputs, and outputs below the water. Each interface type has a custom class that handles digital and analog pins, communication protocols, relevant calibrations or settings, and any control algorithms implemented.

Sensors

The onboard PCB current and temperature sensor classes actively monitor readings and perform moving averages to reduce random error from noise. The current measurements are compared to empirical values to detect stoppage or disconnection of each individual motor. The temperature sensors monitor the high voltage regulators, with a caution level of 90°C, and warning fail safe limit of 120°C. Sensors external to the PCB communicate over a one-wire interface and two devices over standard I2C, for the water temperature sensor, pressure sensor, and IMU, respectively.

Closed Loop Control

To prevent damage from thruster back EMF to the electronics, and reduce noise throughout the system, each thruster object uses a proportional gain loop to smoothly ramp rpm up and down. In addition to ramping thrusters, our custom PID library also operates system stabilization algorithms. Optional closed loop control governs depth (based on pressure) or orientation (based on IMU sensor fusion). These can greatly assist operators, allowing them to focus on specific control aspects while software holds the ROV level or at a consistent depth.

Driving and Vectored Thrust

Translational movement of the ROV is accomplished by four vectored thrusters. Received from the surface are the commanded direction and speed, as well as yaw rate. Each of these terms provides a gain that is added to each motor, keeping in mind each thruster's physical orientation and propeller left or right handedness. Since each motor can have a maximum commanded speed from forward/reverse, left/right, or yawing motion separately, value saturation must be managed. When the motors are commanded above 100%, in order to maintain relative thrust vector lengths, the speeds are normalized by the largest of them. Dividing each speed by the largest of them makes one motor run full speed, while the others are scaled by their respective speed ratio. This serves to maintain maneuverability regardless of signal saturation. Because of this, yawing can still be accomplished while commanding the ROV fully in any direction.

Pneumatics

Pneumatic valve objects are operated via a PWM signal, allowing for proportional or standard two-way control of the valves. The standard two-way pneumatic circuits run digital three-way valves that either extend or retract their respective cylinder fully. The two multi-position pneumatic circuits each run a PWM proportional valve to control speed, and a digital three-way valve to hold the cylinder's position or retract via exhausting control. The pneumatic driver circuit also runs the power system cooling loop pump, which is controlled by PWM fully on or fully off, resulting in standard digital control.

Interfacing

Communication to and from the ROV is accomplished by either USB or Bluetooth Serial, or Ethernet UDP. Regardless of the interface, streams or packets are parsed as character arrays and split into numbers and text. In effect, each relevant text character runs a function, to which its associated number is passed. These functions include, for example: "C2" or "2C" changing Video Feed 1 to pass camera 2 video; "20a255r99w" passing translational control at a 20° angle, full speed, and rotating full speed clockwise. Due to the custom parsing sequence, the previous command could be passed in a number of ways: "20ar255w99", "a20r255,99w", "arw20,255,99", and these are just a few combinations that would be interpreted in the same manner. Outgoing communication can be printed directly over either Serial connection, or sent as UDP Packets over Ethernet.

Safety

The ROV software contains safety measures not only for electronics, but for operators as well. Electrically, the H-bridge circuits are sensitive to low value inputs, while their PWM signals are inverted. This means the top-end, or high speed operation is limited by a small percentage (~2% of range) to preserve the circuit hardware. The onboard current sensors ensure that a disconnected motor is not commanded (undercurrent), or a motor is not stalled or jammed (overcurrent), as these could spell damage to the ROV or injury to personnel. Additionally, the ROV has a depth safety feature that shuts off thrusters when out of the water, with an override for testing. This reduces risk of injury to operators and crew and damage to equipment from propellers. Another safety, typical of systems that interface hardware and software, is a timeout failsafe. The failsafe will shut off motion and manipulator systems if new data is not received from the surface control station within the timeout period.

Topside System

Mechanical - Pneumatics

The surface control station runs a pneumatic compressor with filter, relieving valve, accumulator, and regulator. The compressor operates from a 12VDC power supply through a pressure cutoff switch that opens at 827 kPa (120 psig) and closes at 620 kPa (90 psig). This ensures the compressor will never operate outside its rated pressure range of 862 kPa (125 psig), and maintains the receiver between the same pressures. The compressor filter and in-line 25 micron filter keep the air system clean and prevent debris damage. After the receiver is a relieving regulator that maintains ROV operating pressure at 276 kPa (40 psig), and all components in the system are rated for a minimum of 689 kPa (100 psig). A pressure rating factor of safety of at least 2.5 applies to all pneumatic hardware. This high pressure line feeds through the tether to the ROV, while a vent line at atmospheric pressure returns through the tether.

The other competition-legal options for pneumatics are pre-pressurized cylinders, such as scuba tanks, or hand operated bicycle pumps. The company's decision was based on the high expense, transportation cost, and weight of the scuba style tanks, as well as the limited manpower, to use a hand pump, available for ROV operation. Additionally, much of the pneumatic circuit components, compressor, and other hardware were already owned by the company and could be repurposed easily.

Electrical

The control station consists of a Raspberry Pi, USB controller, joystick, two RCA-VGA converters, two monitors, Wi-Fi router, and a 12VDC power supply. Each of these components operates on 120 VAC through a power strip. A 21.3 m (70 foot) tether consists of power, Ethernet, and two video lines. A 20 Amp fuse is in-line with a main power disconnect switch that plugs into the MATE Competition receptacle.

Software

GUI

The graphical user interface (GUI) provided with the ROV is a one-stop data hub for all information about the current state of the ROV. It displays pitch and roll angles, depth, ambient water temperature and pressure, current drawn by each motor, which cameras are currently being displayed, and safety warnings. The interface also provides convenient access to the controls of the ROV that change less frequently than joystick input data, such as camera management. The GUI is written in Python using the graphics and peripheral input module Pygame and is run on a Raspberry Pi connected to the ROV through Ethernet. The GUI may be most readily accessed through a local SSH connection to the Raspberry Pi, through which the graphics are forwarded to an X11 server running on the client computer. The X11 server accepts X Window System remote graphics data and renders graphics on a connected machine instead of the host.

Ethernet

Commands from the joysticks and GUI are gathered by the Raspberry Pi and sent to the ROV in UDP packets over a local Ethernet network. The network is setup such that every connected machine has a static IPv4 address. To avoid conflict, these are organized in a table listing each new user with their own address. This system ensures that the IP addresses of both the ROV and the Raspberry Pi are known constants, and can be coded as literals in any software for reliability.

Biggest Technical Challenge

As this is the NIU Robotics Team's first year involved with MATE, and first experience with an aquatic environment, we were underqualified to waterproof effectively. As trial and error lead to a more and more reliable electronic enclosure, our team gained confidence in our building capabilities. Our first pool submersion test resulted in catastrophic leakage like we had never seen. After solving the what-should-have-been-obvious problem, things progressed rather quickly and more smoothly than expected. In general, our waterproofing skills improved as well as our ability to identify potential problem areas.

Biggest Non-Technical Challenge

Being our first year in MATE, we did not sufficiently anticipate construction and testing time requirements and deadlines. This lead to a scramble near the end of the build season, trying to locate testing facilities. The DeKalb Park District pool cost us $50 for approximately five seconds of submersion when our severe leak occurred. We were unable to recover for the next day of scheduled pool time, and were forced to seek out another resource for the next steps. Using a Northern Illinois University pool, we were able to submerge the ROV successfully and get it moving in the water, though not correctly. After the pool closed, we re-located to our third pool, the one at our CEO's apartment complex. Utilizing this pool for several hours, we managed to obtain good control of the ROV and start attempting the demonstration video. Approaching pool close time yet again, we were mid-way through an attempt when the complex's security guard entered the pool room. He was there to inform us that it was time to leave. Luckily, he was impressed by our project and allowed us to stay another hour. Shortly after that, we successfully completed the video for submission. Next time around, we will plan use of facilities much further ahead.

Future Improvements

The team discussed throughout build process many alternatives to the chosen methods and hardware. For example, we argued about analog versus digital cameras for a whole summer. In future versions, we would like to operate digital cameras to reduce circuitry and improve video image quality.

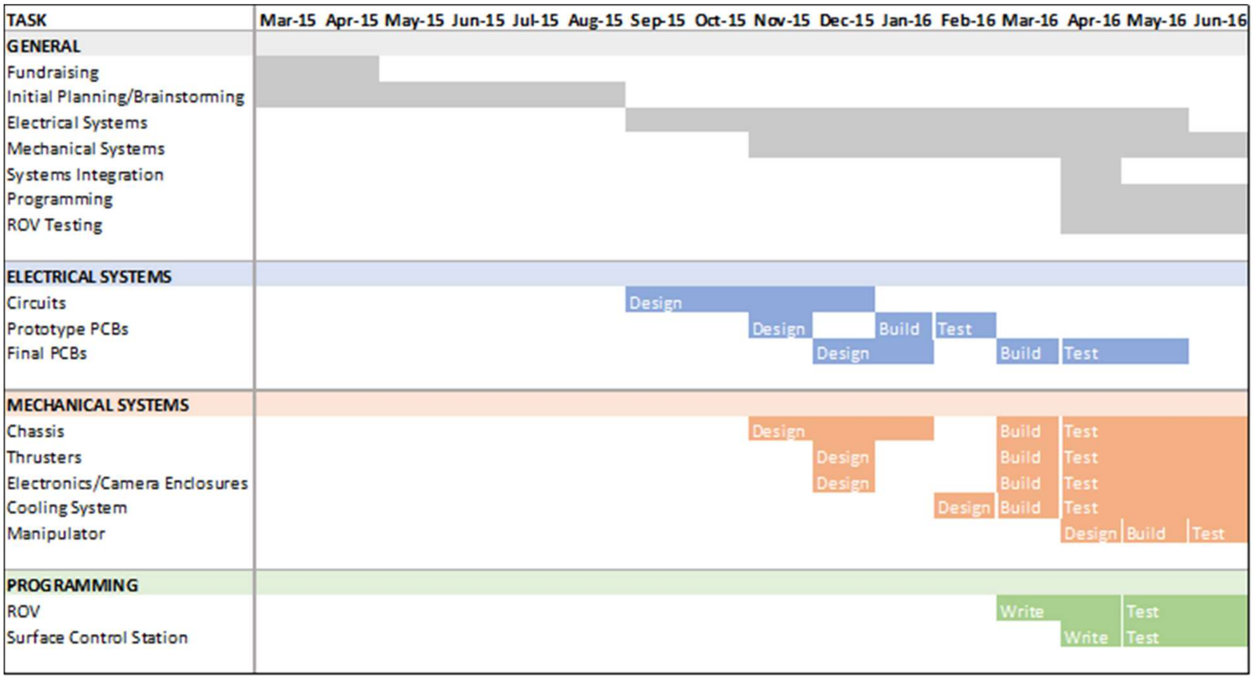
We will also research more into other options for power regulation, as our liquid cooling system added much unneeded complexity to the design, and made construction difficult.

In preparing the electronics enclosure for wiring, the holes for our wire glands were drilled oversize, causing significant leakage that had to be repaired with silicone sealant. Properly sizing the holes would have saved us days of waterproofing troubleshooting.

Budget

	Type	Quantity	Unit Price	Total Price
ELECTRICAL EQUIPMENT				
Prototype Components	Purchase	1	$347	$347
Prototype PCBs	Purchase	1	$89	$89
Final PCBs	Purchase	1	$245	$245
VICOR Regulators	Donation	8	$159	$1,272
Other Regulator Circuitry	Purchase	2	$55	$110
Microcontroller Circuitry	Purchase	2	$44	$87
Motor Control Circuitry	Purchase	4	$80	$320
Actuator Control Circuitry	Purchase	2	$28	$56
Communication Circuitry	Purchase	2	$6	$13
Vision Circuitry	Purchase	2	$17	$33
Cameras	Purchase	4	$18	$72
Sensor Circuitry	Purchase	1	$38	$38
Control Station Electronics	Donation/Purchase	1	$698	$698
Tether	Purchase	1	$114	$114
Soldering Materials	Purchase	1	$32	$32
			TOTAL:	**$3,527**
MECHANICAL EQUIPMENT				
Chassis	Purchase	1	$472	$472
Thrusters	Purchase	9	$78	$703
Manipulator	Donation/Purchase	1	$434	$434
Electronics Enclosure	Purchase	1	$162	$162
Cooling System	Purchase	1	$286	$286
			TOTAL:	**$2,057**
LOGISTICS				
Travel	Purchase	1	$1,100	$1,100
Hotel	Purchase	1	$1,000	$1,000
NIU Pool Access	Purchase	1	$125	$125
MATE Registration	Purchase	1	$260	$260
			TOTAL:	**$2,485**
FUNDING				
NIU USOAR	Donation	1	$2,500	$2,500
VICOR Donated Components	Donation	8	$150	$1,200
NIU Robotics	Donation	1	$648	$648
NIU CEET	Donation	1	$4,000	$4,000
			TOTAL:	**$8,348**

Timeline



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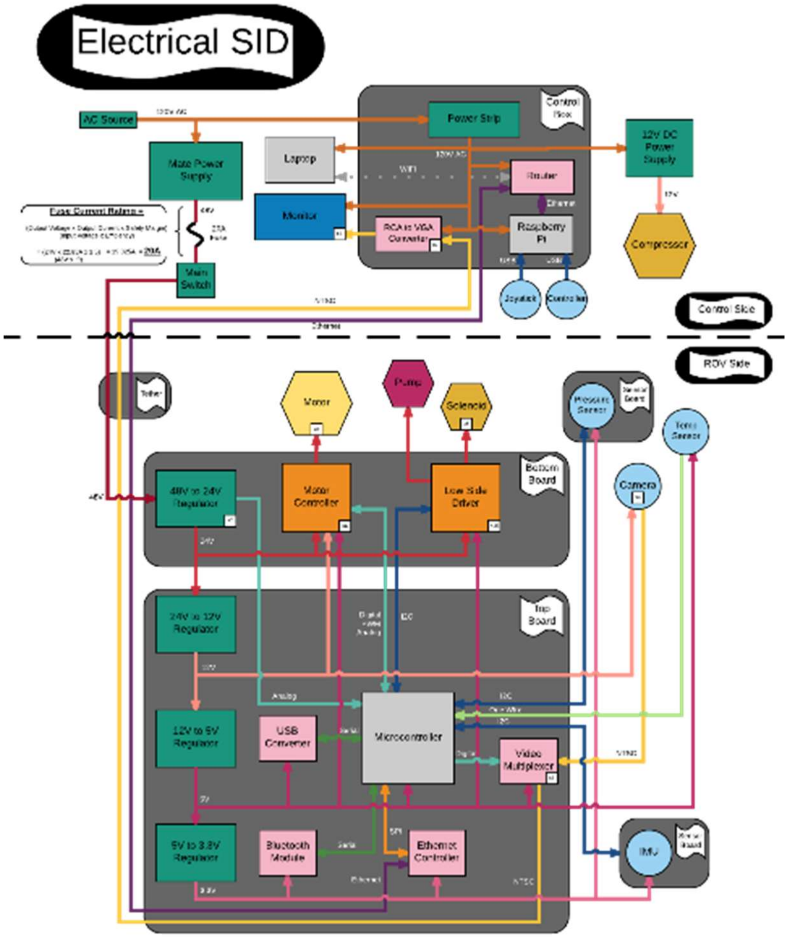
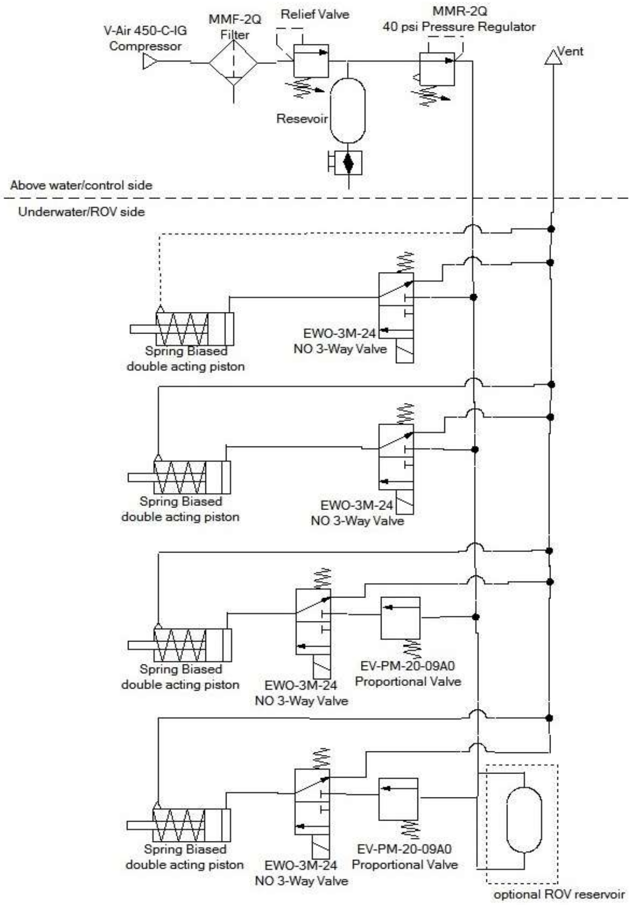
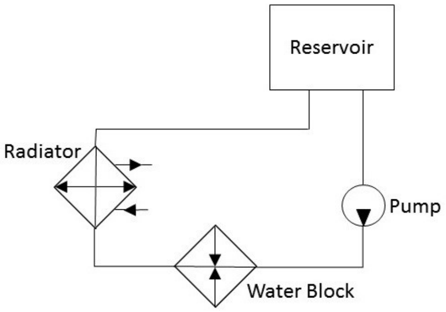


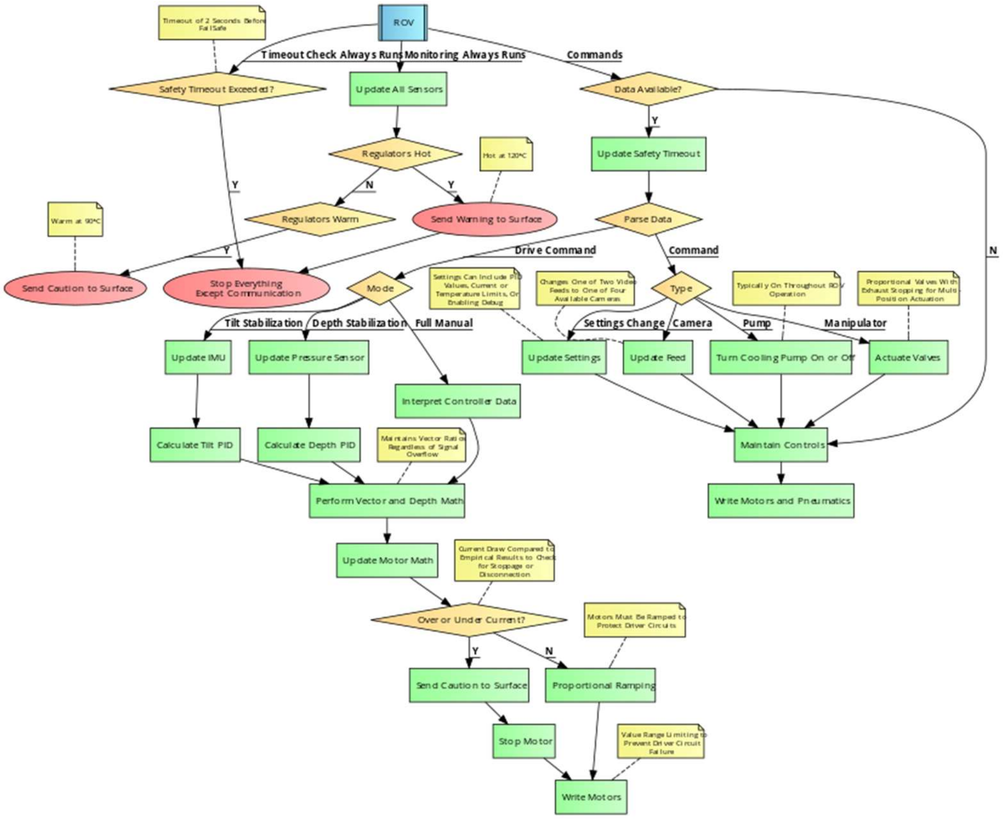
Electrical SID



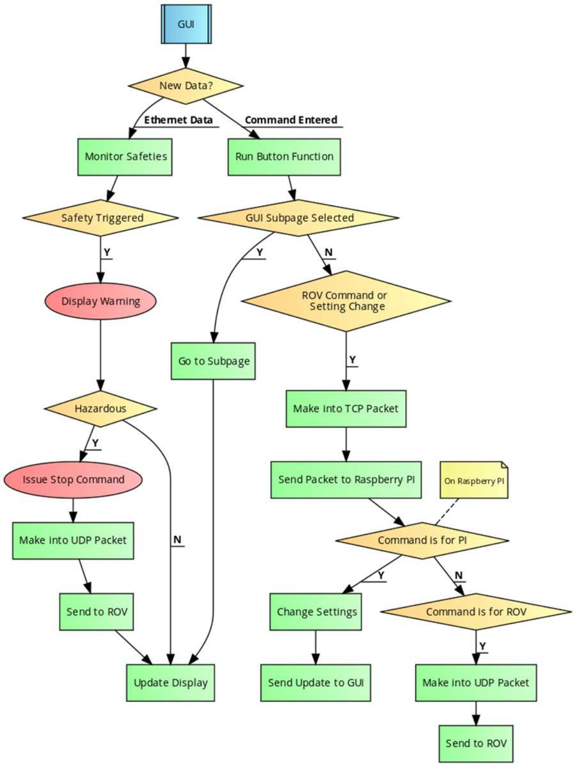
Pneumatic SID



Hydraulic SID



ROV Software Flowchart



Control Station Software Flowchart