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AVALON

Technical Report 2018

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Abstract

Avalon has designed and built an ROV in response to The Applied Physics Laboratory at the University of Washington's request for an ROV capable of operating in the fresh and salt waters of the Pacific Northwest. Avalon's ROV is the product of the hard work of 12 dedicated engineers. The vehicle is designed to locate and retrieve the wreckage of vintage planes, installing or recovering a seismometer, installing a tidal turbine and environmental monitoring instruments.

Avalon is in a strong position to develop ROVs to operate in a wide range of environments and to carry out mission-critical tasks. The company is formed of 12 multidisciplinary engineers with a strong technical background. It is split into an electrical, mechanical, software and non-technical departments. Avalon implements agile development methods to reach optimal solutions. The technical efforts are supported by a strong leadership and an administrative team that ensures appropriate funds and marketing are available throughout the project life-cycle. At the core of the organisation is a focus on safety and customer requirements.

Avalon's ROV utilises 6 Blue Robotics T100 thrusters that enables it to manoeuvre in 5 degrees of freedom. The chassis of the vehicle is designed from light and versatile materials such as aluminium and acetal. It is controlled through a dedicated GUI, which is optimised for the missions. Custom manipulators have been designed to meet the customer's requirements.

This report provides a detailed documentation of the vehicle and work carried out by Avalon to fulfil The Applied Physics Laboratory's request.

Figure 1 Left to Right: Dhruvit Shah, Khaled Saad, George Boufidis, Marwan Taher, Marta Grzybek, Aaron Liu, Ronak Sharma, Myrtle Easter, Adham Darwish, Sam Maxwell, Henry O'Keeffe

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1.1 Mechanical Design

1.1.1 Overview

Based on Avalon's performance in last year's competition, Avalon identified three main areas of improvement: suitable manipulators for performing the missions, better design or configuration for the electronics enclosure to utilise the available space more efficiently, and adding multiple cameras provide enough visual information for the pilot to perform the missions. Given, the good performance of last year's chassis, Avalon decided to re-use it and focus the design effort on the above three areas.

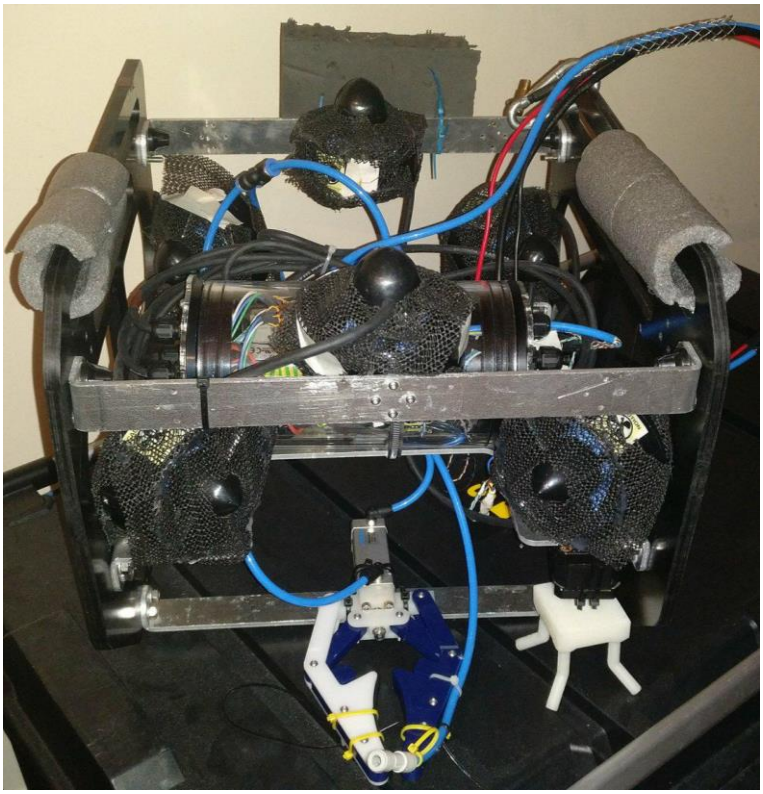

Figure 2 Avalon's 2018 ROV

1.1.1 Chassis

Frame

The main focus of the frame design was to make it light and modular, so that it can be easily adapted to fit various manipulators, the control box and the propulsion system. The aim was to have these features without sacrificing the frame strength.

Avalon's design consists of two side plates and four connecting brackets at the top, middle and bottom of the side plates. The side plates were designed with middle slots for effective water flow through the thrusters and ease of access to the control box. Upper slots were designed for ease of handling of the ROV. Other slots were added to reduce drag during lateral movement. The top brackets are used to mount the vertical thrusters, while the middle bracket is used for the horizontal, vectored thrusters and for mounting the control box. The bottom bracket is used to mount manipulators. Brackets are secured to the side plates using nuts and bolts.

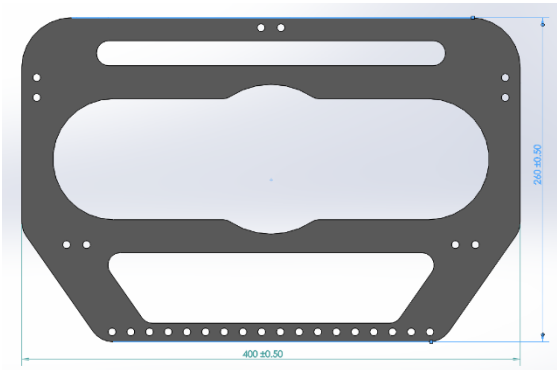

Figure 3 Avalon's new side plate

The frame design was implemented by utilising two acetal (Polyacetal-Copolymer) for the side plates, which were CNC routed, and three aluminium brackets, which were laser cut and CNC folded. Acetal was chosen for its strength (Tensile strength 67 MPa) and low density (1430 Kg/m^3). Aluminium was chosen because of its light weight and resistance to corrosion.

Control Box

A single control box for encapsulating the control electronics as well as a portion of the power electronics. Avalon has opted for buying the enclosure from Blue Robotics, because it matched the design specifications and was cheaper than manufacturing a custom enclosure. The cylinder is sealed from both ends with end-caps which are interfaced together with two O-rings, the cables are allowed in and out through IP69 cable glands. This

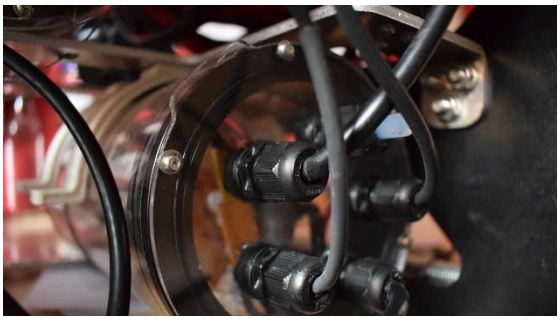

Figure 4 Cable glands used to allow cables into the control box

control box has been tested using a vacuum pump to an equivalent pressure of 7m and was able to hold the vacuum for more than 15 minutes.

One of the challenges faced last year during the maintenance of the electronics box was the need to disassemble the top bracket to get access to control box. This was time consuming and decreased the work efficiency as frequent access to the control box is needed. To solve this problem Avalon came with the solution of rotating the control box, making the end caps parallel to the side plates and holes were created in the side plates to allow direct access to the control box without the need to remove any structural parts. This also had a positive effect on the vehicle's stability as the centre of buoyancy was shifted to the top of the vehicle, since the density of the control box is low due to the presence of air inside it. Moreover, Avalon decided to use one control box instead of the older three. This freed more space at the bottom of the vehicle for mounting manipulators, cameras and other functional components, thus shifting the centre of mass further to the bottom of the vehicle and further increasing its stability, as maximum stability is achieved by having the centre of mass as low possible and the centre of buoyancy as high as possible.

Propulsion

The ROV is propelled by six T100 brushless thruster from Blue Robotics. For motion in the horizontal plane four thruster are used in a vectored configuration at 45° relative to the horizontal plane allowing the ROV to surge, sway, yaw. Additionally, any vector in the horizontal plane can be achieved with this configuration. For vertical motion, two thrusters allow the ROV to heave and pitch. This configuration gives our ROV 5 degrees of freedom, three of which are translational and two are rotational, thus allowing the pilot the required control to perform the mission with ease. The T100 thruster were re-used from last year, as their performance was stable and they were easy to maintain and operate while providing the required thrust to propel the ROV as each thruster is capable of providing 2.36 kgf of thrust while being efficient especially on the low rpms which is the nominal operating range.

Figure 5 T100 thrusters

Buoyancy

Avalon uses a combination of closed cell foam and weights to ensure that the vehicle stays neutrally buoyant. Foam is also added to the tether at regular intervals to prevent it from restricting the ROV's motion.

1.1.2 Vision system

This year Avalon used 6 analogue cameras to provide the pilot with all the visual information needed to perform the missions by strategically placing them to focus on a specific target/manipulator, four cameras are used for navigation, two facing forward and 2 facing backward. Two cameras are dedicated for the gripper and the OBS spinner.

Avalon have developed its own waterproof casing for the cameras and multiple design iterations took place before finalising the design. The final case is SLA 3D printed. The reason for choosing SLA printing instead of FDM printing was due to the way the layers were bonded together in SLA printing, making parts without seams that can let water in. The casing is sealed with a gasket that provides a seal between the SLA casing and an acrylic back plate which is fixed with bolts and nuts, a cable leaves the casing through a cable gland carrying power in and signal out of the casing. This design allows for having easy access to the camera in case maintenance is needed.

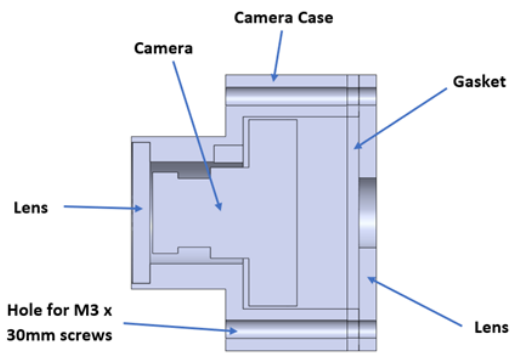

Figure 6 Cross section view of the camera casing

1.2 Electrical System Design

1.2.1 Overview

The Avalon ROV electronics system comprises of three major parts: Surface Communication, ROV Control Electronics and Power & Actuation Electronics.

The Surface Communication Electronics are responsible for interfacing between the Control Electronics and the controlling PC. In the ROV itself, they consist of an SPI-to-Ethernet controller, a pair of three to one analogue video switches, and a pair of single-ended to differential video signal converters to enable the transmission of two simultaneous video feeds. These are all on a custom PCB called the Communication, or Comms PCB.

Figure 7 Communications PCB

These components send their signals down a standard CAT-5E cable that forms part of the tether. On the surface, the CAT-5E terminates at another custom PCB called the Surface PCB. This has a pair of differential to single-ended signal converters which allow the video to be output to a computer-connected DVR via standard composite video sockets. The Ethernet that takes up the other two twisted-pairs is broken out separately to allow connection to a router.

The Control Electronics are also mostly housed on the Comms PCB, with the most notable exception being the controlling Arduino Due. The Due communicates with various sensors (an Inertial Measurement Unit (IMU), a pressure sensor, and a WiFi module (ESP8266)) via the I2C protocol which is broken out of the Due by the Comms PCB, where some of the sensors reside. The Due sends the data from the sensors via UDP packet to the controlling PC whilst receiving commands to actuate the manipulators and control the thrusters.

The Power and Actuation electronics consist of the custom Power PCB, the thrusters, the ESCs to control them, and the stepper motor used to level the OBS. The PWM signals to drive the ESCs are broken out on the Power PCB after passing through the Comms PCB before terminating at the two multi-thruster ESCs, which can drive 4 thrusters each (leaving two spare channels). The driver for the levelling stepper is also housed on the Power PCB.

Power for the ROV is sent down the tether via a pair of 2.5 mm^2 wires, before being reduced to 12 V by a DC/DC converter. The power is sent to the control box which is the hub for all the electronics on the ROV, and then fed to the Power PCB where it's distributed to the rest of the electronics.

1.2.2 ROV Power

Tether

The tether consists of power wires and a Cat5 Ethernet cable to carry data. The wires carrying the 48 V were sized to ensure they were large enough to carry the maximum current but small enough to allow flexibility and unrestricted movement of the ROV.

The 6 thrusters use 135 W each when operating at full power, the cameras use approximately 15 W in total, the stepper motor 5 W and the rest of the ROV uses a maximum of 20 W. This equates to 850 W of power on the 12 V rail. When the 85 % efficiency of the DC/DC converters is accounted for, this becomes 1000 W of power on the 48 V DC rail.

The length of the tether is 25 m. When accounting for the positive and negative wires, the total length is 50 m. The chosen wire area was 2.5 mm^2, which has a resistance of 6.72 mΩ/m. The total resistance is therefore 0.336 Ω. With a current of approximately 1000/48 = 20.8 A, this would appear to result in a maximum voltage drop of 7 V during peak current draw and a dissipated power of 146 W.

The Cat5 Cable consists of four twisted wire pairs that can be used for communications. The Avalon custom circuit boards use two pairs for UDP Ethernet communication and the other two pairs for Analogue Video Transmission. This allows for high speed communication between the ROV and the surface as well as two Analogue Video signals to provide a live feed from the ROV.

Power Conversion

The 48-to-12 V DC/DC converter is formed from four isolated 150 W Meanwell MHB150 series DC/DC converters, each of which can tolerate 140% over-current for short periods, allowing all the thrusters to be used for short bursts. The converters are placed in parallel to optimise the space efficiency of the converters, allowing a fewer number to be used. Without current sharing, a single converter would have to be used per thruster, resulting in a 50% increase in space required. The reduced size of the power conversion system allows the ROV to have a lower mass and reduced drag.

Figure 8 Meanwell MHB150 DC/DC converters

The power converters are housed externally to the other electronics, and immersed in water after coating the exposed terminals with waterproofing epoxy resin. This allows the water to cool the converters to allow continuous running at medium power, and increased reliability.

A small module on the Power and Actuation board boosts the 12 V DC to 24 V DC in order to power the Solenoid Valves. This functionality has been implemented due to the low availability of Solenoid Valves that operate at 12 V, allowing a range of solenoid valves to be considered to optimise their other parameters. For example, the chosen solenoids are extremely small, which is beneficial for the reasons mentioned above.

Two semi-discrete buck converters on the Communications PCB step the 12 V down to 5 V and 3.3 V. These voltages are required to power the digital and analogue circuitry of the system, including the Arduino, Ethernet Controller and Analogue Video switches.

1.2.3 ROV Communication

Communication with the ROV is facilitated by the ROV Communications Circuit Board and the Surface Communications Circuit Board. UDP Protocol communications are sent between the Surface PC and the ROV Communications Board via the Surface PCB and the tether.

Analogue Video Transmission

In order to ensure that the composite video signal from the ROVs on-board Analogue Video reaches the Surface PCB with low levels of distortion a method of differential signalling has been employed to transmit the signal up the tether.

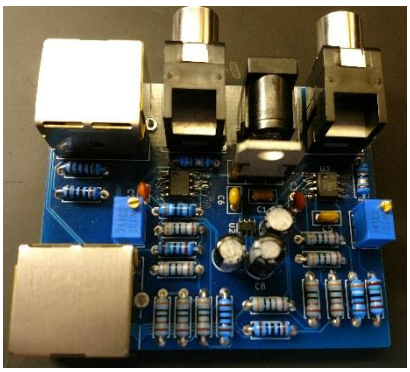
Figure 9 Surface PCB

This differential signalling system uses a pair of High Gain-Bandwidth Operational Amplifiers to convert the 0v referenced Composite Video Signal into a split pair Differential Signal which is then transmitted via one of the Ethernet Cable twisted pairs. At the Surface another pair of Operational Amplifiers is used to convert the Differential Composite Video signal back to a 0V referenced signal. This method reduces the effect of external noise on the signal as it travels along the tether; ultimately this will improve signal reliability and clarity, making the ROV easier to pilot via the live video feed.

Avalon determined that up to six cameras were required to ensure that the pilot always has a good view of the task currently being performed by the ROV. Because only two video signals can be transmitted to the

surface a pair of 1 to 3 Analogue Video switches were implemented on the ROV communications board, one for each video transmission line. This allows two of a possible six video signals to be selected for viewing at the surface.

Custom circuit boards were designed for the Avalon ROV system partly to ensure that this Video Transmission method could be implemented. This allowed us to implement the Video Transmission section in a compact form factor to ensure that the system would fit inside the control box. Analogue Video Switching circuit shields are also not readily available for the Arduino Platform.

UDP Communication

UDP communication between the ROV and the surface was implemented using an ENC28J60 Ethernet Controller, an IC commonly used with the Arduino platform due to the relative ease of setup.

An SPI bus is used to communicate between the Arduino and the Ethernet Controller. To avoid system communication bottlenecks, this SPI bus is used exclusively by the Ethernet Controller. This allows the use of standard Arduino Libraries written specifically for interfacing with the ENC28J60 to be used making the process of programming the ROV much easier.

1.2.4 ROV Control

Main Microcontroller - Arduino Due

An Arduino Due has been selected as the ROVs main Microcontroller due to its high clock speed, number of hardware interfaces and GPIOs. In contrast to the Arduino Uno used in last year's system. The Due is capable of accommodating a greater number of control pins at higher processing speeds.

Thrusters

As the motors in the thrusters are brushless DC motors they require Electronic Speed Controllers (ESCs). Pre-built ESC units were found online that incorporate four speed controllers into one circuit board. This removed the necessity of implementing speed control on our custom circuit boards (saving development time) and reduced the form factor of the speed controllers significantly, ensuring that they would fit along with the other electronics inside the control box. The speed controllers are controlled directly from the Arduino Due GPIO using Pulse Width Modulation (PWM) signals.

1.3 Mission Tools Design

1.3.1 Multi-Purpose Gripper

The ROV is equipped with a multi-purpose pneumatic based gripper designed and manufactured in-house. The gripper fits the purpose of moving the debris and the engine in the aircraft task after their lift bags have been inflated. It can also be used for installing the underwater turbines for the energy task.

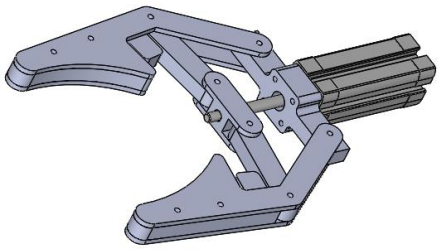

Figure 10 Avalon's multi-purpose gripper

The gripper claws move in an angular fashion through the translational motion of the double acting pneumatic cylinder that extends to provide an opening of up to 96mm, ensuring enough space to pick up the designated objects. The main body was designed to occupy minimal space whilst meeting the constraints of objects to be carried. The choice of using acrylic sheets for manufacturing was primarily due to the ease of manufacturing through laser cutting. Rubber was added to the inside of the claws to increase contact friction ensuring any object carried does not slip.

The gripper is controlled using a 5/2 solenoid valve that controls the pneumatic cylinder, non-return valves are installed on the exhausts of the solenoid valve to prevent water from getting into the pneumatic system. The default state of the gripper underwater is the open grip-extended cylinder rod state.

1.3.2 Lift Bag

To move debris and retrieve the airplane engine lift bags are used to alter their buoyancy to be able to move them easily. Avalon chose a lift bag capable of lifting up to 12 kg.

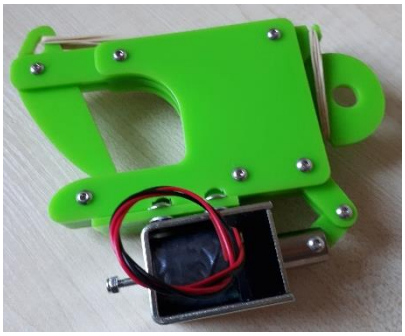

Figure 12 Lift bag release mechanism

To remove the debris from on top of the airplane engine, a solenoid operated locking mechanism was developed to release the lift bag from the debris. The design of the mechanism has two degrees of freedom, which act like a carabineer when clipping to the U-bolt on the debris but releases using an electronically controller linear solenoid that causes the mechanism to de-latch. To trigger the solenoid, a pair of Ultrasonic Transducers is used, one on the lifting bag and one on the ROV. The Ultrasonic Transducer on the ROV is directly controlled by the ESP8266 via a transistor inverter circuit.

A circuit board is attached to the release mechanism to convert the sinusoid produced by the Ultrasonic Transducer to a Digital Signal. When the correct sequence of pulses is received by the board the solenoid is triggered. This system was implemented using a set of low cost Operational Amplifiers in non-inverting and comparator configurations, a peak-detector circuit and an Atmel Tiny microcontroller to interpret the digital signal.

Figure 11 Lift bag with engine hook

In order to retrieve the airplane engine a lift bag with a simple hook allow the bag to hook easily to the engine's U-bolt, and the tension force caused by the lift bag's buoyancy and the weight of the engine are enough to keep the hook in place.

Both lift bags are fitted with a rectangular shaped jig that keeps the opening of the lift bags open to allow air in when pumped through a pneumatic tube through a non-return valve to prevent water from getting into the pneumatic system, this allows the pilot to place the tube under the opening of the lift bag to inflate it.

1.3.3 OBS Levelling Actuator

The OBS levelling actuator is designed to the PVC pipes on the OBS frame. The actuator was designed and manufactured in-house and coupled to a stepper motor to operate it. The main body of the actuator was SLA 3D printed. This method was chosen due to the toughness of the printed product, which should withstand the torque from the motor attached to it. Multiple design iterations were carried out before the final design was reached.

Figure 13 Avalon's OBS levelling actuator

The angled supports provide easy alignment while the vertical supports provide the strength to turn the pipes once slotted inside. The top of the actuator was made such that the motor's shaft fits tightly into it.

1.3.4 OBS Power

The Wireless Power module was implemented using an off the shelf system that could be easily integrated into the mechanical sections of the design. The system was chosen because it is smaller than what Avalon is capable of producing to transmit the required power. A battery is incorporated into the module to ensure that the OBS can be powered for up to 15 minutes.

1.3.5 OBS Communication

The Wireless Communication for the OBS was implemented using a low cost ESP8266 WiFi Module with an add-on board that allows external antennas to be connected. The requirement for an external antenna was added after WiFi range testing was preformed underwater, the results of which can be seen in Figure 14. The results show that the signal strength degrades to very low below 1m of distance between the transmission and receive antennas. As a result, external antenna was used to ensure reliable communication at a distance of approximately 1m. The ESP8266 communicates directly with the Arduino Due via an I2C interface.

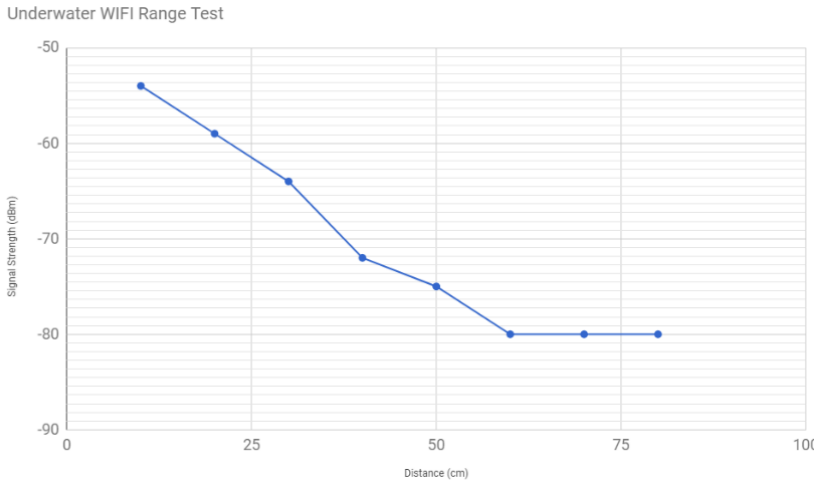

Figure 14 Underwater WiFi testing results

1.3.6 Distance Recognition Algorithm

An image processing algorithm was designed for Task 3, to measure the distance from the base of a tidal turbine. The software solution was chosen over other available solutions like sonar, because it was easier and cheaper to implement. A GUI was created so that the pilot could mark the coordinates of a reference object on the image taken by the ROV. For example, in the case of Figure 15, one of the red vertical pipes can be used as a reference since its length is known. This reference is then used to calculate the scaling factor between the image and the actual distance required to move. Finally, the result obtained is marked as a blue line on the GUI thus showing the pilot the position at which the mooring needs to be placed.

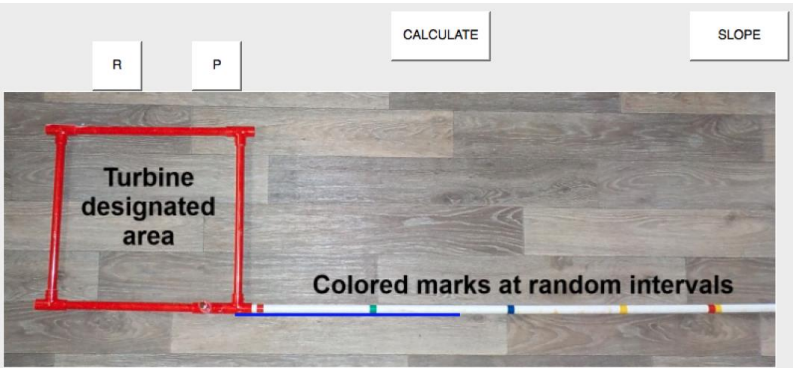

Figure 15 Screenshot of the Distance Recognition Algorithm result

1.3.7 Tail Detection Algorithm

An image processing algorithm was written to detect the aircraft tail. When underwater, the live feed from the camera is used to look for the tail. HSV masking is applied to the feed, to show only red, blue and yellow colours, ignoring the rest of the colours by turning them black. Edge detection is then applied to the masked feed to identify the edges in order to classify the tail as a rectangle or triangle. For robustness, brightness and contrast are adjusted tackle the challenge of varying lighting conditions. Finally, both colour and shape are combined identify the correct type of tail. Figure 15 shows the result from using the algorithm.

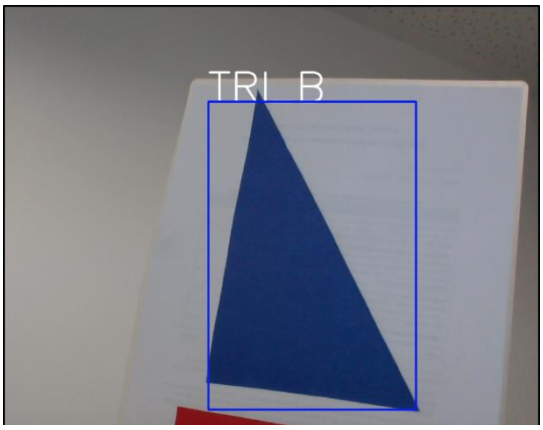

Figure 16 Blue Triangle as detected by the Tail Detection Algorithm

1.4 Software Design

1.4.1 Overview

Avalon's software has been developed with a focus on ensuring comfort and minimum effort from the Pilot. GUIs have been developed in Python to provide functionality for the Pilot and Co-Pilot, such as controlling the ROV and performing mission-specific calculations. The main Pilot GUI reads in data from a joystick and communicates with the ROV's controller over User Datagram Protocol (UDP), which has been chosen over other protocols, due to its low latency.

Another addition this year was the development of software tools, such as the thrusters debugging tool, to speed up the maintenance time. The Software Team utilised GitHub to manage and track software changes.

1.4.2 Pilot and Co-pilot GUIs

GUIs have been designed for controlling the ROV. The two main GUIs are the Pilot and Co-Pilot GUIs. Using GUIs means that Avalon have full control over what is displayed to the Pilot and Co-Pilot during the tasks, aiming to make completing the tasks easier. Both GUIs receive data from the ROV over Ethernet via a UDP connection.

Avalon chose to use Python programming language and the PyQt module to develop the GUIs. Python was chosen due to its ease of use and short implementation time. PyQt is a specialised module which makes the QT GUI toolkit available to use in Python. PyQt enabled Avalon to create GUIs using widgets, which are simple to adapt to fit the company's purpose.

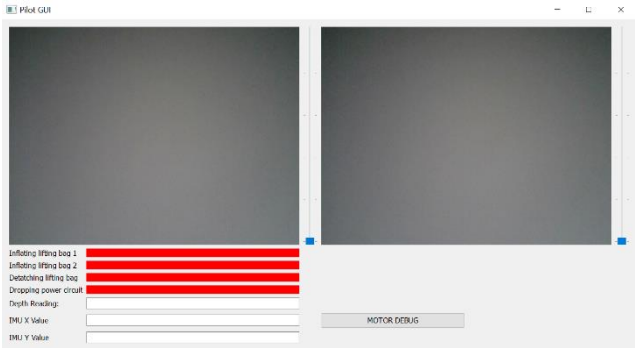

Figure 17 Screenshot of the Pilot's GUI

The Pilot GUI contains displays for two camera feeds (to be displayed simultaneously), sliders to change each camera feed independently, indicators for the lifting bags, indicator for dropping the inductive power circuit, readouts for the OBS IMU data and depth of ROV, and buttons for enabling and disabling tail detection and Distance Recognition software. The indicators are linked to the joystick used for controlling the ROV.

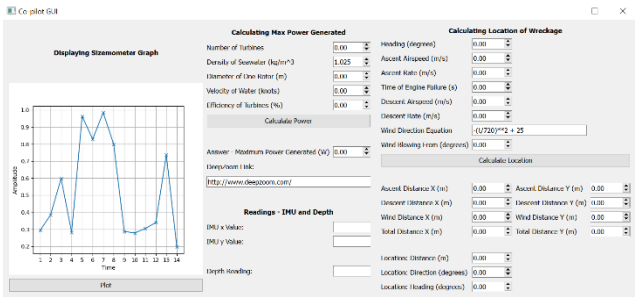

Figure 18 Screenshot of the Co-pilot's GUI

The embedding of the camera feeds into the Pilot's GUI is an improvement from last year, as the camera feeds were separated from the main GUI, which made it difficult for the Pilot to focus on one screen when piloting the ROV.

The Co-Pilot's GUI contains a graph for the OBS measured data, readouts for the OBS's IMU data, a section to calculate the aircraft wreckage location, a section to calculate tidal power generation, and a section to record depth. The variables for calculations will be inputted manually during the competition by the Co-Pilot, and the output is displayed within the GUI.

1.4.3 Movement Control

The Pilot controls the ROV through a Thrustmaster T. Flight Hotas X Joystick. To map between the joystick and the ROV's 6 thrusters, Avalon developed a simple algorithm that applies a linear transformation on the joystick's X, Y, Z and Yaw axes to produce 6 outputs for each thruster. A dead zone was implemented to

prevent the ROV form moving when the controls are in the nominal position. Furthermore, a scaling factor was used to limit the ROV power for precise movements. This factor can be easily changed in the software.

1.4.4 Debugging Tool

A smaller GUI was designed for the purpose of debugging the thrusters' direction. During repairs or maintenance of the ROV there is often a need to disconnect the thrusters from the circuit boards, and thrusters' signal wires can often be swapped when the boards are re-installed. As a result, signals would be sent to the wrong thrusters, to fix this the Pilot GUI had to be manually re-programmed to accommodate the new thrusters' configuration. Having a GUI enabled Avalon to apply these changes more easily, saving time during operations.

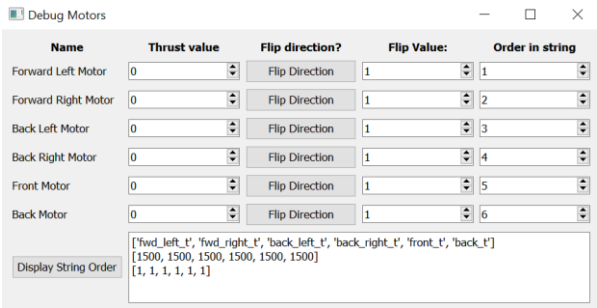

Figure 19 Screenshot of the Debugging Tool

2. Safety

2.1 Safety philosophy

The main priority at Avalon is the health and safety of the company's employees. All members of the company are required to comply with the company's safety rules and protocols. This mind-set has enabled Avalon to work efficiently while maintaining a record of zero accidents. Avalon is committed to maintaining this record by constantly reviewing its safety protocols and improving them.

2.2 Safety protocols

To ensure all employees are aware of correct safety procedures in labs, they must complete a safety training and induction, which is provided by the University of Sheffield, before they are allowed to access the labs. The company has also completed a Job Safety Analysis (JSA) for all activities, including working in labs and testing in pools. The JSA has been reviewed by a Safety Officer at the University of Sheffield, to ensure it complies with safety regulations.

While working in the labs or operating the pneumatic system, all employees are required to use eye and hearing protection. In addition to this, all electrical equipment must undergo Portable Appliance Testing (PAT). This ensures a safe working environment for all the lab users.

A set of safety rules have been developed to follow while working on the ROV. For example, when the pneumatic system is operated, there should be at least 2 employees present. All employees must have a full understanding of the pneumatic system and how to shut it down safely in case of an emergency.

In addition to the JSA, a health and safety checklist have been developed to remind the employees of the risks associated with working on the ROV, this includes how to handle common workshop tools, how to work with the pneumatic system safely, how to solder safely, and how to operate the ROV safely on the pool.

2.3 Vehicle Safety Features

Following our safety philosophy, the ROV must be safe to handle and operate. This is accomplished by ensuring that all sharp edges are filled and deburred, safety stickers are added to the thrusters to indicate rotating propellers, along with having guards and shrouds on the thrusters. Furthermore, a pressure release valve is installed for the pneumatic system to avoid over pressurising the system. For electrical safety, all wire connections are covered using heat shrink to avoid having any exposed wires that might cause a short circuit, a 30-amp fuse is also used to safely handle any electrical faults.

Figure 20 Safety sticker on the thruster

3. Teamwork and Organisation

3.1 Project Management

Avalon's project management strategy was centred around key work packages, such as Fabrication and Testing, that were identified at an early stage. A Gantt chart was then made to keep track of the overall plan and dependencies. The key objectives identified in the Gantt chart were then broken down into specific tasks, which were assigned to individuals in the team. To track progress and communicate information about tasks, Avalon utilised Trello, a web-based project management application that displays all information about a given task, such as relevant documents and deadlines, in one place. This enabled all members of the team to seamlessly access information about tasks.

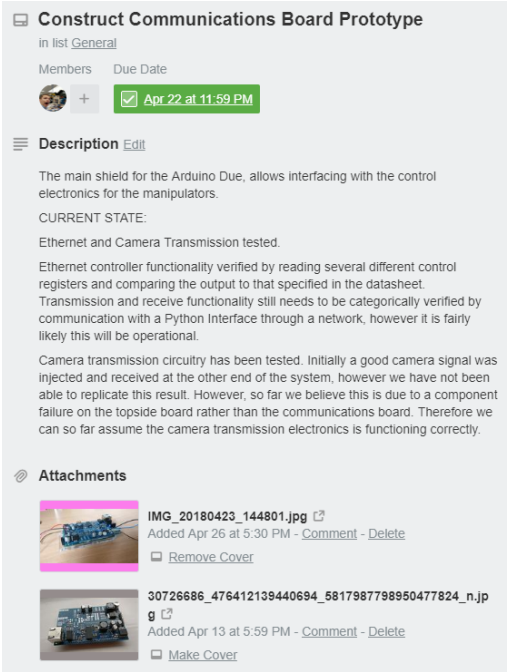

Figure 21 An example of a task posted on Trello

To ensure all members of the team worked well together, the team held 3 meetings a week, in which ideas were discussed, problems were tackled collaboratively and progress was shared. This has proven to be a much more efficient way to work, compared to holding separate meetings for each sub-team. In addition to these meetings, smaller meetings were held to communicate important updates and resolve technical issues. Biweekly reviews were also held to discuss progress, tackle problems and set short-term plans.

In addition to Trello, all technical and non-technical files and documents were organised, stored and shared in the cloud using Google Drive. Software files were maintained on GitHub. This ensured that all files can be quickly and easily accessed by all members of the team as and when needed.

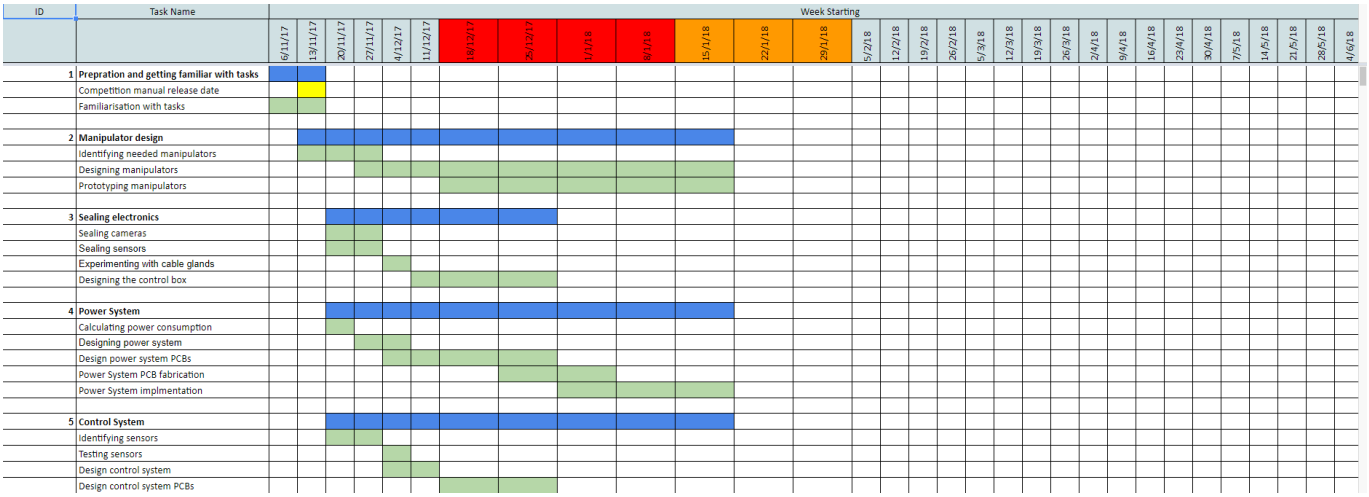

Figure 22 A section of Avalon's Gantt Chart

3.2 Organisational Structure

All team members were involved in the early brainstorming sessions to collaborate on solutions for the missions; however, once the idea generation stage was completed, the team was divided into electrical, mechanical, software and non-technical teams. Each sub-team developed the ideas generated in the brainstorming sessions, discussed the main objectives and then individual tasks were assigned in meetings to each member. The technical teams were supervised by the CTO, who set the high-level goals and assisted individuals with their tasks. The CEO worked closely with the CTO and the non-technical teams to ensure the work was done on time and on budget.

3.3 Challenges

Technical

The Distance Recognition algorithm utilised for Task 3 relies on an image taken by the ROV. However, the camera used on-board the ROV has a fisheye lens, which introduced the major challenge of distortion, causing the algorithm to produce the wrong results, because different parts of the image were distorted by different amounts.

To overcome this challenge, the camera was calibrated to be able to undistort the image. This was done by subjecting the camera to multiple images of a uniform checkerboard pattern and distances between the squares were measured, in order to quantify the distortion. The identified parameters were then applied to the captured image before running the algorithm.

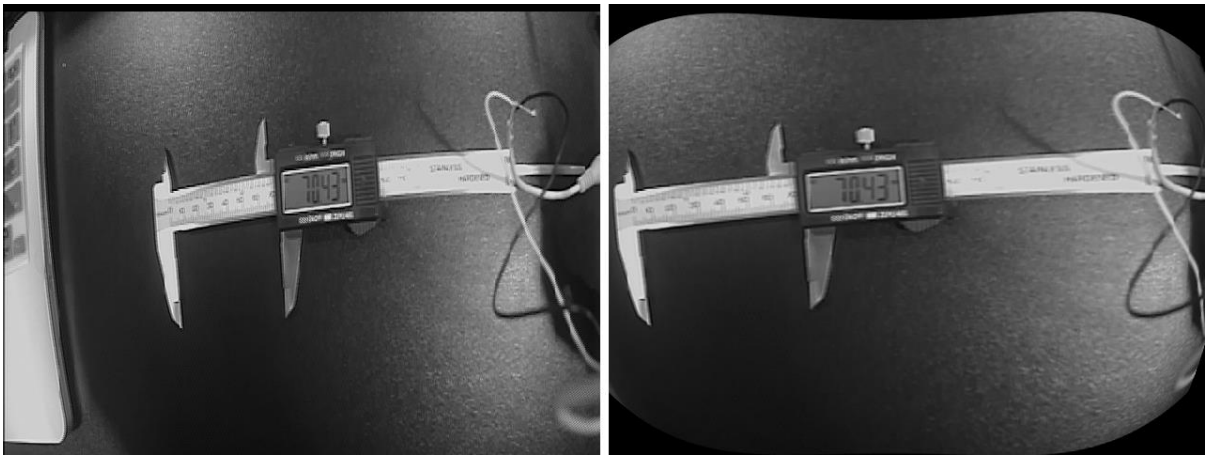

Figure 23 On the left: the distorted image from the camera. On the right: the undistorted image

Non-technical

One of the main organisational challenges faced by Avalon since its foundation last year has been allocating an appropriate amount of time for each task. This is particularly problematic when uncertainties are high, e.g.: when a new technology is being used. Another factor is the availability of employees throughout the project timeline, which can be particularly problematic around exams and holidays. To overcome this, safety factors have been used to adjust the estimated time for a given task. These safety factors were determined based on the novelty of the task, technical difficulty and the time of the year in which the task is completed. This approach is very similar to Avalon's budgeting approach, which has proven to be very successful last year. As a result, most tasks were better managed and completed on time.

3.4 Testing and Troubleshooting

To assess the performance of newly developed parts, such as the OBS levelling actuator, periodic tests were carried out in a local swimming pool. Results from these tests guided the design process and helped Avalon improve and refine the final product.

The image processing algorithms were tested using footage from underwater. The tests were based on predetermined metrics such as the accuracy and speed by which the algorithm can detect the tail.

The full vehicle was tested over a series of visits to the local pool, in which the pilot assessed the performance of the vehicle and suggested improvements in various areas, such as the motion control and camera placement.

For troubleshooting, Avalon utilised Root Cause Analysis (RCA). Once a problem is detected, relevant systems are identified and isolated for testing and fault-finding. This approach allows Avalon to find the precise cause

of the fault and identify any damage caused by it. The next step is then to fix the faulty component/sub-system and put in safety measures to prevent it from repeating.

4. Budget and Costing

At the beginning of this year's development cycle, Avalon has put together a budget based on last year's budget. For new components and tools, the team carries out extensive online research to obtain a good estimation for the budget. Moreover, a safety factor is applied to items with high uncertainty.

Table 1 Avalon's Budget

Income (at the start of the project)				
Source				**Amount**
Automatic Control and Systems Engineering Department				$ 4,040.00
Expenses				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
Electrical System	Purchased	Electronic components, PCB manufacturing and Tools	$ 1,172.00	$ 1,172.00
Thrusters	Re-used	6x Blue Robotics T100 Thrusters	$ 970.00	$ -
Workshop Tools	Re-used	Pliers set, wrench set, screw driver set	$ 80.00	$ -
	Purchased	Hot air station and cordless drill	$ 365.00	$ 365.00
Materials and Machining	Purchased	Plastic Sheets, CNC machining and laser cutting	$ 472.00	$ 472.00
Consumables	Purchased	Adhesives, solder, electric tape, bolts and nuts	$ 263.00	$ 263.00
Storage Units	Purchased	Toolbox, ROV storage box and plastic storage units	$ 270.00	$ 270.00
Pneumatics	Purchased	Air compressor and pneumatic actuators	$ 1,510.00	$ 1,510.00
General	Purchased	Prop materials and miscallenious items	$ 175.00	$ 175.00
Mechanical	Re-used	Electronics housing	$ 440.00	$ -
	Purchased	Cabel glands and O-rings	$ 100.00	$ 100.00
Travel	Purchased	Flight tickets and accomodation in Seattle for 10	$ 13,500.00	$ 13,500.00
			Total Income	$ 4,040.00
			Total Expenses	$ 19,317.00
Note: These figures assume a conversion rate of 1 GBP = 1.35 USD			**Total Expenses - Re-use**	$ 17,827.00
			Total Fundraising Needed	$ (13,787.00)

5. Conclusion

5.1 Future Improvements

Avalon is constantly reviewing its performance and seeking new ways to improve it. Over the past two years, the company has realised the true importance of testing for the success of the final product. This realisation has motivated the company to consider a new workflow in the future, in which the initial design time would be reduced to allow more time for iterative testing and development. This would speed up the transition from theoretical ideas to physical design iterations, thus improving the overall performance. To support this workflow, the company is looking into building a test facility that would allow employees to test more frequently.

5.2 Lessons Learned

Due to the current organisational structure, the technical and non-technical do not often interact. This caused a clear divide in the company's vision and goals. As a result, the technical team is often driven purely by the technical work and does not contribute to the fundraising efforts and other non-technical functions. To mitigate this problem in the future, Avalon is considering an organisational restructure to bring the technical and non-technical functions closer together under a common vision.

This year, Avalon has developed a better understanding of machine vision and how to employ it to solve missions and provide tools to assist the pilot. In particular, the company has gained an appreciation of the

challenges involved in detecting objects and identifying colours under different lighting conditions. The company has also gained experience in tackling these challenges and minimising their effects.

In regards to project management, the company, particularly the senior members, has improved the delegation and tracking of tasks, as compared to last year. This improvement is a result of the lessons learned about communication and crisis management.

All employees have developed presentation and communication skills through showcasing their work in local and national events. They have also gained time management skills, which was crucial in balancing the work with studies and other commitments. Moreover, they have gained an intuitive understanding for the life-cycle of an engineering project and the skills required to achieve it.

5.3 Reflection

"Being part of Avalon's leadership has been a true eye-opener for me. I have gained a huge array of technical, project management and project skills. Working on the project has helped me apply a lot of the theoretical concepts that I have studied. The project has provided me with opportunities to interact with companies and organisations at the forefront of sub-sea R&D, which helped me gain a better understanding of the industry and develop my networking skills. The experience has also made me more employable. In summary, being part of Avalon has made me a better engineer and project manager." - Khaled Saad (CEO)

"Being a member of Avalon's Electrical Team has provided me with many new technical challenges that I would not have faced as part of my Degree Programme. The chance to work with Communications Electronics such as Ethernet and Analogue Video Transmission as well as to design custom Circuit Boards has given me invaluable practical experience that will help me as a graduate engineer. I have had the opportunity to develop Electronics as part of a team, giving me valuable team working and communication experience. Ultimately being a member of Avalon helped me prepare for being a Graduate Engineer." - Sam Maxwell (Electrical Engineer)

"Being a member of the Avalon Team this year was really exciting. I had the chance to learn and develop new skills by solving real-life problems with a team of amazing people with interesting ideas. It was an amazing first year at university full of challenges." - George Boufidis (Mechanical Engineer)

"Working in Avalon has been a great learning experience. Being a university student, Avalon has provided me with various opportunities to apply the knowledge gained through my lectures into practical engineering. Over the period of two years, I have developed my critical thinking skills while tackling the real-world engineering problems this competition brings forward. Working in a multidisciplinary team, helped me to experience the wonders that can be achieved with great teamwork. I have been grateful to be able to grow both technically and personally through this competition. I now feel more confident as an engineering student and proud to make some great friends. This competition exposed me to the field of underwater robotics which I was initially unaware of. Thank you once again, Avalon and MATE, for providing me with such an enriching experience which I will cherish through my lifetime." - Ronak Sharma (Software Engineer)

6. Acknowledgment

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- Dr. Sean Andreson: The team's mentor
- Liz Taylor: For her continuous guidance about funding
- Margaret Craig: For her ongoing support with all aspects of the project

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- Automatic Control and Systems Engineering Department- University of Sheffield
- The Faculty of Engineering – University of Sheffield
- Goodwin Sports Centre
- The Alumni Fund – University of Sheffield

Finally, we would like to extend a huge thank you to our sponsors and partners:

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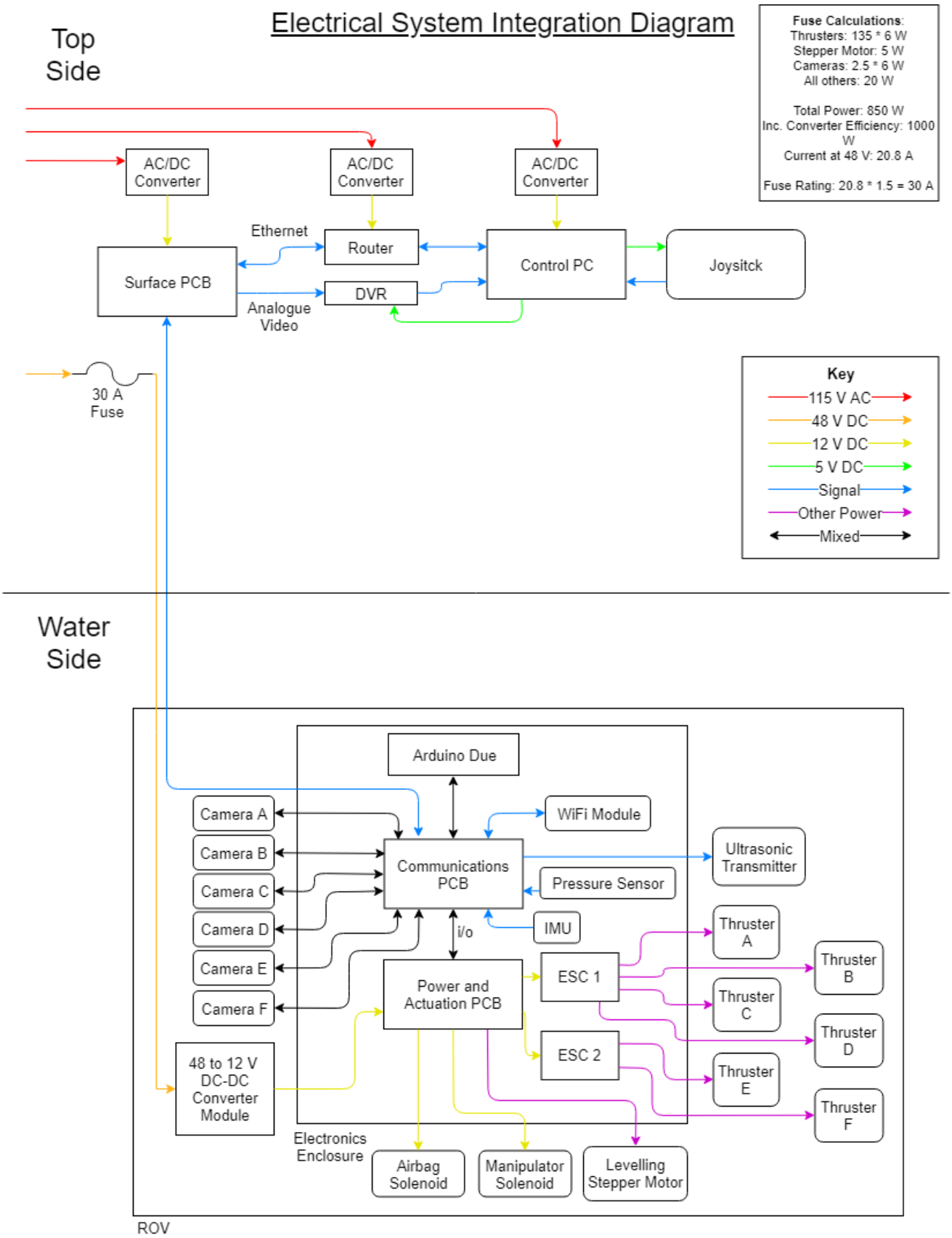
Appendix A: Project Costing

Category	Item and Description/Examples	Type	Amount	Paid/Recived
Income	ACSE Department Funding	Cash donated	$ 4,050.00	$ 4,050.00
	Faculty of Engineering Travel Funds	Cash donated	$ 9,045.00	$ 9,045.00
	IMarEST Donation	Cash donated	$ 675.00	$ 675.00
	Marketing Funds	Cash donated	$ 1,518.75	$ 1,518.75
	Alumni Fund	Cash donated	$ 270.00	$ 270.00
General Expenses	Storage Units	Purchased	$ 228.53	$ (228.53)
	Prop Building Materials	Purchased	$ 104.38	$ (104.38)
	Workshop Tools	Purchased	$ 202.50	$ (202.50)
	Joystick	Re-used	$ 40.50	$ -
		Total General Expenses	**$ 575.91**	**$ (535.41)**
Electrical Expenses	Tools (crimping tool, multimeter)	Donated	$ 390.04	$ -
	Electronic components (risistors, capacitors, MOSFETS)	Donated	$ 1,749.05	$ -
	Microcontrollers (Arduino Due)	Donated	$ 86.40	$ -
	Cables and wires (signal wire, power wires)	Donated	$ 321.75	$ -
	Sensors (IMU and pressure sensor)	Purchased	$ 73.83	$ (73.83)
	Actuators (electromagnet and solenoids)	Purchased	$ 131.64	$ (131.64)
	Vision system (cameras, analogue video grabber and video switch)	Purchased	$ 63.92	$ (63.92)
	Consumables (Flux and solder)	Donated	$ 170.80	$ -
	PCB Manfacturing	Purchased	$ 39.17	$ (39.17)
	DC-DC converters	Re-used	$ 648.28	$ -
	48V Power Supply	Re-used	$ 441.81	$ -
		Total Electrical Expenses	**$ 4,116.69**	**$ (308.56)**
Mechanical Expenses	Raw materials (acrylic sheets and 3D printing filmant)	Donated	$ 270.00	$ -
	Pnumatics (fittings, valves and acutators)	Purchased	$ 382.33	$ (382.33)
	Air Compressor	Purchased	$ 97.19	$ (97.19)
	T100 thrusters	Re-used	$ 970.00	$ -
	Chassis (inc. materials and machining)	Re-used	$ 318.00	$ -
	Electronics Housing	Re-used	$ 277.00	$ -
	Consumables (nuts and bolts)	Purchased	$ 34.38	$ (34.38)
	Foam	Re-used	$ 28.32	$ -
	Cable Glands	Donated	$ 137.70	$ -
		Total Mechanical Expenses	**$ 2,514.93**	**$ (513.90)**
Marketing Expenses	Business cards	Donated	$ 89.78	$ -
	Travel to national events	Donated	$ 229.50	$ -
	Team Apparel	Donated	$ 725.76	$ -
	Marketing display	Donated	$ 67.50	$ -
		Totoal Marketing Expenses	**$ 1,112.54**	**$ -**
Travel Expenses	Flights	Purchased	$ 7,020.00	$ (7,020.00)
	Hotels	Purchased	$ 2,025.00	$ (2,025.00)
	Transportation	Purchased	$ 810.00	$ (810.00)
		Total Travel Expenses	**$ 9,855.00**	**$ (9,855.00)**
		Total Income		$ 15,558.75
		Total Amount of Expenses		$ 18,175.07
Note: These figures assume a conversion rate of 1 GBP = 1.35 USD		**Amount - Donated/Re-used**		$ 11,212.88
		Net balance		$ 4,345.87

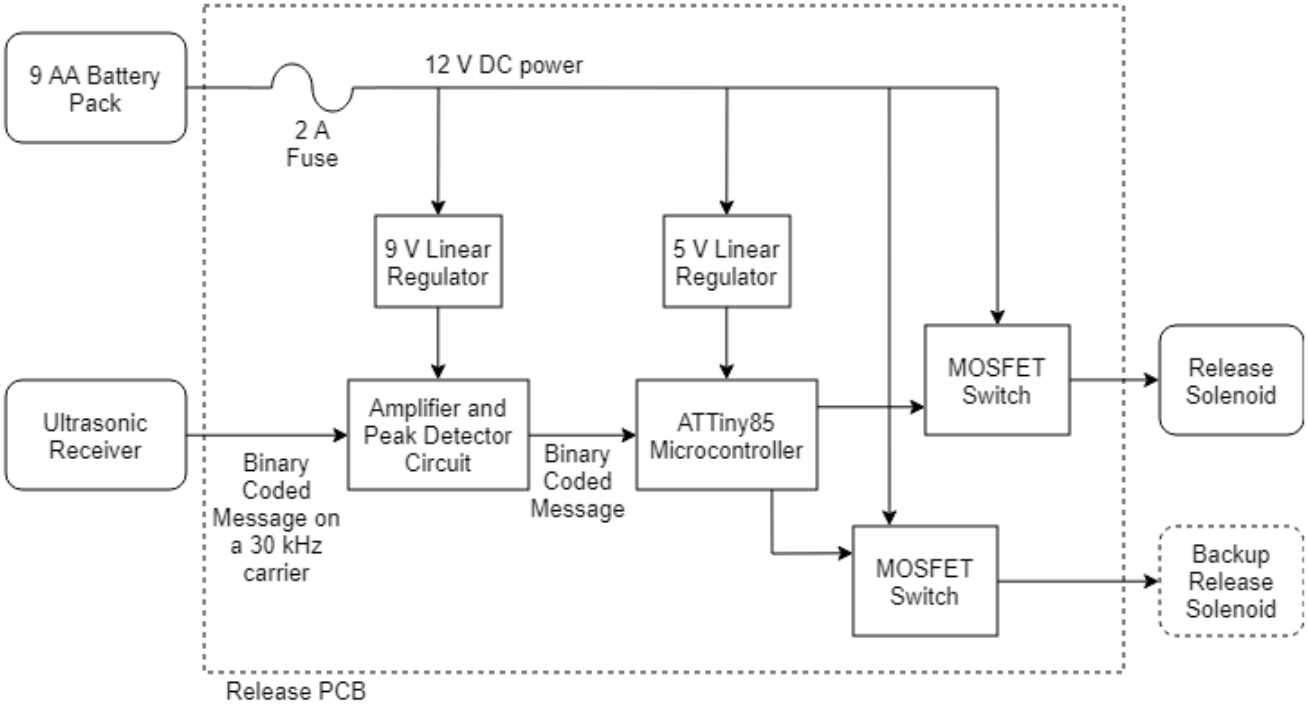
Appendix B: System Integration Diagrams (SIDs)

Electrical System

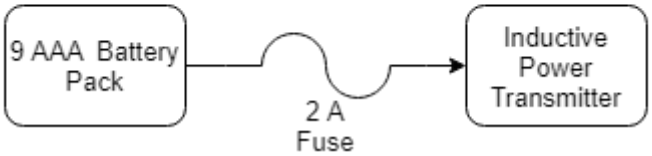


Non-ROV devices

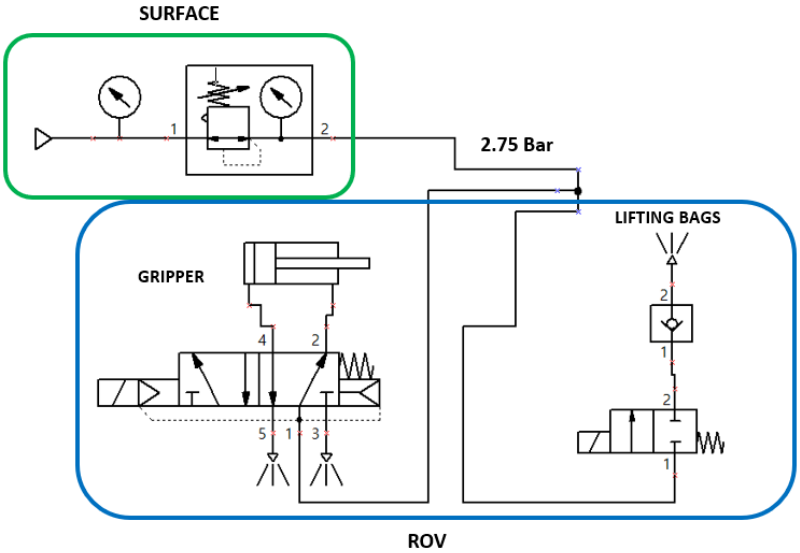
Remote Lift-Bag Release: System Integration Diagram



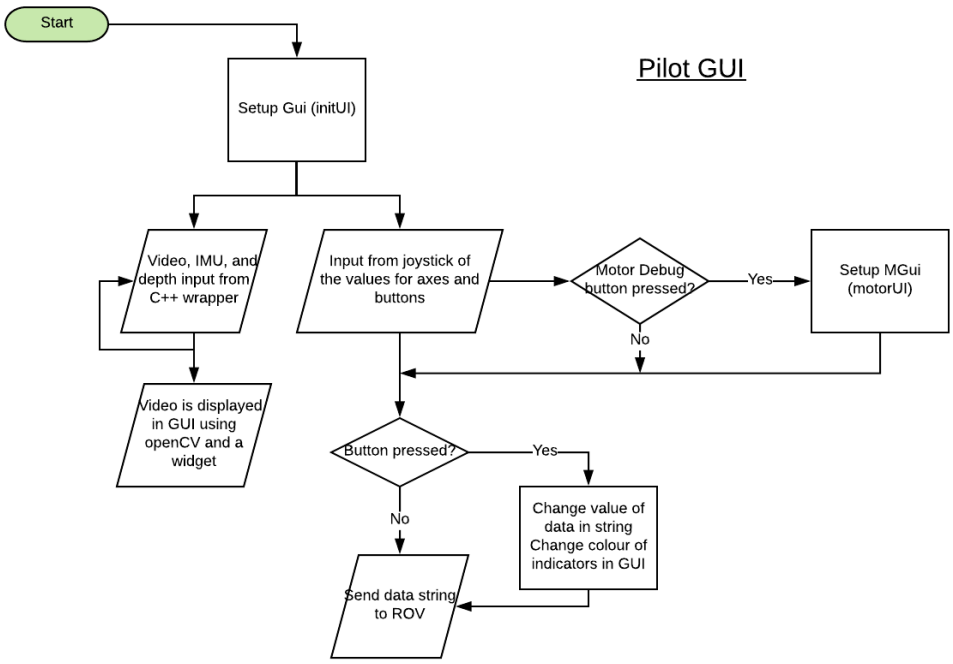
Inductive Power Transfer System Integration Diagram



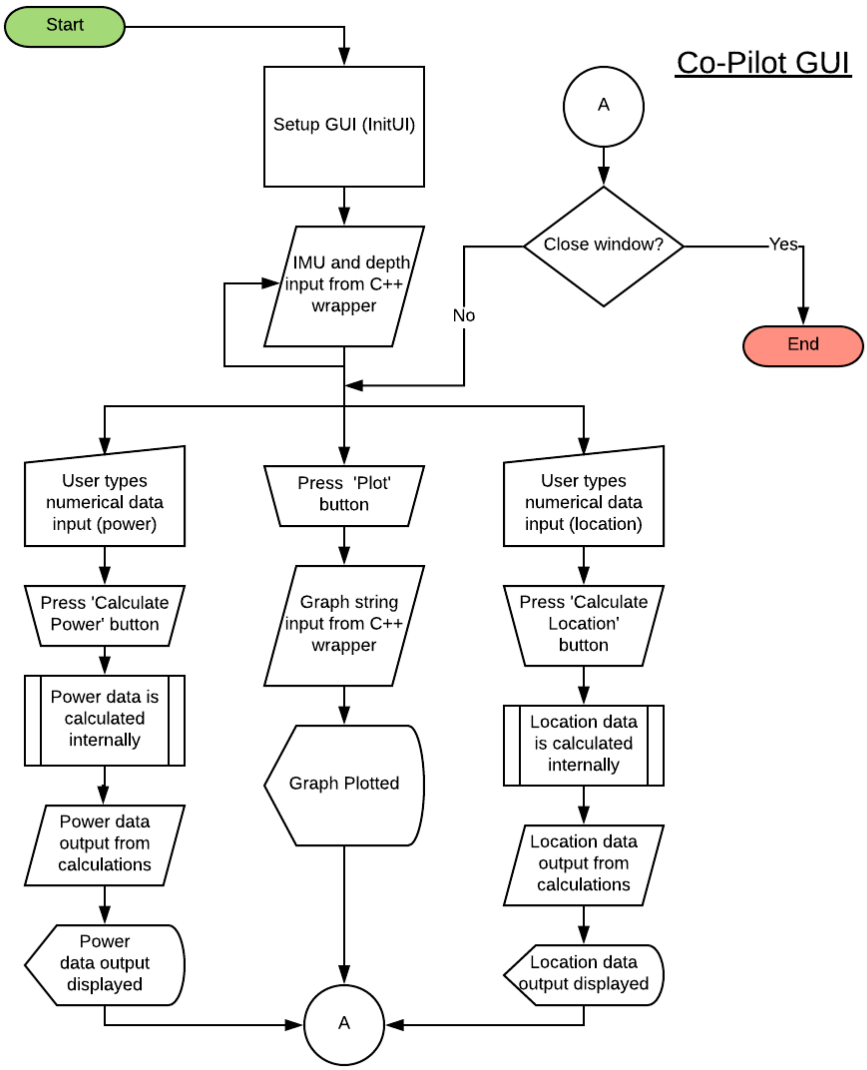
Pneumatics



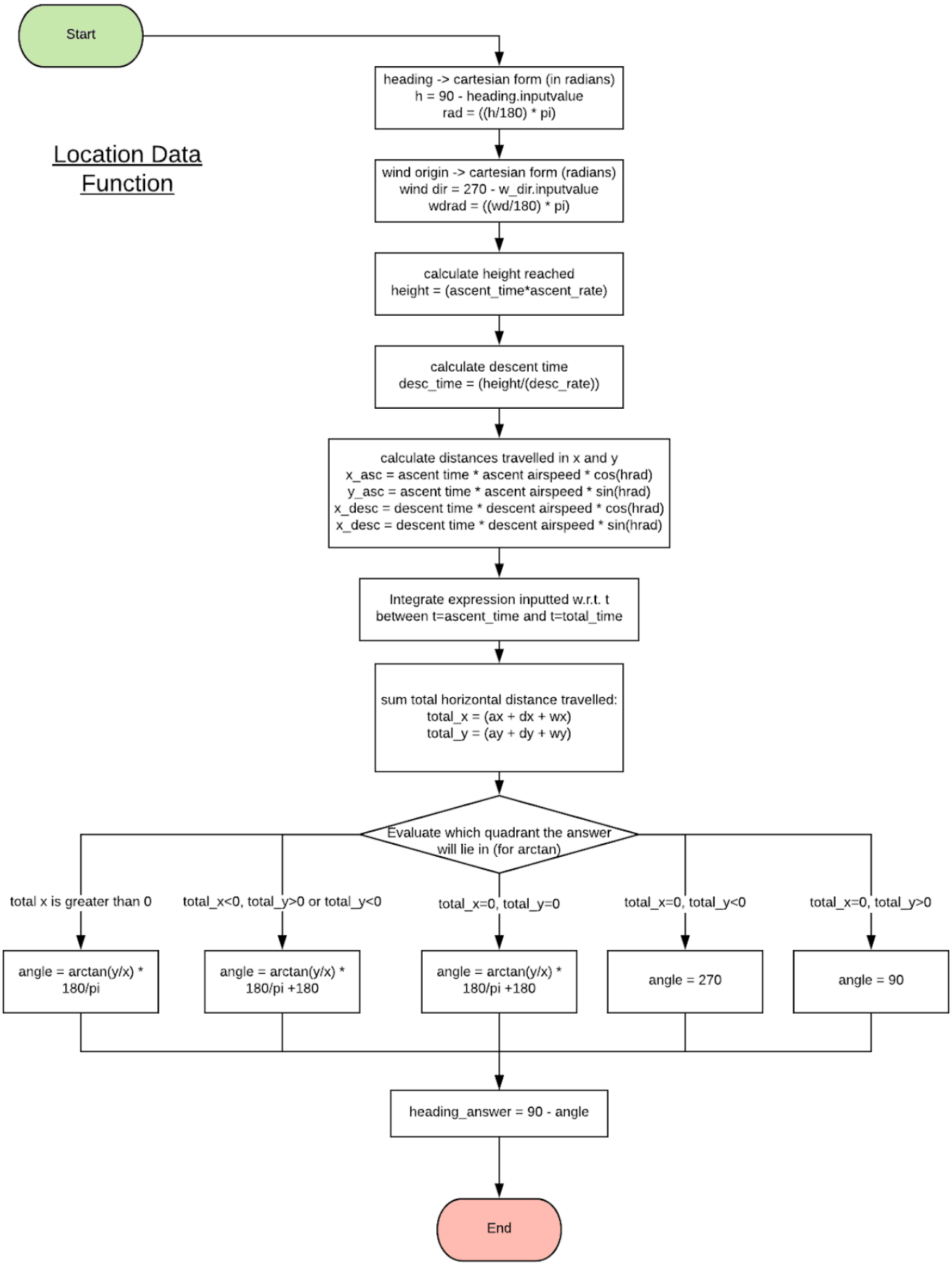
ROV Control (Pilot's GUI) Flow Chart



ROV Co-Pilot GUI Flow Chart



Location Data Function Flow Chart



Appendix C: Safety Checklist

Before deploying the ROV

- ✓ Preform a visual check to ensure all systems are undamaged.
- ✓ Ensure all employees are wearing appropriate safety gear.
- ✓ Preform a dry test to ensure controls are working appropriately.

During operation

- ✓ Ensure the power switch is within arm's reach at all times, in case of emergency.
- ✓ If a fault is observed by any employee, he/she must immediately call for a "STOP!" The closest employee to the power switch is then required to immediately kill all power.
- ✓ In case of communication loss, immediately call "STOP," retrieve the ROV and inspect for damage.
- ✓ In case bubbles are observed, immediately call "STOP," retrieve the ROV and inspect for damage.

After operation

- ✓ Clear the pool side of any tools or obstructions.
- ✓ Retrieve any dropped items from the pool.
- ✓ Disconnect all power connections.
- ✓ Safely pack all items and scan the pool side for any missed items.