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AVALON

- Underwater Robotics -

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1 Abstract

Avalon has designed and built a novel ROV, capable of operating in rivers, lakes and dams. The company's innovative design is the result of the collaborative work of 17 dedicated and highly creative engineers. The vehicle was designed to inspect and repair a hydroelectric dam, monitor the water quality and bring to light previously unknown sides of history.

The company's highly qualified workforce of multidisciplinary engineers (split into electrical, mechanical, software and non-technical departments), makes Avalon capable of developing ROVs able to operate in a wide range of environments, to carry out critical tasks and solve real-world problems.

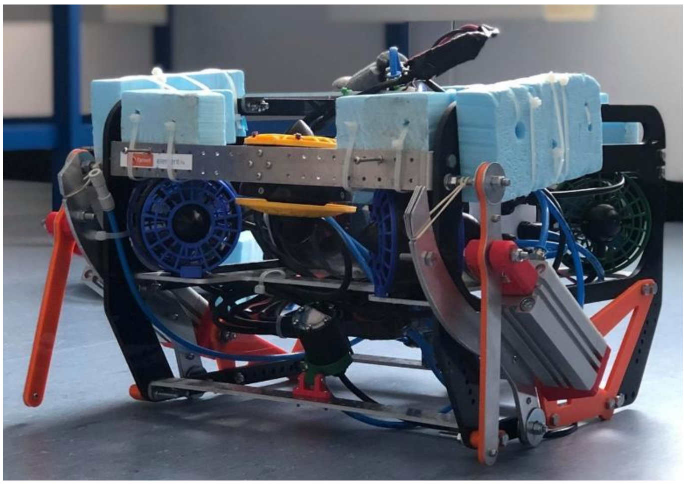

Figure 2, Front view of the complete vehicle.

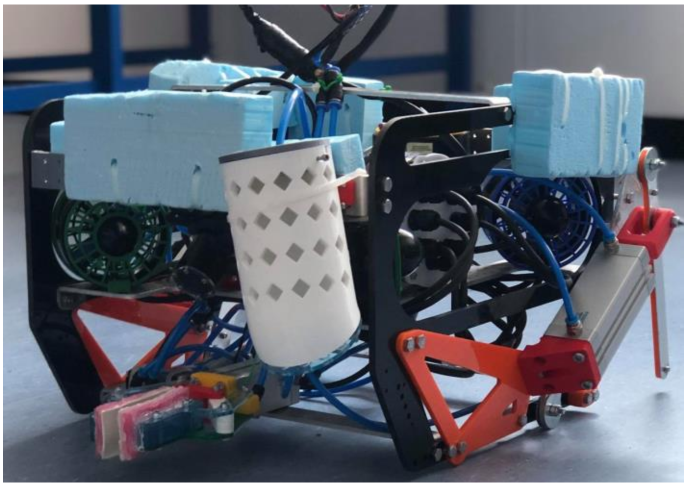

Figure 1, Rear view of the complete vehicle.

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's culture are the focus on sustainability, public safety and unprecedented customer experience. As part of the Corporate Social Responsibility, Avalon participates in various outreach events, aiming to inspire the next generation of scientists and engineers.

Avalon’s ROV utilises six Blue Robotics T100 thrusters that enables it to manoeuvre with 5 degrees of freedom. Selection of light and versatile materials has been achieved on the chassis and a dedicated GUI has been optimised for the ROV's best control of the missions. Custom manipulators have been designed to meet the customer’s requirements. This report provides detailed documentation of the vehicle and works carried out by Avalon to fulfil the customer's needs and requests.

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2 Design Rationale

2.1 Overview

Avalon followed a systems engineering approach and utilised a V-model to structure its workflow. Initially, the system requirements were captured after brainstorming sessions that yielded the system design presented below. Testing was done pre and post integration to ensure subsystem and system level components met the requirements.

2.2 Mechanical System

2.2.1 Overview

At Avalon, we use previous experiences to keep developing and improving, while at the same time training the future generation of the team. Utilising those experiences from last year's competition, this year we focused on the following three main tasks:

- Design and manufacture suitable and user-friendly manipulators to perform the missions with minimum pilot effort.
- Effective sealing of all ROV's components to prevent feed lose from the cameras when underwater, as that was last year's main problem.
- Perform a lot of testing.

2.2.2 Chassis

The main focus of the chassis design was to make it light and modular so that it can be easily adapted to fit various manipulators, cameras, control box and the propulsion system. The aim was to have these features without sacrificing the frame strength and stiffness. Given, the good performance of last year's chassis, only a few changes were made on the chassis to solve some issues such as placement of foam, mounting of the new actuators, ease of access to the control box.

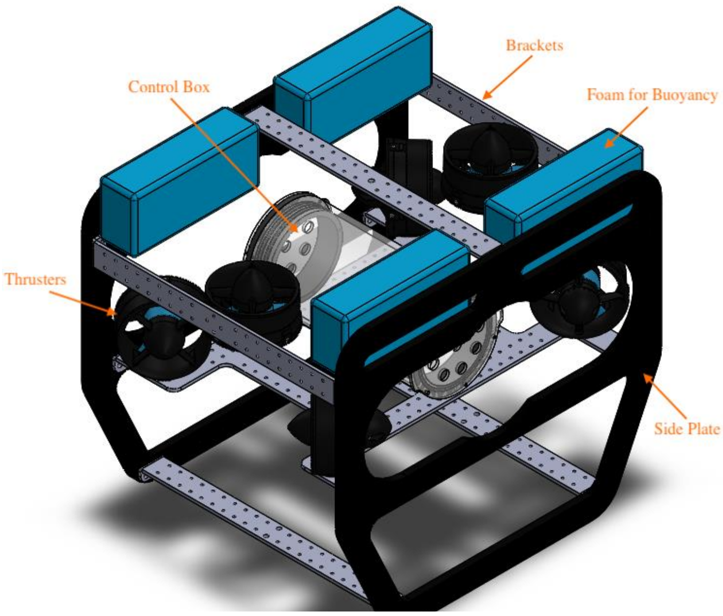


Figure 3, ROV Chassis.

Avalon's design consists of two side plates and six connecting brackets at the top, middle and bottom of the side plates. The side plates were carefully designed with slots for effective water flow through the thrusters, to ease access to the control box and to reduce drag during lateral movement. Some addition upper slots were designed to ease handling of the ROV.

The top brackets are used to mount the vertical thrusters and the tether, while the middle bracket is used for the horizontal vectored thrusters and for mounting the control box (Figure 3). The bottom brackets are used to provide additional mounting points for the manipulators. Brackets are secured to the side plates using nuts and bolts. The design took into account easy access to the control box

The frame design was implemented by utilising acetals (Polyacetal-Copolymer) for the side plates, which were CNC routed, and laser cut aluminium brackets, which were CNC folded. Acetal was chosen mainly for the high strength to density ratio and the good impact and wear properties, especially in wet or moist environments. Aluminium was chosen for the brackets because of its strength, lightweight and corrosion resistant. Stainless steel was not chosen, as it is usually 2.5 time heavier.

2.2.3 Control Box

A single control box was used for encapsulating the control electronics as well as a portion of the power electronics. The enclosure was bought from Blue Robotics because it matched exactly the design specifications and was found to be cheaper than manufacturing a custom enclosure in-house. Two aluminium end-caps, each one having two radial O-rings in series, were used to seal both ends of the cylinder. The cables are allowed in and out of the control box through IP69 cable glands. The 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.

2.2.4 Propulsion

The ROV is propelled using six T100 brushless thrusters [1] from Blue Robotics. For motion in the horizontal plane, four thrusters are used in a vectored configuration at 45° relative to the horizontal plane allowing the ROV to achieve any vector in the horizontal plane. 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. Figure 4 demonstrates the configuration of the thrusters and the degrees of freedom. The T100 thrusters were reused 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 23.1 N of thrust while consuming low currents at low RPMs which was our nominal operating range.

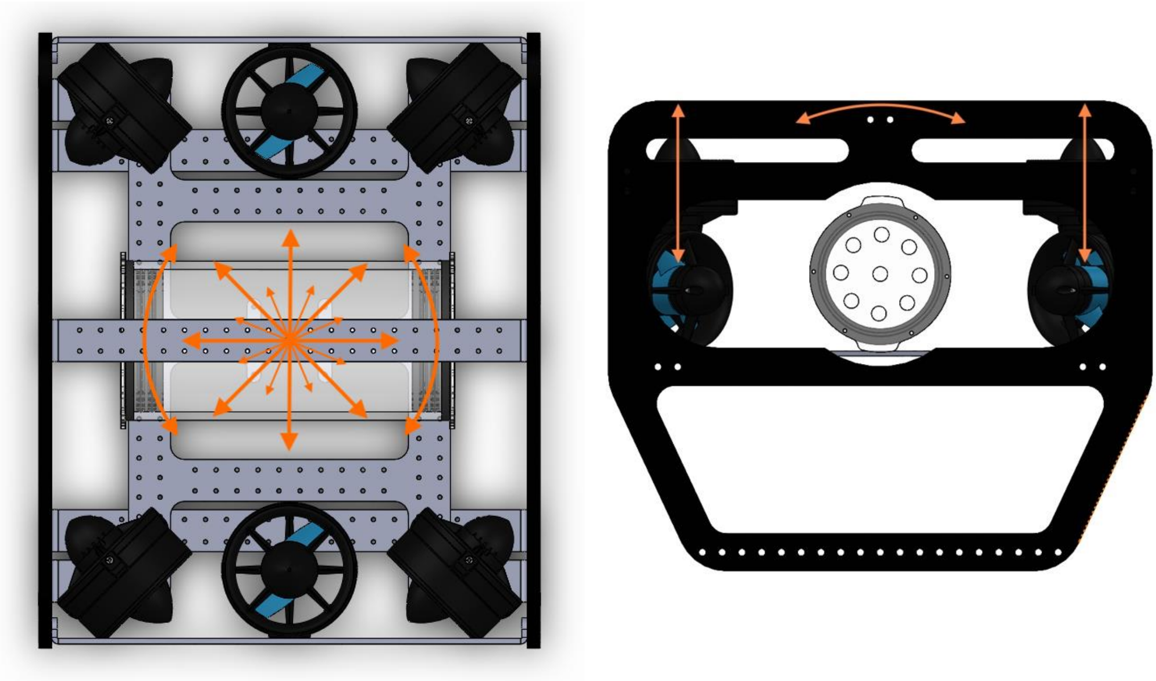


Figure 4. Configuration of Thrusters and Degrees of Freedom.

2.2.5 Buoyancy

Avalon uses a combination of closed cell foam and weights to ensure that the vehicle stays neutrally buoyant. This is based on the Archimedes principle stating that the buoyant force equals the weight of the displaced fluid. Using foam that is lighter than the water, the buoyant force is increased more than the total weight of the ROV. That principle was also applied to the tether to prevent it from restricting the ROV's motion by adding foam at regular intervals.

Maximum stability was achieved by having the centre of mass as low possible and the centre of buoyancy as high as possible. This was achieved by positioning of the control box as high as possible to raise the centre of buoyancy to improve the vehicle's stability underwater. Manipulators and other functional components were placed as low as possible to shift the centre of mass to the bottom of the vehicle, further increasing its stability.

2.2.6 Vision System

The pilot relies on visual feedback to be able to pilot the ROV, for this reason it was important to have feed with minimum latency, based on this requirement analogue cameras were selected. They were connected to a DVR which was connected to router to stream its feed over RTSP.

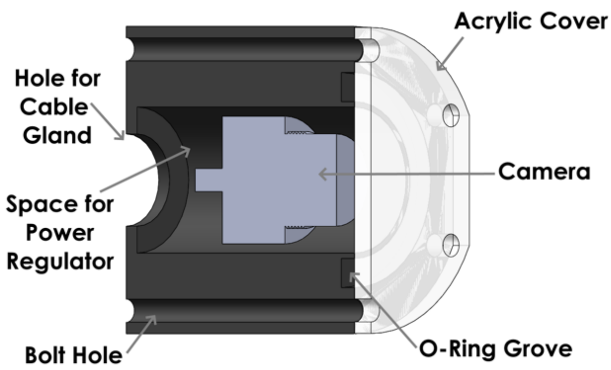


Figure 5. Camera casing cross-section.

The ROV utilises five cameras with a field of wide field of view of 120°, they are strategically positioned each focusing on a manipulator. The cameras and their power regulators are cased inside a custom designed and manufactured in house, it was made from an acetal body, milled from a solid block, and a transparent acrylic cover, with an O-ring creating a seal between them. This creates a waterproof joint that can be disassembled for camera maintenance. At rear of the camera housing there is an IP69 cable gland, out of which passes the cable carrying power and signal.

2.2.7 Tether

The tether consists of a CAT-5E cable with 4 twisted pairs, 2x 2.5mm2 silicone wires, and a 6mm pneumatic tube all enclosed in a webbed cable sleeve. Two of the twisted pairs are used for communications with TX and RX which allows for bi-directional communication to the ROV. The other two twisted pairs are unidirectional from the ROV to the surface and carry differential analogue camera signals. The two 2.5mm2 cables can carry 30A in air, higher when cooled in water. The pneumatic tube carries 2.75 bar of air pressure for use by the pneumatic actuators. Webbing surrounds the whole tether and keeps it as homogenous, preventing tangling.

2.3 Electrical System

2.3.1 Overview

There are four main electronic systems that work together to achieve the ROVs functionality and control requirements. These are the surface communication system, the on-board ROV control electronics, the motor/actuator power electronics and the power converters.

All these separate electronics systems are built onto custom designed PCBs, where the control and power electronics are designed to fit together as a modular system via PCI connectors and interface PCBs, as seen in Figure 6.

One of issued faced in the previous years' design was that the electronics were all constructed onto a single board, with many separate connectors being used to wire up the ESCs etc. This made fault finding difficult as the process of removing the electronics from the capsule was complicated and time consuming due to the number of connectors. With this new design, each PCB is a separate subsystem and can be individually replaced in the event of a failure. Furthermore, since the external connections are soldered only onto the PCBs bolted onto the end caps, the entire electronics assembly can be removed easily without having to de-solder external devices due to the use of PCI connectors.

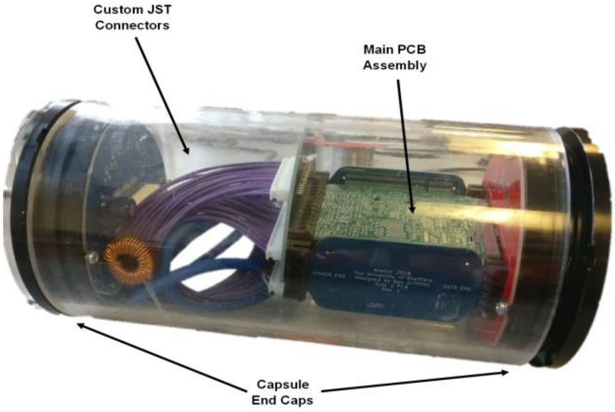
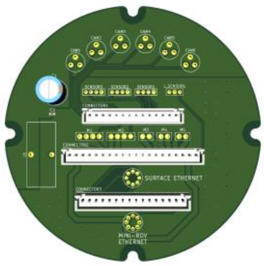
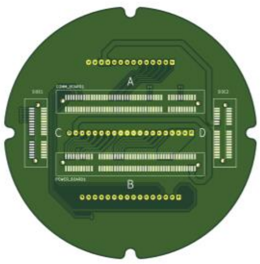


Figure 6. PCB stack inside the control box.

<table>
<tr><th>PCB</th><th>Function</th></tr>
<tr><td></td><td>Data End PCB:

Bolts onto one of the capsules end caps, and connects to external devices such as the data input ethernet, cameras, sensors, Mini-ROV, pneumatic solenoids and DC motors.

These signals communicate with the main electronics system through a series of custom JST cables, so that the main PCB assembly can be disconnected and removed from the capsule easily.</td></tr>
<tr><td></td><td>Data Middle PCB:

Takes signals from the data end PCB and routes them to the control PCB and power PCB via the PCI connectors.

This PCB is also a crucial part in the structure of the main PCB assembly.</td></tr>
</table>

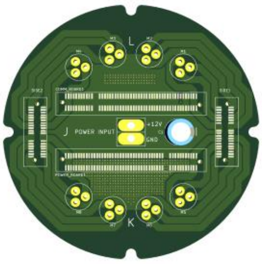
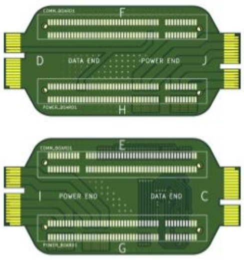
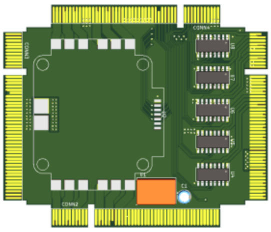
	**Power End PCB:** Bolts onto one of the capsules end caps, and routes the brushless ESC connections from the power PCB to the external thrusters through the PCI connectors. Furthermore, this PCB receives the main +12V power line and feeds it to the power PCB.
	**Side Connector PCBs:** These two PCBs sandwich the control and power PCBs together and allow the different PCBs to communicate with one another. For example, the ESC control signals are routed from the control PCB to the power PCB through these side PCBs.
	**Control PCB:** This PCB is the brain of the on-board electronics system, with an ATmega2560 microcontroller processing the incoming data and sending the necessary control signals to the various actuators. It also contains a camera switch to switch between the multiple on-board camera feeds.
	**Power PCB:** This PCB contained the thruster ESCs and the H-Bridges to control the pneumatics solenoids and DC motors. It also contains a +5V regulator to power the control PCB.

Table 1. PCBs functions.

2.3.2 Power

A single XP Power QSB600 was used to convert 48 V to 12 V. By using a single converter over the multiple parallel converters as were used in previous years, there is no need to ensure current balancing, eliminating the possibility of nuisance tripping due to overcurrent in one of the several converters. This converter is held outside of the ROV and vacuum potted in an epoxy resin for waterproofing.

Figure 7, DC-DC converter.

The Power PCB is held inside the control box with all the on-board PCBs, its purpose is to provide power to the ROV and route power to the communication boards. The PCB powers two 4 in 1 ESCs, 5 H Bridges and some passive components for smoothing noise and ripple. Before power is routed to the communication PCB, it is sent through a TSR_2-2450 buck converter, converting 12V to 5V.

2.3.3 Controller

The main controller of the ROV is an ATMEGA2560 on a custom PCB. This controller is responsible for: communicating with the surface board over serial; communicating with sensors and switching between the cameras using I2C; controlling the ESCs by bit-banging the pins using the servo protocol; and sending the correct digital and PWM signals for the H-Bridge motor or solenoid control. The ATMEGA2560 is programmed over its ISP header with the Arduino programming language as though it was an Arduino Mega. The controller also runs the PID control loop and runs binary to floating point conversion on the sensor data before reporting back to the surface board.

2.3.4 Communication

Communications are implemented using the UART protocol. ASCII characters are sent down a differential line to the control box using a MAX488E+ using the RS485 standard used in full duplex mode. This is then converted to single ended and decoded by the Arduino. Data is sent in packets where each has an identifier letter at the beginning followed by a string of data and an '!' is used as a packet terminator. The data in the packet are used to indicate values of what to set parameters of the ROV, such as thruster power percentage or PID gain values etc. The Arduino can also use UART to send data to the surface computer in order to give back data from the sensors and debug information.

The differential lines allow for cancellation of the noise in the signal when it is received as a lot of noise is superimposed by the power lines which run parallel to the data.

The surface board also contains a MAX488E+ which decodes and transmits the two differential signals and converts this data into a USB serial data and decoded by a Python script. We decided to use UART instead of UDP because it allowed for less overheads in the communication packets which allowed for a higher data rate and reduced complexity.

All the cameras are put through an analogue switch and sent differentially down two differential lines where cameras on the output can be selected by the Arduino module. The surface board decodes the differential camera data which is sent out on a standard video RCA connector and viewed using a CCTV DVR system.

2.3.5 Sensors

Inertial Measurement Unit (IMU)

The inertial measurement unit used in the ROV was the MPU6050, it encompasses a tri-axis gyroscope, and a tri-axis accelerometer; this allows for the device to measure acceleration in the X, Y and Z axis, and rotation in W, U and V. The data from the IMU is used for closed loop control of pitch.

Figure 8, MPU6050 IMU.

Humidity Sensor

Figure 9, SHT30 sensor.

The humidity sensor that is used is the SHT30, it is both a humidity and temperature it has a range of -40 to +125 degrees. It is connected to the I2C bus for communication. This is used to measure the humidity levels inside the control enclosure and the higher this value, the worse for the electronics and is an early indicator of moisture ingress as the heat from the ESC drivers will cause the water to evaporate.

pH Sensor

A pH Sensor is an instrument that measures the relative amount of hydrogen (H+) and hydroxide (OH-) ions in a solution, to measure whether the solution is acidic or alkaline. The system consists of a pH probe, a reference pH electrode and a high input impedance meter [2].

Any solution is like a small battery that has a potential difference depending on the concentration of hydrogen ions. Therefore, the probe measures the voltage of the solution and converts that measurement into a hydrogen ion concentration using:

$$E = \frac{RT}{zF}\ln\frac{[\text{ion outside cell}]}{[\text{ion inside cell}]} = 2.3026\frac{RT}{zF}\log_{10}\frac{[\text{ion outside cell}]}{[\text{ion inside cell}]}$$

Equation 1, The Nernst equation.

In order to make electricity flow through the solution, the probe has two built in electrodes (electrical terminals): a measuring electrode that has a varying voltage for different hydrogen concentrations and a reference electrode that has a constant voltage output.

An external circuit amplifies the current that is sensed, and outputs an 0-5 V scale that is read by the Analogue to Digital Converter built into the microcontroller, allowing the pH to be fed back to the surface.

Inductive Proximity Sensor

A Telemechanique XS512B1NAL2 inductive proximity sensor is used to detect the presence of metal cannon shells amongst other, non-ferrous, debris. It comprises of a potted LC circuit, excited at its resonant frequency. When brought near a ferrous metal, the inductance of the pick-up coil changes, resulting in a change of resonant frequency, which is detected by an internal circuit and outputs a +12 V signal, stepped down by a potential divider before being fed into the microcontroller.

Depth Sensing

Figure 10, MS5803 sensor.

An MS5803 pressure sensor [3] was used to measure the depth of the water. The operating pressure range of the sensor goes from 0 to 14 bar and it can be therefore taken to a maximum depth of 143 m. ($p = \rho gh$, ρ for water at 25°C = 997kg/m^3). In regard to its performance characteristics, it has a precision of 0.2 mbar (or ~2 mm of water depth), for a temperature range from 0 to 40 °C, which allows precise closed-loop control of the depth of the ROV for easily manoeuvring during all of the challenges.

2.3.6 Closed-Loop Control System

In the control system of our ROV, we provide a closed loop holding routine for the ROV when it was not being controlled from the surface, ensuring that it would maintain depth and pitch. Using the MPU6050 and the MS-5830-14BA (pressure sensor) the ROV is capable of calculating its exact depth and pitch angle, feeding these into our MIMO control system. Adopting a cascade control architecture, we implemented two Proportional Integral and Derivative controllers as they are computationally lightweight and simple to implement. Initial testing began with a single thruster and a small vertically submersible rig, this progressed to using multiple thrusters and refining the control parameters. With effective depth stabilisation in place, the rig was adapted to also accommodate single axis rotation allowing the pitch controller to be developed. Finally, the controller were tuned on the ROV.

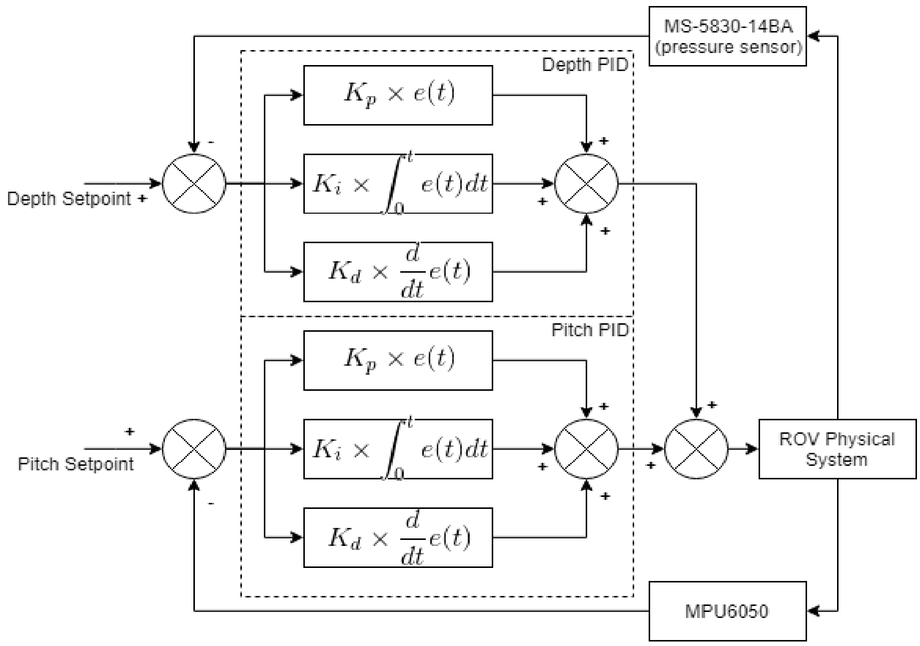


Figure 11. Control system block diagram.

2.4 Surface Control Station

2.4.1 Overview

This year big updates were made to the surface control station to improve the pilot experience and aid him in performing missions easier and more efficiently. These changes were made based on the issues identified from the previous years.

2.4.2 Video Feed Monitor

A dedicated 21.5" monitor was used for viewing the ROV camera feed. Using a Monitor connected directly to the DVR gives an independent way of viewing the camera that is not affected by other processes, a large visual feed makes the piloting experience more immersive and finally reduced latency to the minimum and the benefits of using analogue cameras start showing up.

2.4.3 Joystick

Another significant change we made this year was the switch to using an Xbox one wireless controller as a joystick for controlling the ROV. The Xbox controller relies on finger movement, which can produce dexterous movements. Also being wireless this has made testing, especially on the poolside more convenient.

Tank style steering was used along with the ability to sway for motion in the horizontal plane. This was done by controlling each pair of thrusters on the sides of the ROV with the corresponding analogue stick on the joystick, e.g. the right analogue stick controls the right pair of thrusters on the ROV. Different push buttons were assigned for different actuators controls.

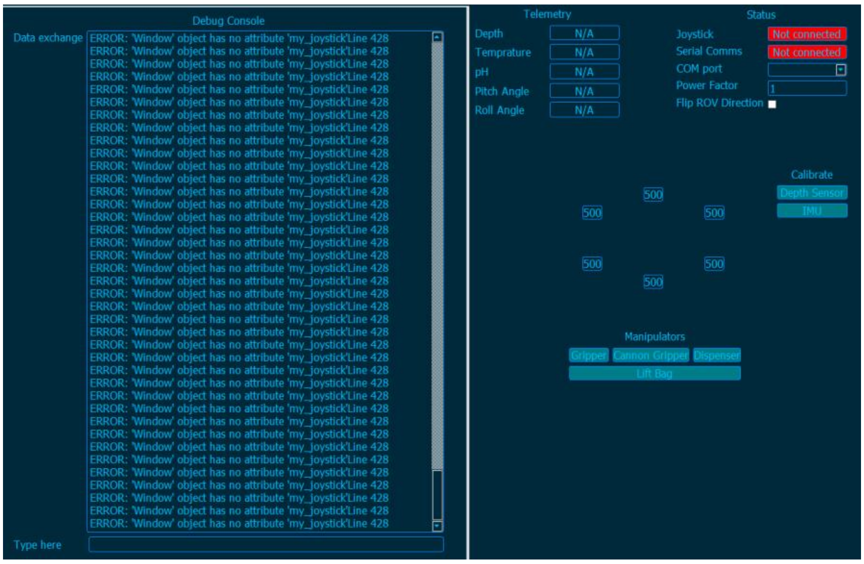


Figure 12. Screen shot from the GUI.

2.4.4 GUI

A GUI was developed to interface with the joystick, exchange data with the ROV over the RS-485 communication bus, display telemetry information along, select camera feed to transmit along with running the computer vision tools.

The GUI was written in python using the PyQT module [4]. The serial communications were implemented as a class using the pyserial module [5], this enabled encapsulation thus enforcing modularity. This allowed for changes to be made easier and for testing to be done independently of the GUI.

In the setting tab of the GUI, thruster re-mapping and direction flipping was added to make updating them if the physical thrusters-ESC connection were changed. To allow for easy tuning of the pitch and depth PID controller dedicated input boxes were set for this purpose. Moreover, a debugging console is showing all message going and coming from the ROV along with a text box was that allows typing literal strings and sending it to ROV which is a useful feature when debugging, this feature was inspired from the Arduino Serial Monitor.

In the mission tab, the pilot/co-pilot were able to perform the canon calculations as well a starting and using the computer vision tools. The GUI grabs the video feed from the DVR through RTSP for use by the computer vision tools.

2.5 Mission Tools Design

2.5.1 Multi-Purpose Gripper

A multi-purpose pneumatic based gripper was equipped on the ROV that was manufactured in-house. The main tasks performed with it are removing the damaged screen and replacing it with a new one, removing the rubber tire and installing the fish/reef ball.

A pneumatic actuator was chosen over of a motor, as the pneumatic actuator was already sealed. The gripper was controlled using a 5 port 2-way solenoid valve with non-return valves were installed on its exhausts to prevent water from getting into the pneumatic system.

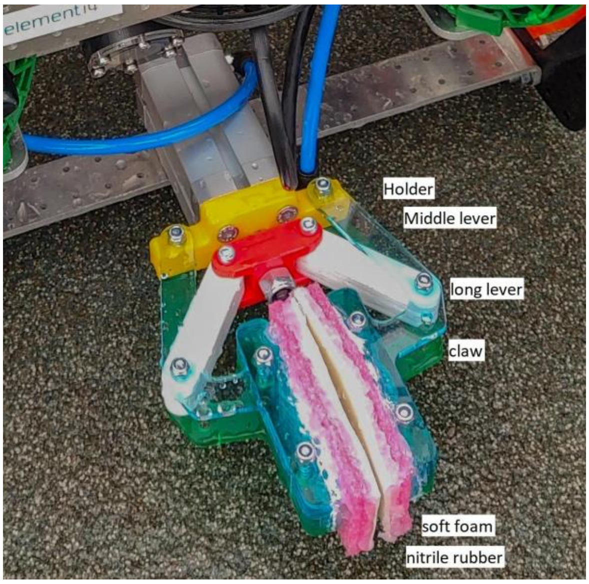


Figure 13. Pneumatic gripper.

This gripper design was an improved version of the one designed last year. The biggest improvement was the use of a 25mm piston instead of 12mm piston, which provided more force to hold objects so they do not slip.

Laser cut acrylic and 3D printing were primarily used for their ease of manufacturing, which made prototyping quick. To increase surface friction, soft foam was added on both inner sides of the claws followed by a layer of nitrile rubber, this allowed for maximum contact area with the object being manipulated.

2.5.2 Micro-ROV

The purpose of the Micro-ROV (Figure 14) was to get inside pipes so that the operator can make a visual inspection for any signs of damage or corrosion. The Mini ROV consists of 3 main parts.

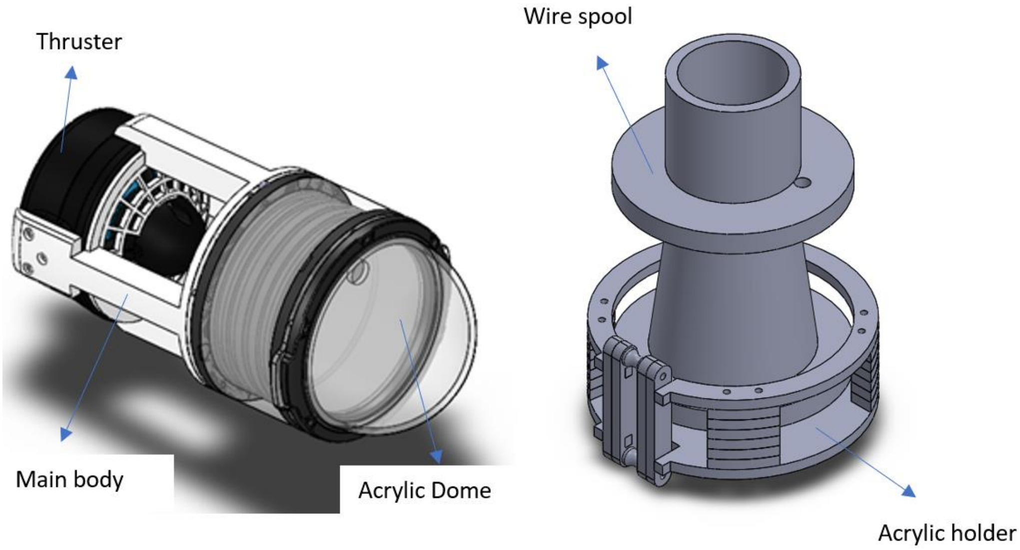


Figure 14, Micro-ROV – Retraction mechanism.

The main body has a cylindrical shape so that it can easily move inside the 6-inch Corex pipe, this part was 3D-printed and it was designed in a way that the thruster guard is incorporated to the main body. A T100 was used to propel the Micro-ROV inside the pipe. An Acrylic Dome houses a camera and LEDs. The LEDs provide lighting in low light environments.

The Micro-ROV was connected to the ROV with a cable that was attached to a retraction mechanism that launches and withdraws the Mini ROV.

The retraction mechanism was fixed to the ROV and it had two parts, the wire spool which will be held stationary and the rotating acrylic holder. The 3D printed wire spool had a motor inside to rotate the laser cut acrylic holder. An oil seal was added to the motor shaft to provide sealing. The final design consists of laser-cut 5mm acrylic sheets that were stacked together and with a combination of acrylic adhesive and mechanical fasteners are rigidly held together to form the acrylic holder as shown in Figure 14. This mechanism was inspired from the fishing reel mechanisms and was designed so that the power cable that is fixed to the main ROV does not twist while retracting the mini ROV.

2.5.3 Canon Retrieval Mechanism

The cannon retrieval mechanism was made up of two distinct systems, a pneumatically powered gripper mechanism and a detachable lift bag. The gripper mechanism was made up of two sets of arms; one on each side of the ROV, the left set can be seen in Figure 15. The lower arms are unpowered and stored folded up, close to the ROV frame. When required, a team member manually releases the lower arms allowing them to unfold.

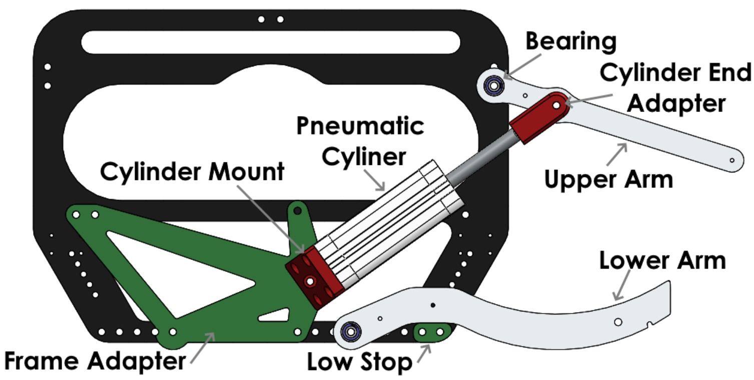


Figure 15. Canon gripper CAD.

When unfolded they rest against a stopper, which takes most of the cannons weight whilst lifting. The upper arms are each powered by a 32mm bore pneumatic cylinder with a stroke of 80mm. The position of these cylinders took a long time to design as there was a trade-off between the travel angle of the arm and the force that could be applied at the tip of the arm. The current position was decided though trial and error in CAD. The upper arms can be controlled by the pilot of the ROV using a pneumatic system, similar to the main gripper. When retrieving the cannon, the cylinders are extended, raising the upper arms so the ROV can be manoeuvred to have the cannon between the upper and lower arms. When the cannon is in position, the cylinders are retracted. This grips the cannon against the main frame of the ROV and lower arm, which stops the cannon from slipping of the lower arms.

Once the cannon gripper has a hold of the cannon, a lift bag located at the top of the rear of the ROV is inflated. This provides the lift required to bring the cannon to the surface, at which point the thrusters can be used to steer the ROV and cannon to the edge of the pool.

2.5.4 Dispenser

The dispenser was used to release pebbles in order to fill a gap/ groove on the dam and for safely carrying and deploying fish that cannot be grabbed using grippers. It was designed to carry both the pebbles and trout fish.

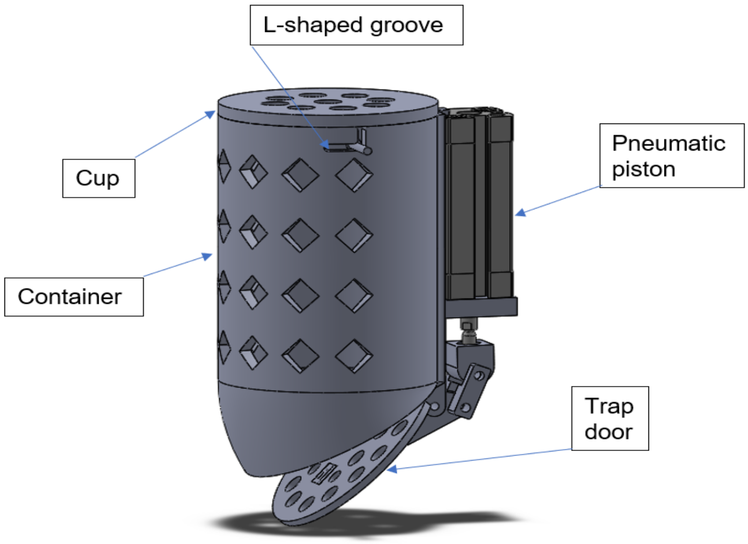


Figure 16, Dispenser CAD.

The main body (container) of the dispenser was 3D printed, which has a volume of 450ml. 3D printing was chosen due to the complex geometry of the cup that allowed for a more creative design. The initial design proposed was manufactured, producing only some strengthening improvements after issues occurred during the process and after testing. For example, the connecting point between the door and the main body was weak and snapped, resulting in increased filament density of 100% during the 3D printing. What is more, different orientations of the direction of printing were proposed, but were discarded as they were time consuming and therefore expensive. The container was designed with a pattern of diamonds on the surface, to allow water to pass through and avoid the creation of air pockets that can alter the buoyancy of the ROV. The top cup was also 3D printed, with two extended bars working as a locking mechanism. Two L shaped grooves on the container work as the guideline for the bars, as they enter the groove, and with a clockwise rotation the cup is locked, and with a counter clockwise turn, it's unlocked and free to pull out (see Figure 16). Finally, the small trap door was made out of 3mm laser cut acrylic.

A pneumatic cylinder actuated the trap door using linear motion to open it and close it. This cylinder was reused in order to avoid additional costs as it was in perfect condition.

2.5.5 Examining the benthic species

A computer vision tool was developed to identify the type and count the benthic species.

This tool was written in Python and uses OpenCV for image processing. The frame initially gets converted into a grey scale image to make edges stand out and is blurred using Gaussian blur filter to make the edges smoother. The image is then converted to a black and white image to detect any black object, it is converted using a threshold which indicates the minimum darkest pixel it should recognize as an object or shape if not it ignores everything else. After the pre-processing, the contours in the image are extracted and stored in a contour array.

For each image the code uses an approximation function to join the nearest contour to form a shape and conditional statements were written to identify the image by counting the number of connected contour lines joined together to form it.

While the code is performing the task above, it outputs a window displaying the feed with an image mask identify the shapes it has identified.

2.4.7 Dam foundation inspection

A computer vision tool was developed to perform the autonomously inspection of the dam foundation. This tool was developed in python using OpenCV.

Line following relied on finding the centre of the biggest contour inside the frame and then send thrusters commands to move the ROV so that the centre of contour is in the centre of the frame.

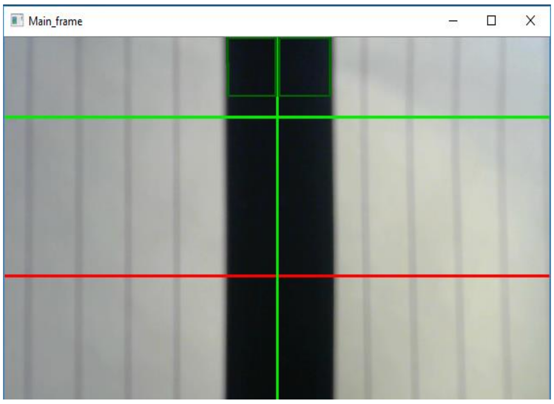


Figure 17, Line following algorithm.

2.5.6 Canon Length measurement

This was a computer vision tool developed to measure the dimension of the cannon by using stereovision. A depth map [6] was created using two cameras. The input for the code is two images from the stereo cameras (left and right). These images are then converted to grey scale so it can be passed as arguments into the OpenCV stereo depth map creator function. After the depth map is created it outputs a grayscale image where on the image white pixels indicates its closest to the cameras and black indicates its furthest from the cameras, which is then used to work out the required length.

3 Safety

3.1 Safety Philosophy

The main priority at Avalon is the health and safety of the company's employees and people in the working environment. 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 and improving its safety protocols.

3.2 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 a pool. 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 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.

3.3 Vehicle Safety Features

Following our safety philosophy, the ROV must be safe to handle and operate. This was accomplished by using a humidity sensor inside the control box to detect any leakage. This is accomplished by ensuring that all sharp edges are removed and deburred, safety stickers are added to the thrusters to indicate rotating propellers, along with guards and shrouds on both sides of the thrusters to prevent injuries. 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.

4 Teamwork and Organisation

4.1 Project Management

At the start of the year after defining the system requirements, a WBS (work breakdown structure) was created containing work packages that were 2-4 weeks long. Then based on the WBS a Gantt chart was created to plan the time each section of the project will take. The WBS and Gantt chart were continuously being updated throughout the project to ensure they were reflecting the real-life situations and adjustments were done as needed.

Tasks were then defined from the created WBS and they were posted on Trello, which is an online tool used for creating and assigning tasks which makes communicating about a specific task easy and contained in one place that is visible for all the team members.

Multiple weekly meetings were the time which was where most of the work was done, two meeting were held with the whole team attending, this ensured that the everyone was aware of the whole project progress and it also allowed for collaborations and discussions to take place. In addition, one more meeting was held for each sub-team this allowed for more focus on a specific topic/sub-system. This combination of different meeting styles provided a good balance between collaborative work and individual level work.

		Points	Solution
Dam Inspection and repair			
Inspecting the dam foundation	Following a transect line to inspect the foundation	25	Image processing + control (Line follower)
	Locating and gathering information about the length of the crack	25	Image processing
	Mapping the locations of the crack	10	Image processing
Inserting grout into voids underneath the dam		10	Dispenser
Inspecting and repairing a trash rack	Removing the damaged screen of the trash rack	5	Gripper
	Installing a new screen	10	Gripper
Deploying a secondary, micro-ROV	Identifying areas of muddy water flow inside the pipe	20	Micro-ROV
	Docking the micro-ROV to the primary ROV	5	Micro-ROV + retraction mechanism
	Total	**110**	
Maintaining Healthy Waterways			
Monitoring water quality	Measuring water temprature	10	Temprature sensor
	Measuring water pH	15	pH sensor that can penetrate a layer of plastic wrap
Determining habitat diversity	Lifting a rock from the bottom	5	Gripper
	Examining the benthic species underneath the rock	25	Image processing
	Recording the date, time, temperature, pH, and species diversity on a data sheet	5	N/A
Transporting and releasing trout fry		10	Some sort of trap door
Restoring fish habitat	Removing a degraded rubber tire	10	Gripper
	Installing a new fish/reef ball	10	Gripper
	Total	**90**	
Preserving history			
Prior to the competition	Determining the lift capability of your ROV	5	Testing
At the competition	Calculating the amount of force needed to lift the cannon	30	GUI
	Determining the composition (specific gravity) of the cannon	5	Image proccessing
	Calculating the weight of the cannon in water	5	GUI
	Determining if the ROV has enough thrust to lift the cannon	5	N/A
	Returning the cannon to the surface, side of the pool	20	Cannon gripper
	Identifying and marking the location of metal cannon shells/non-metal debris	20	Inductive sensor + markers dispencer
	Total	**90**	

Figure 18, System requirements used in defining the WBS.

In addition to Trello, all technical and non-technical files and documents were organised, stored and shared in the cloud using Google Team Drive. Software files were maintained on GitHub. This ensured that all the team members effortlessly access all files.

Figure 19, Weekly team meeting.

4.2 Organisation

This year Avalon expanded to include 17 members, the team was then divided into four sub-teams, mechanical, electrical software and non-technical, people were allocated their position based on expertise and interest. The mechanical and electrical teams were assigned their own sub team leaders due to the amount of work done by these sub-teams this organisational level was added. Each technical employ was assigned with a specific section of the ROV being his/her responsibility during the whole year.

5 Challenges

5.1 Technical

In previous years there have been problems integrating the control box in a neat, coherent, easily accessible manner, free from tangling wires, and poor interconnects. This year, the challenge was taken to create an easily changeable, modular, clutter-free design that would facilitate the maintenance, upgradability and future design process.

Tight collaboration between the electrical team members, each tasked with their own printed circuit board to design, populate and test, resulted in a robust, fully functional three-part system, with Power, Control and Interconnect PCBs being able to be swapped quickly and easily via PCI-E slots and edge connectors for maintenance purposes or for different tasks, such as those that may be encountered in a future competition.

5.2 Non-technical

One of the non-technical challenges face by Avalon was tasks not being delivered on time. This was caused by multiple factors but mainly a lack of clarity, caused confusion in the employee leading to delays in completing it. This was overcome by using SMART - criteria when defining a task with the employ being involved in the task definition to avoid any possible confusion. This strategy has led to improved task turnaround time and quality.

6 Budget and Costing

At the beginning of this year's development cycle, the previous year's budget were analysed and the suppliers that Avalon used the most were identified and contacted for sponsorship in an attempt to decrease spending. Following this, a budget was set to include the expected new components, tools and travel expenses. Moreover, a safety factor was applied to items with high uncertainty.

Income (at the start of the project)				
Source				**Amount**
Faculty of Engineering				$ 4,940.00
Expenses				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
Electronics	Purchased	Electronic components, PCB manufacturing and Tools	$ 1,480.00	$ 1,480.00
Thrusters	Re-used	6x Blue Robotics T100 Thrusters	$ 970.00	$ -
Workshop Tools	Re-used	Pliers set, wrench set, screw driver set	$ 80.00	$ -
	Purchased	Vaccum pump	$ 170.00	$ 365.00
Materials and Machining	Purchased	Plastic Sheets, CNC machining and laser cutting	$ 500.00	$ 500.00
Consumables	Purchased	Adhesives, solder, electric tape, bolts and nuts	$ 200.00	$ 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	Cameras, Prop materials and miscallenious items	$ 300.00	$ 300.00
Mechanical	Re-used	Electronics housing	$ 440.00	$ -
	Purchased	Epoxy, Cabel glands and O-rings	$ 300.00	$ 100.00
Travel	Purchased	Flight tickets and accomodation in Tennessee for 13	$ 13,208.00	$ 15,600.00
			Total Income	$ 4,940.00
			Total Expenses	$ 19,428.00
Note: These figures assume a conversion rate of 1 GBP = 1.27 USD			**Total Expenses - Re-use**	$ 17,938.00
			Total Fundraising Needed	$ (12,998.00)

Figure 16, Avalon's 2019 budget.

7 Conclusion

7.1 Future Improvements

More testing was Avalon's future improvement from last year. Avalon worked on this and made more testing. However, testing takes up lots of time and resources. Avalon needs to work on developing faster testing methods to increase productivity. For example use simulations to verify designs before manufacturing them, which should save time and money.

7.2 Lessons learned

Failing fast was the way Avalon went about doing technical and non-technical work, things do break and fail while in development, so we might as well do this fast and try as many methods as possible to reach our goal quickly; if there is doubt about whether a technique is the correct one, answering the question the fastest (try all possibilities) proves the most effective. This was the philosophy followed in the workflow and it proved its worth.

The benefits of having an organised and well laid out control box, made finding problems and debugging them easier which lead to shorter maintenance time. From that we understood the important of organisation and the impact it can have on the quality of the work produced.

7.3 Reflections

"That was an amazing year! I learned so many things and I met many new people who share similar passions and interests with me... Wonderful people, endless ideas, countless opportunities and one common goal: to put Sheffield in the map of underwater robotics. The journey to the MATE ROV 2019 has been amazing and very transforming... I've learned through experience that teamwork makes the dream work and, that every single member of the team has something special to offer. That's what makes our team unique! I'm proud to have been a member of this wonderful team." Dimitris Boufidis (CMO)

"Being part of Avalon has increased my affinity to socialise, it has also aided me on my path to knowledge. It has helped drive home some of the core concepts taught in my degree and has earned me the chance to challenge myself regularly by learning new things." Hutheyfa El-Hames (Electrical)

"Over the last year I've helped to form and develop a sub-team of 5 engineers to create an innovative, unique and useful electronic system design. There were periods where nothing worked as intended, but persevering (sometimes late into the night) resulted in solutions being found and, as time was made available, better solutions were found. Seeing a design go from the planning stage to the development stage, to a completed product is the most rewarding part of a large project, with the possible exception of helping other engineers develop. An amazing experience!" Henry O'Keeffe (Electrical sub-team lead)

8 Acknowledgement

Avalon would like to thank the following individuals and organisations for their continues support of the project:

- MATE Center – For organising the competition
- Dr Viktor Fedun – His time, support and guidance for the team
- Ryan G Jones – His help with the setting up the Lab
- The Faculty of Engineering – Donation of cash
- Automatic Control and Systems Engineering Department - Donation of cash
- Computer Science Department - Donation of cash
- EEE Department - Donation of cash
- Mechanical Department - Donation of cash
- Interdisciplinary Engineering - Donation of cash
- RS – Donation of components
- MacArtney Connectors – Donation of components
- Hathersage Swimming Pool - For offering their facility for testing

9 References

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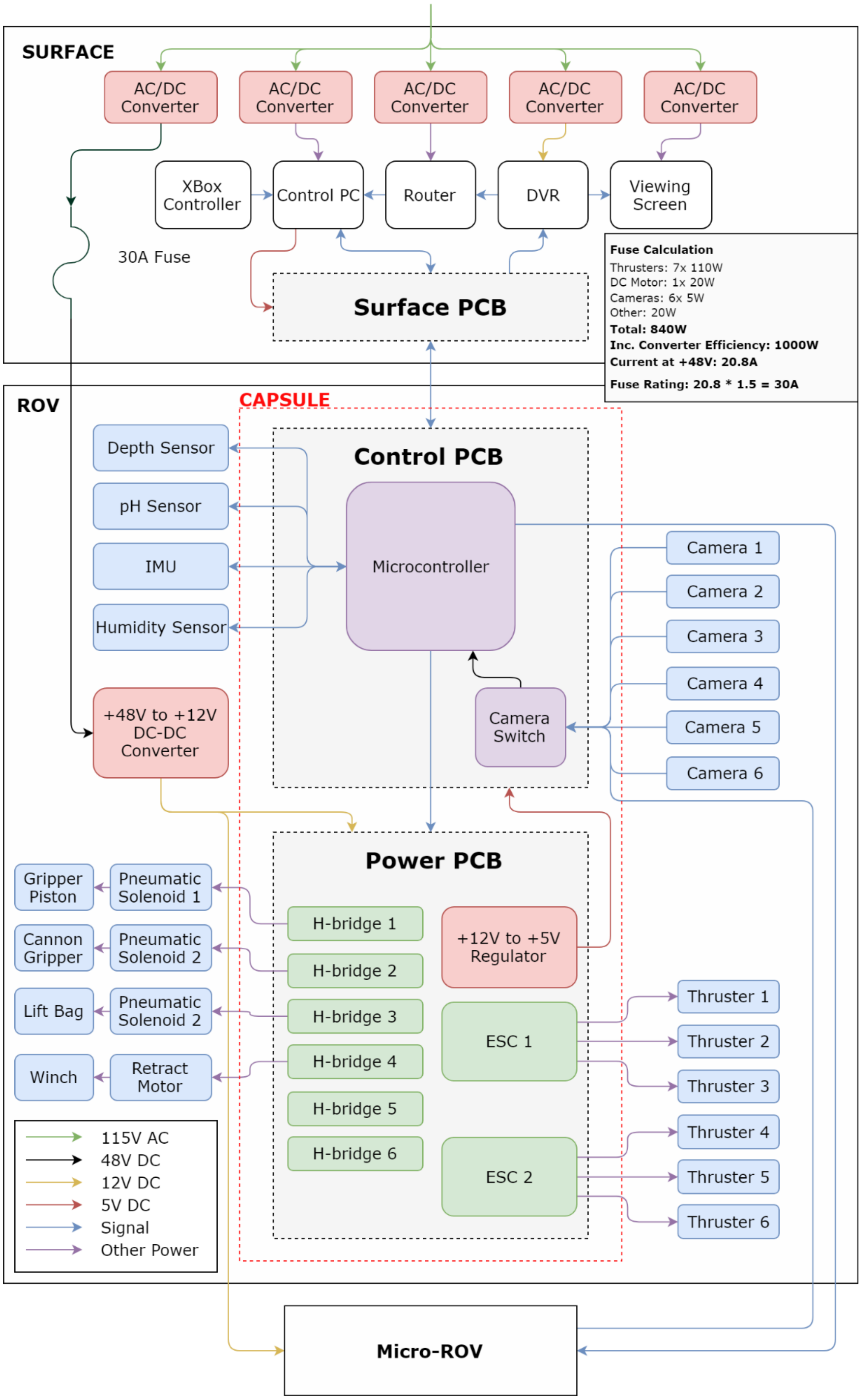
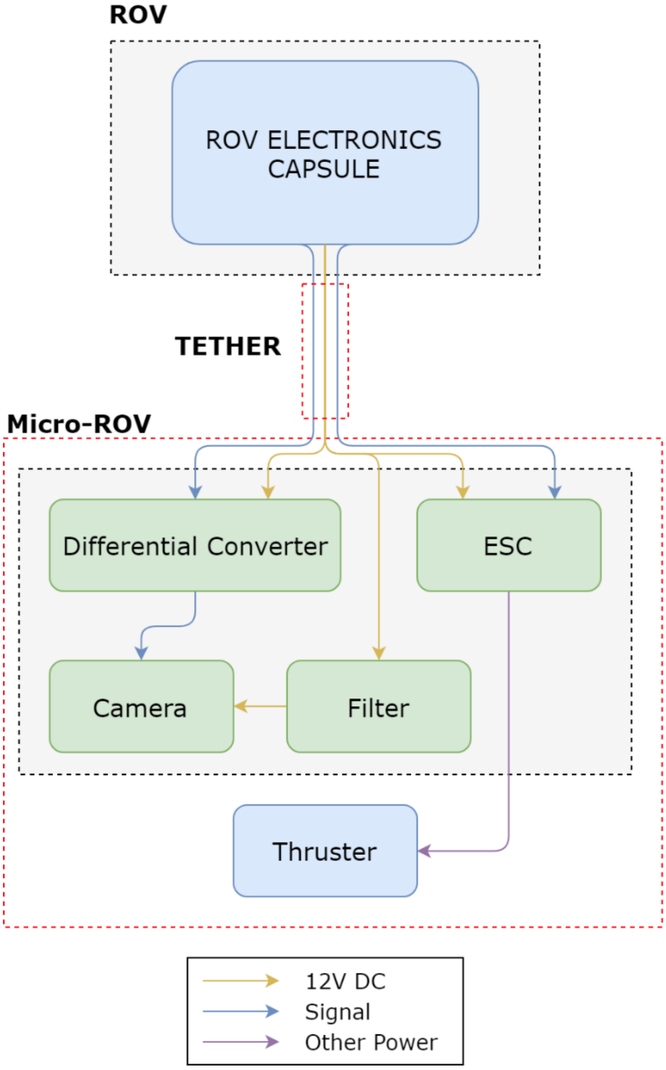
Appendix A: System Integration Diagrams (SIDs)

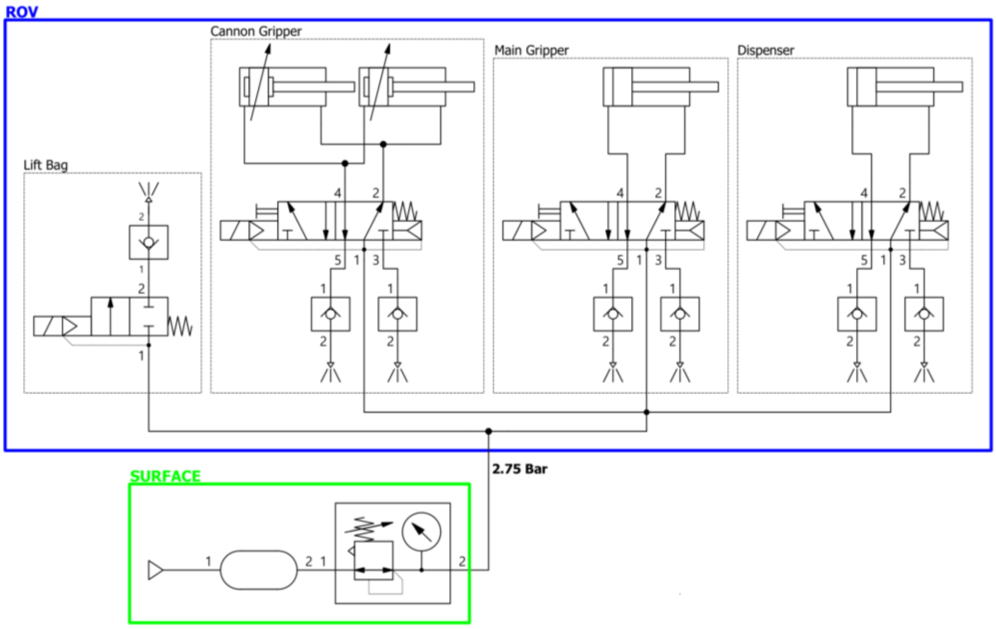
Electrical System



Micro_ROV SID



Pneumatic diagram



Appendix B: Project Costing

Category	Item and Description/Examples	Type	Amount	Paid/Recived
Income	Faculty of Engineering	Cash donated	$ 4,940.00	$ 4,940.00
	Interdisciplinary Engineering	Cash donated	$ 508.00	$ 508.00
	Automatic Control and Systems Engineering	Cash donated	$ 1,524.00	$ 1,524.00
	EEE Department	Cash donated	$ 1,555.75	$ 1,555.75
	Mechanical Department	Cash donated	$ 635.00	$ 635.00
	Computer Science Department	Cash donated	$ 3,100.50	$ 3,100.50
		Total Income	**$ 12,263.25**	**$ 12,263.25**
General Expenses	Storage Units	Re-used	$ 228.53	$ -
	Prop Building Materials	Purchased	$ 104.38	$ (104.38)
	Workshop Tools	Re-used	$ 202.50	$ -
	Joystick	Purchased	$ 63.20	$ (63.20)
		Total General Expenses	**$ 598.61**	**$ (167.58)**
Electrical Expenses	Tools (crimping tool, multimeter)	Re-used	$ 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)	Re-used	$ 73.83	$ -
	Actuators (motors and solenoids)	Donated	$ 313.00	$ -
	Vision system (cameras, analogue video grabber and video switch)	Purchased	$ 63.92	$ (63.92)
	Consumables (Flux and solder)	Donated	$ 60.00	$ -
	PCB Manfacturing	Purchased	$ 240.00	$ (240.00)
	DC-DC converters	Donated	$ 130.00	$ -
	48V Power Supply	Re-used	$ 441.81	$ -
		Total Electrical Expenses	**$ 3,869.80**	**$ (303.92)**
Mechanical Expenses	Raw materials (acrylic sheets and 3D printing filmant)	Donated	$ 270.00	$ -
	Pnumatics (fittings, valves and acutators)	Donated	$ 382.33	$ -
	Vaccum pump	Purchased	$ 171.45	$ (171.45)
	Air Compressor	Re-used	$ 97.19	$ (97.19)
	T100 thrusters	Re-used	$ 970.00	$ -
	Chassis (inc. materials and machining)	Purchased	$ 125.00	$ (125.00)
	Electronics Housing	Re-used	$ 277.00	$ -
	Consumables (epoxy, foam, nuts and bolts)	Purchased	$ 223.00	$ (223.00)
	Cable Glands	Purchased	$ 142.00	$ (142.00)
		Total Mechanical Expenses	**$ 2,657.97**	**$ (758.64)**
	Banners	Purchased	$ 100.00	$ (100.00)
	Team Apparel	Purchased	$ 317.50	$ (317.50)
	Marketing display	Purchased	$ 67.50	$ (67.50)
		Totoal Marketing Expenses	**$ 485.00**	**$ (485.00)**
Travel Expenses	Flights	Purchased	$ 7,020.00	$ (7,020.00)
	Hotels	Purchased	$ 2,025.00	$ (2,025.00)
	Transportation	Purchased	$ 913.00	$ (913.00)
		Total Travel Expenses	**$ 9,958.00**	**$ (9,958.00)**
		Total Income		$ 12,263.25
		Total Amount of Expenses		$ 17,569.38
Note: These figures assume a conversion rate of 1 GBP = 1.27 USD		**Amount - Donated/Re-used**		$ 11,188.14
		Net balance		$ 1,075.11