The University Of Sheffield.

Technical Report

Avalon Underwater Robotics - Sheffield, United Kingdom

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AVALON

- Underwater Robotics -

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1. Design Rationale

1.1. Mechanical System

1.1.1. Overview

The mechanical system was designed around previous iterations of the ROV. The limitations of the previous design were analysed and changes were made to overcome these limitations. The main areas of focus for the mechanical system were:

- Design and manufacture suitable and user-friendly manipulators and subsystems to perform thenmissions with minimum pilot effort.
- Effective sealing of all ROV components to ensure the ROV can operate reliably.
- Perform extensive testing to assess design effectiveness.

1.1.2. Chassis Design

The chassis is designed to be light, versatile and rigid as well as provide a clear flow path through the thrusters.THhe chassis consists of delrin side panels connected by three aluminium cross brackets. Four delrin 'wings' are connected to each side panel at 45 degrees with aluminium brackets to provide a compact and accessible mounting location for the 8 thrusters. The bottom 'wings' are also connected by an aluminium cross brace to provide additional rigidity as well as mounting point for peripherals. One of the delrin sides features the housing for the mini-ROV to be used in task 3.1. The entire chassis is assembled using stainless steel M3 nuts and bolts for simplicity.

- Versatility: the aluminum cross braces are full of holes, allowing a multitude of peripherals such as grippers and cameras to be fitted to the most appropriate position for a given use case. The delrin side plates also feature cable routing holes, allowing any cables/ pipes to the peripheral and thrusters can be neatly routed, minimising the chance of the ROV becoming entangled as well as ensuring a professional aesthetic.
- Flow optimisation: previous iterations of the ROV have had difficulty ensuring a good, predictable flow through the thrusters as they were mounted inside the chassis. This new design mounts the thrusters on the outside of the chassis, allowing an uninterrupted flow through the thrusters, maximising speed and maneuverability of the ROV.
- Rigidity: The combination of delrin side panels bolted to aluminium cross braces allows a rigid and light construction,as well as being easy to assemble and disassemble, allowing easy maintenance and mounting of other components within the chassis.
- Weight: excess material was removed from the delrin side panels to minimise weight and allow a better flow of water through the chassis. Aluminium was used for the cross braces rather than the stainless steel alternativeto minimise the weight, while still being corrosion resistant.

Figure **1**

1.1.3. Propulsion

The ROV is propelled using eight T2000 brushless thrusters 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, four 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 2 demonstrates the configuration of the thrusters and the degrees of freedom.

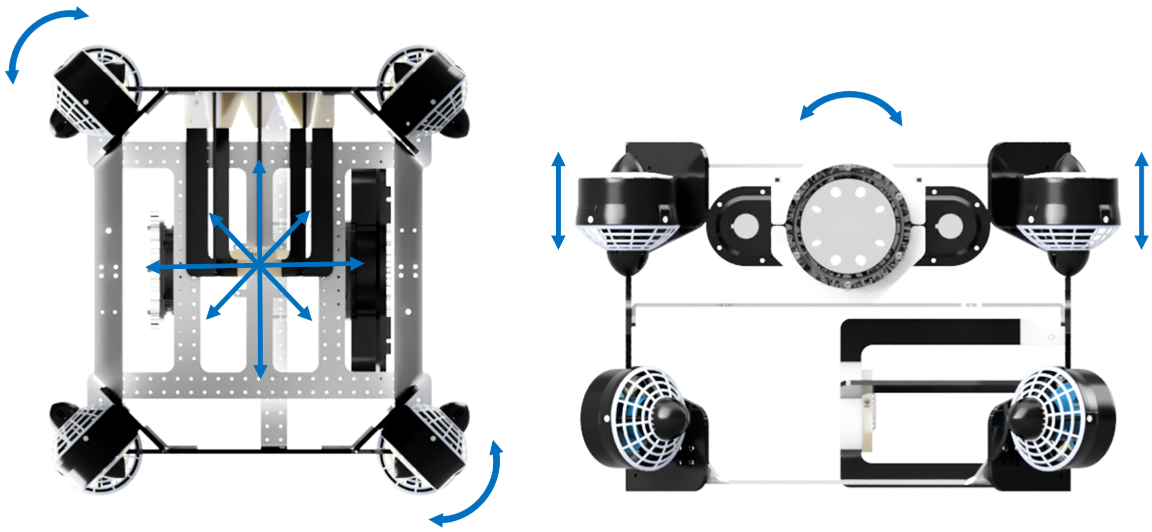


Figure **2**

1.1.4. 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 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.

1.1.5. 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, but this is limited to 30A by the fuse. The pneumatic tube carries 2.75 bar of air pressure for use by the pneumatic actuators. Webbing surrounds the whole tether protecting the various cables and tubes. The webbing also helps to prevent tangling.

The tether is strain relieved at the ROV using a traction finger trap. This ensures any force applied to the ROV through the tether is transported through appropriate components, rather than the cables.

1.2. Electrical System

1.2.1. Control Capsule Design

The electronics is isolated from the water using an underwater capsule, designed by Blue Robotics, that contains a 200mm long clear acrylic tube (4" series), with anodised aluminium end caps at each end, shown in **Figure 3**. A water-tight seal is achieved with rubber O-rings on the end caps. Underwater connectors. manufactured by MacArtney and Bulgin. are secured to the capsule via acrylic mounting plates bolted onto the end caps. Custom 3D-printed capsule clamps secure the capsule to the ROV chassis, and a capsule extension was designed to mount more connectors than we previously could in past competitions.

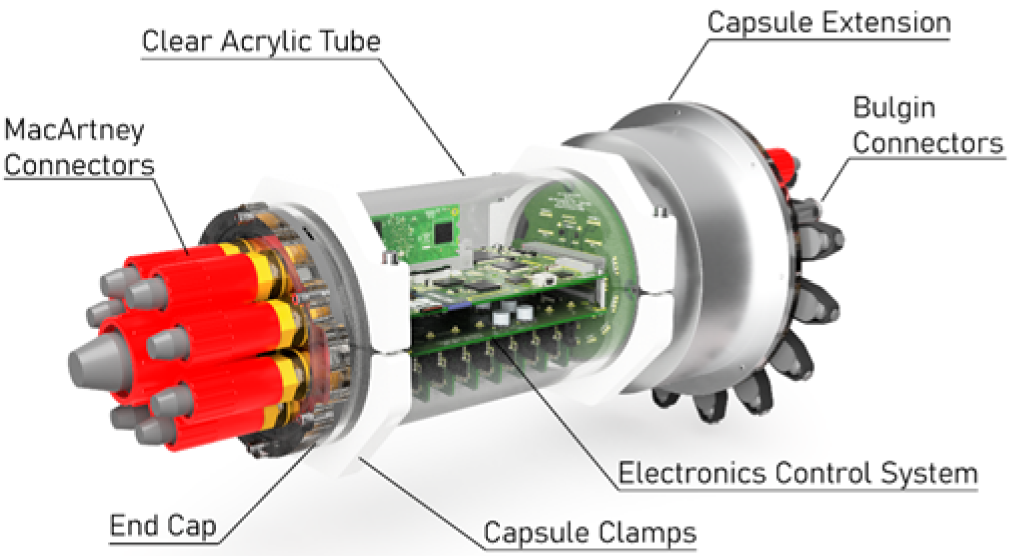


Figure **3**: Underwater capsule that contains electronics control system.

The physical structure of the electronics had to be designed to fit inside the control capsule. Special care was taken when designing the shape of each PCB in CAD, taking the tolerance of the capsule's length into consideration to guarantee a reliable connection between the board-board connectors. The system takes the form of a modular, interconnected stack of printed circuit boards (PCB), shown in **Figure 3**. This design was chosen for a few reasons. Firstly, it allowed us to design the system as a team, with each member being responsible for the design and development of one of the boards. Secondly, it introduced a form of modularity and redundancy into the system, where if a board was to fail, only that single board would be replaced, as opposed to replacing the entire system.

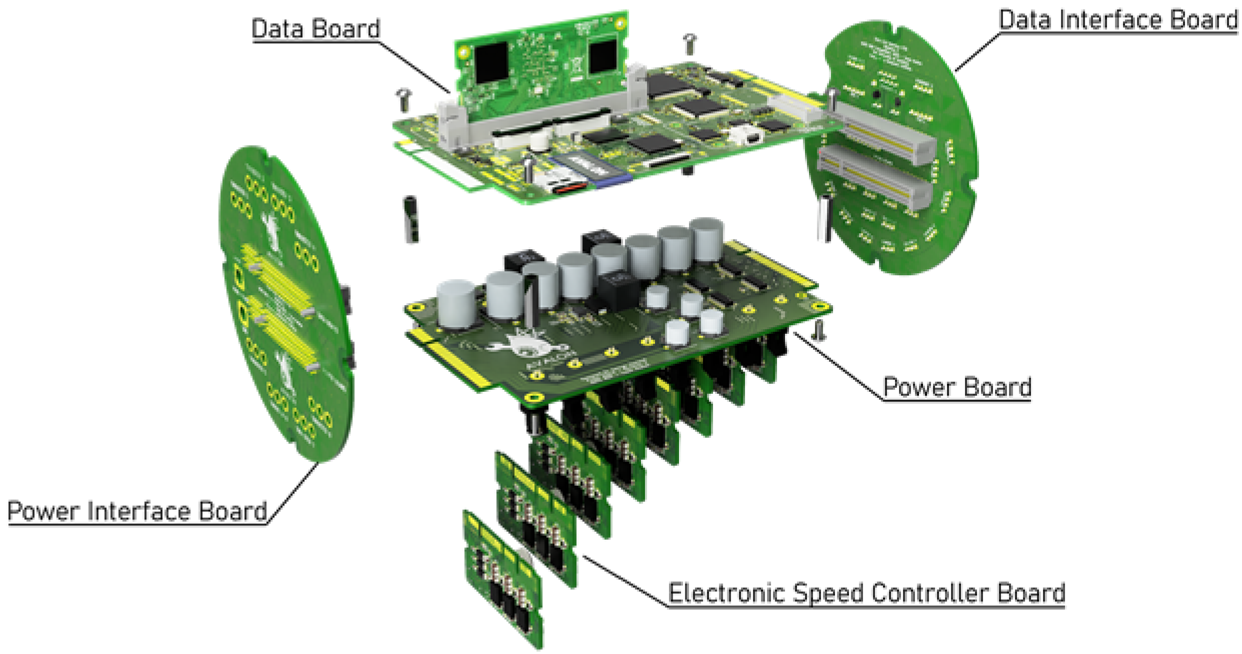


Figure **4**: Exploded view of the electronics control system.

1.2.2. PCB Design

Data PCB:

The data PCB uses an ATSAM3X8EA microcontroller which handles all processing done on the ROV. It controls actuators via H-Bridge ICs found on the Power Board, sets the camera selection via a video matrix switch, controls the thrusters using an RS-485 half duplex protocol sent to the ESCs and receives data from pressure and temperature sensors, sending it back up the tether using the RS-488 full duplex serial protocol.

Out of the 10 analog composite cameras available to the data board, two can be selected and sent differentially up the tether on two twisted pairs.

Power PCB:

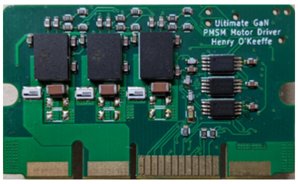
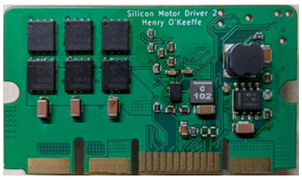
The Power PCB provides the backplane on which the ESCs connect, and also has a pair of 48 V to 12 V DC/DC converters one to power the cameras, and the other to power the actuator solenoids via the H-Bridges, VNH7070s which are also on the Power PCB.

End PCBs:

The End PCBs have the simple job of connecting the data and power PCBs to each other and to ROV components external to the control capsule. They only have connectors on them, and no other components.

1.2.3. ESCs

Several types of electronic speed controller (ESC) have been designed on modular daughter boards. Each is swappable with the others and several types are able to be used concurrently. The differences between each are below.

<table>
<tr>
<td>GaN MOSFET Motor Driver (primary)
</td>
<td>Silicon MOSFET Motor Driver (primary)
</td>
<td>Commercial ESC Motor Driver (backup)
</td>
<td>Motor Driver with Integrated Driver and Controller (backup)
</td>
</tr>
<tr>
<td colspan="4">● Powered only from the 48 V rail, with optional 5 V input for backup.
● Control via RS-485 (multiple units on one bus), analog speed input, I2C or UART
● Form factor of 54.6 x 32 mm with an edge connector for all inputs/outputs
● Maximum of 4-layers, 35 µm thick copper PCB
● Four power-level indication LEDs</td>
</tr>
<tr>
<td colspan="2">● A dsPIC33CH512MP505 dual-core 16-bit microcontroller for control
● Three INA240 Current sense amplifiers for current feedback
● Permanent Magnet Synchronous Machine Field Oriented Control System (PMSM FOC)</td>
<td colspan="2">● An ATMega4809 to interface with either the Commercial ESC or integrated driver
● 48 to 12 V DC/DC converter to supply either the Commercial ESC or integrated driver.</td>
</tr>
<tr>
<td>● Three LMG5200 Gallium Nitride Half-Bridge Modules for the output stage
● Capable of driving one thruster at 40 W</td>
<td>● Three LM25101 MOSFET Gate Driver ICs
● Three different types (for comparison) of 6 SO-8 packaged MOSFETs for the output stage
● Capable of driving one thruster at 80 W</td>
<td>● Footprint for a 20 A Off-the-shelf Electronic Speed Controller
● Capable of driving one thruster at 35 W</td>
<td>● A Texas Instruments DRV10987 2 A integrated motor driver and controller
● Capable of driving one thruster at 20 W</td>
</tr>
</table>

1.3. Surface Control Station

1.3.1. Software

A powerful GUI was developed to control all ROV functions. The program is capable of displaying live camera feeds, connecting to external joysticks, communicating with the ROV and displaying telemetry on graphs.

The GUI is highly configurable, which allows the program to be set up for different ROV designs/configurations without needing to modify the source code. For example, the buttons on the controller can be mapped to different functions, such as toggling an actuator, changing the sensitivity of the joysticks, or cycling the active camera feeds. Multiple pilot profiles can be created and saved, allowing each pilot to adjust the controls however they prefer.

The GUI was developed in Python using the PyQt5 application frameworks. Serial communications were implemented by developing a custom module using the PySerial library, which is able to communicate with the ROV via the tether to set actuators states, thrusters speeds, receive sensor readings, set active camera feeds etc. OpenCV was used to display the camera feeds and allow the use of image processing for certain tasks.

The GUI is split up into two key sections, the *control panel*, and the *configuration panel.*

The *control panel* contains all widgets required to control and manoeuvre the ROV as well as displaying the live camera feeds and telemetry data. The *configuration panel* on the other hand, contains all widgets required to configure and customise the program.

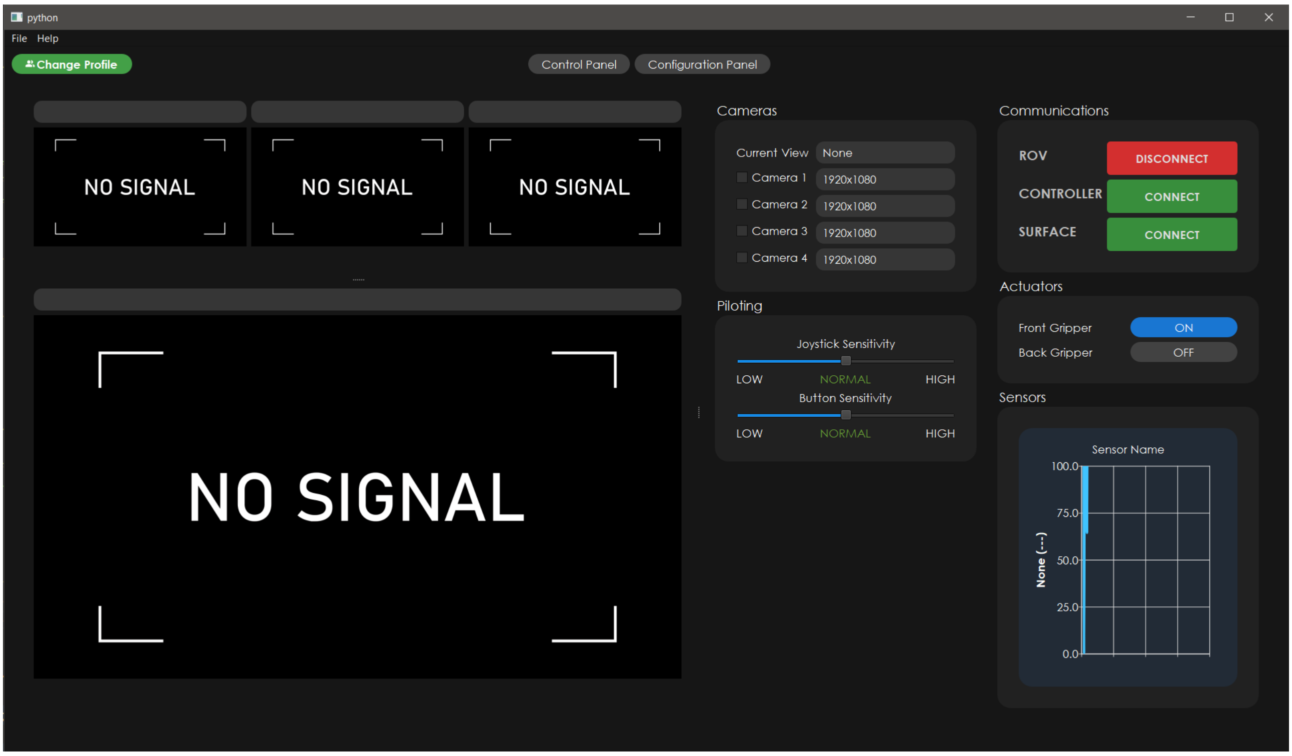


Figure 5: GUI Piloting Screen

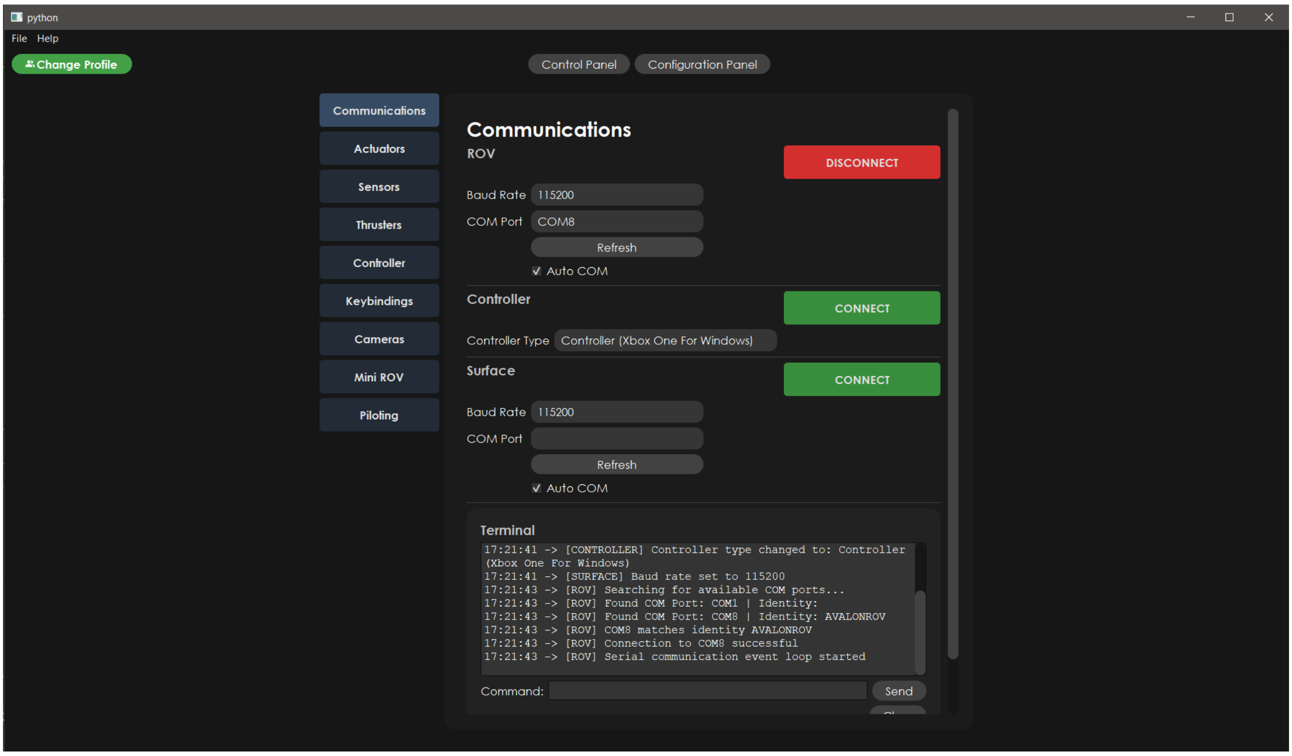


Figure 6: GUI Settings Screen

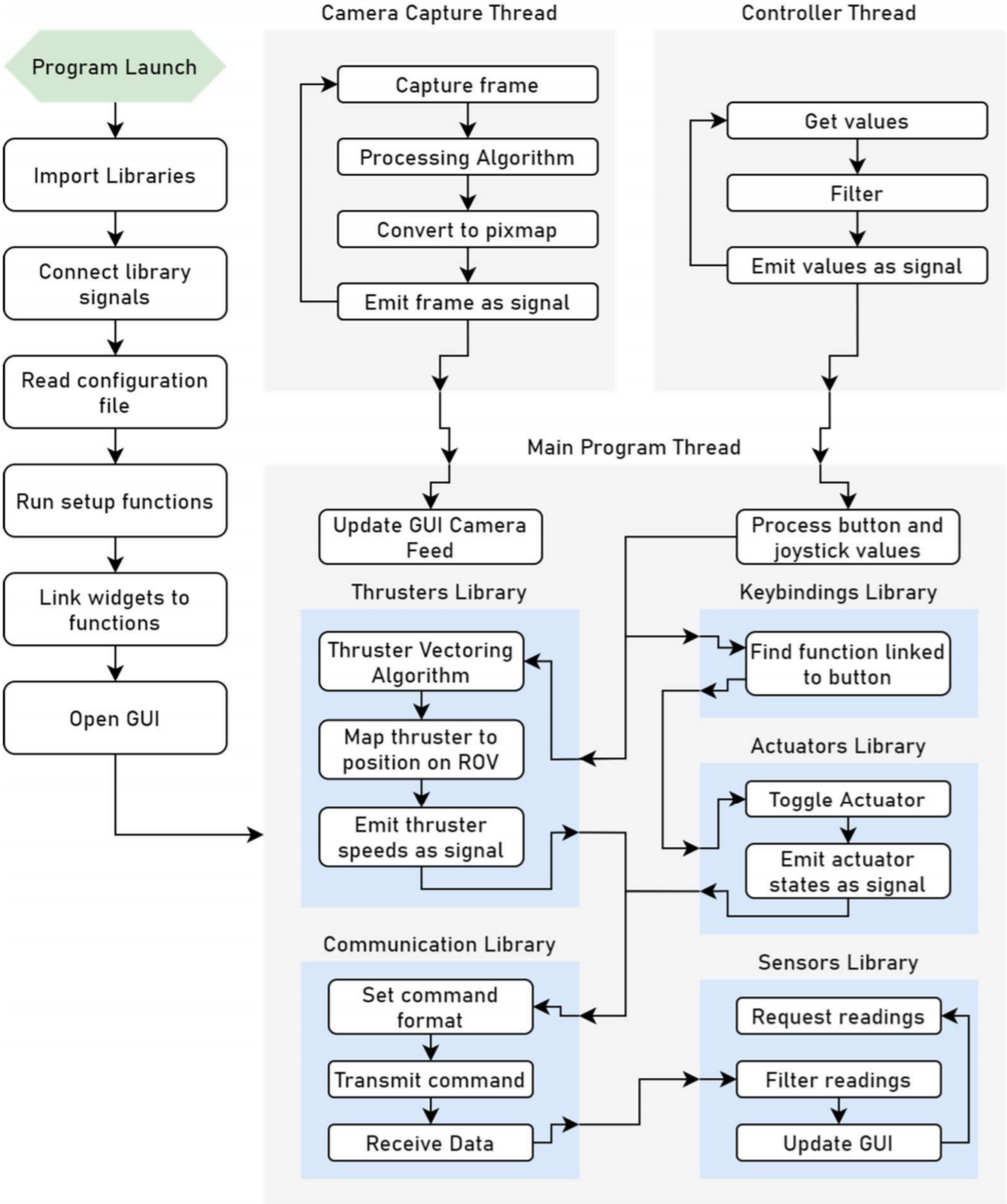


Figure 7: GUI Block Diagram

1.3.2. Design

The surface control station was developed as an all-in-one, plug and play solution to piloting the ROV on location. It contains a custom computer to run the program on, a monitor to view the GUI, and a monitor to view the analogue camera feeds via a DVR. Panel mounted connectors are used to attach the ROVs, and an IEC socket to power the computer. A Bluetooth keyboard and an array of reconfigurable buttons, each with an LCD screen can be connected to the control program and bound to ROV functions. Under the surface panels, the custom computer, an internet router, the surface PCB and necessary power supplies are mounted. Everything is secured inside a heavy-duty waterproof equipment case, making the surface station easily transportable to testing locations and the competition.

Figure **8**: Surface control station CAD render.

1.4. Mission Tool Design

1.4.1. Grippers

The first thing I considered was the sizes of objects the gripper would have to pick up, to calculate an appropriate size for the jaws. The largest cylinder to be picked up would be 50mm in diameter and the smallest would be 12.5mm. I also knew which pneumatic actuator I would be using – a Festo ADN-32-80-I-P-A – so I knew how far apart I could feasibly have the pivot points of the two jaws. With the jaws fully open, they have an opening of 68.6mm. This larger opening would make getting the jaws in place around a prop easier. When fully closed the opening is 10.5mm. The jaws are made of many layers of laser cut acrylic, of 4 different shapes which allow the jaws to overlap each other. Acrylic is light, and when layered together strong enough to withstand the forces applied by the piston. The bracket which attaches the jaws to the piston is made of a single piece of aluminium, cut with a water jet cutter, and bent into shape manually. The final part was a bespoke aluminium pin which connects to the piston and controls the movement of the jaws by sliding along paths cut in the layers of acrylic. It was made using a CNC router. Rubber strips were glued onto the jaws to provide much more grip, as underwater the props often slipped through the acrylic alone.

2. Team Organization

For this year Avalon consists of 9 team members, split into 3 engineering teams. The electrical team is responsible for the PCB design and build. A mechanical team concentrates on the chassis design and build, in addition to building any props which are required for the competition. Finally, the software team develops the GUI for piloting the ROV and microcontroller code for running on the custom PCBs.

Due to COVID restrictions, in-person team meetings have not been possible. Instead, online meetings were conducted using Google Meet. There were 2 full team meetings a week, with an initial team briefing and updates, followed by a breakout session for the individual sub-teams. In addition, the sub-teams had one dedicated meeting a week, resulting in 3 meetings a week for team members. Team members individually, or in pairs, made use of university workshops to complete practical work were required.

Trello was used to assign tasks to team members and keep track of tasks as they were completed.

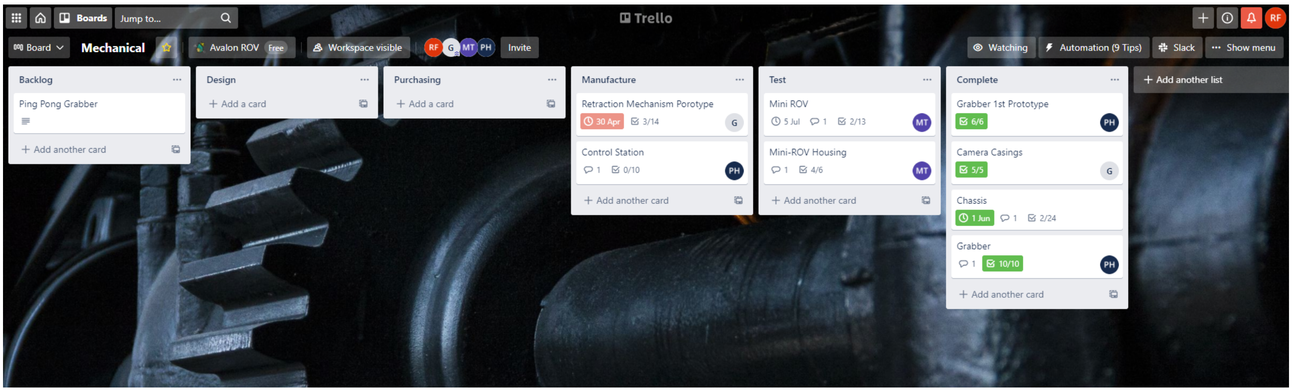


Figure **9**: Mechanical team trello board.

3. Budget and Costing

Income (at the start of the project)				
Source				**Amount**
Faculty of Engineering				$3,450.00
Sonardyne				$6,900.00
Expenses				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
Electronics	Purchased	Electronic components, PCB manufacturing and Tools	$ 2,000.00	$ 2,000.00
Thrusters	Re-used	9x Blue Robotics T200 Thrusters	$ 1,449.90	$ -
Workshop Tools	Re-used	Pliers set, wrench set, screw driver set	$ 80.00	$ -
	Re-used	Vaccum pump	$ 170.00	$ -
Materials and Machining	Purchased	Plastic Sheets, CNC machining and laser cutting	$ 200.00	$ 200.00
Consumables	Purchased	Adhesives, solder, electric tape, bolts and nuts	$ 200.00	$ 263.00
Storage Units	Re-used	Toolbox, ROV storage box and plastic storage units	$ 270.00	$ -
Pneumatics	Re-used	Air compressor and pneumatic actuators	$ 1,510.00	$ -
General	Purchased	Cameras, Prop materials and miscallenious items	$ 300.00	$ 300.00
Mechanical	Re-used	Electronics housing	$ 440.00	$ -
	Donated	Waterproof Connectors	$ 4,557.38	$ -
	Purchased	Epoxy, O-rings, Fasteners	$ 300.00	$ 300.00
Travel	Purchased	Fuel for transport to test pool	$ 82.80	$ 100.00
			Total Income	$ 10,350.00
			Total Expenses	$ 11,560.08
Note: These figures assume a conversion rate of 1 GBP = 1.38 USD			**Total Expenses - Re-use**	$ 3,163.00
			Total Fundraising Needed	$ (7,187.00)

As a result of limited available manufacturing time, it was decided to reuse previous designs and components where possible. The electronics capsule on the ROV required further improvement and purchasing new PCBs and components for this was Avalons largest expense for the year.
In addition, travel costs were drastically reduced, from competing from the UK via telepresence, rather than flying to the USA.
These factors, combined with generous donations of components from companies meant Avalon did not have to raise any cash this year, which is very fortunate.

4. Acknowledgements

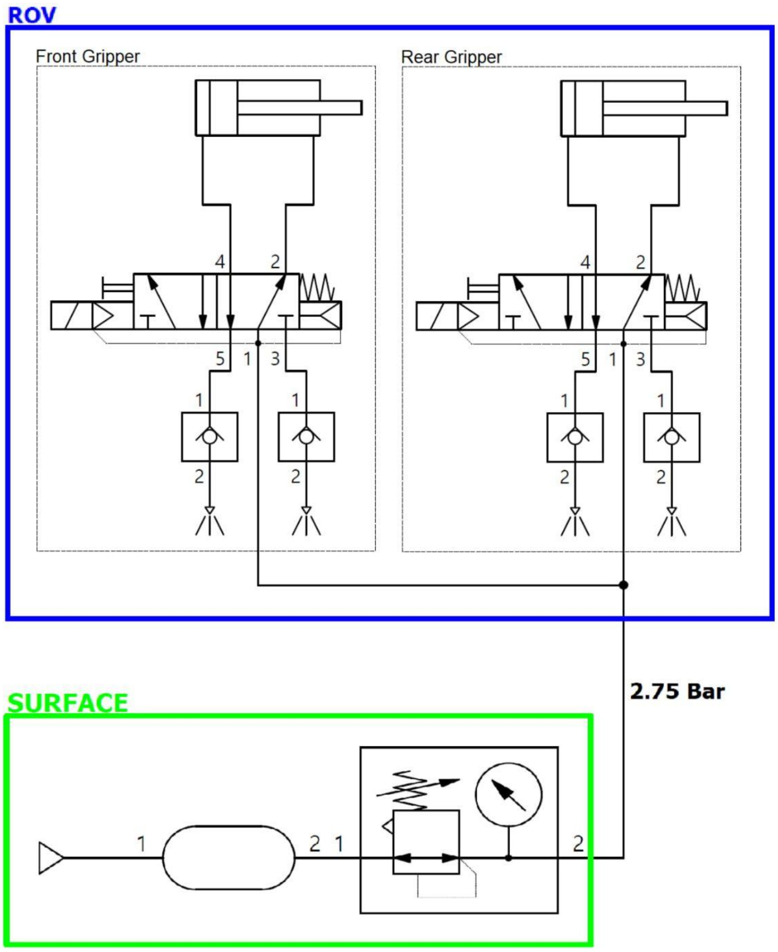
Avalon would like to thank the following individuals and organisations for their continued support of the project:

- MATE Center – For organising the competition
- Dr Viktor Fedun – His time, support and guidance for the team
- The Faculty of Engineering – Donation of cash
- Sonardyne - Donation of cash
- Photocentric – Donation of resin 3D printed components
- MacArtney Connectors – Donation of components
- John Drakeford - For offering pool facilities for testing

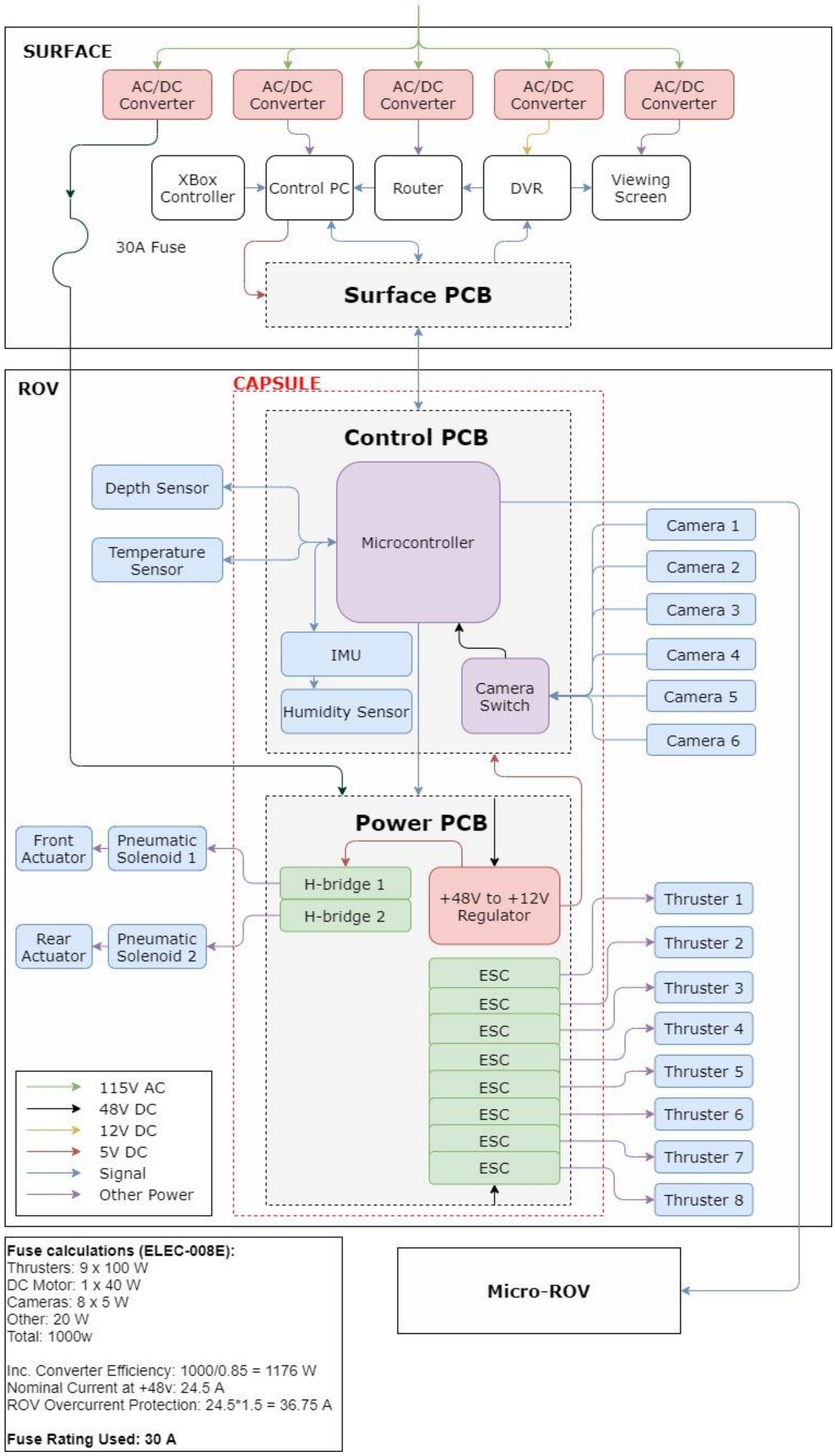
![AVALON logo]

5. Appendix - SIDs

5.1. ROV Fluid SID



5.2. ROV Electrical SID



5.3. Mini ROV Electrical SID