



The  
University  
Of  
Sheffield.

# 4<sup>th</sup> Year Project Interim Report

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## Group 1

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### Design and Manufacture of Electrical and Control Systems for an Underwater ROV

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Joseph Orford

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**Word Count:**

## 1. Project Aims and Objectives - Review (BG)

As discussed in the initial project initialisation report, the overall objective of this project is to design, manufacture and test an electronics and software control system for an underwater remotely operated vehicle (ROV). The control system must be capable of controlling the various electromechanical and sensory devices on the ROV, such as thrusters, pneumatic actuators, cameras and sensors.

Figure 1 shows the projects current status based on the aims presented in the initialisation report.

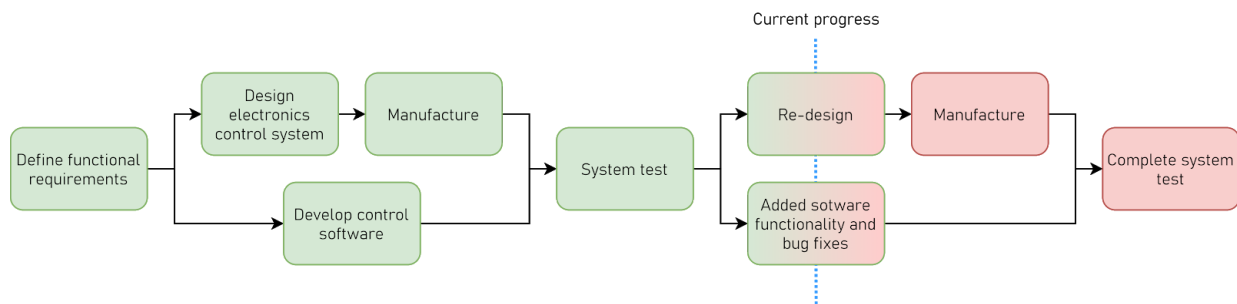


Figure 1: Project progress.

The functional requirements and technical specification have not changed significantly since the start of the project, hence the progress so far has been as predicted and there is confidence that most or all of the aims will be met or exceeded.

The final specification for each task that the ROV must be able to complete has been released, so the functionality requirement is now known for the electronics system and the control software. This was suitably accounted for in the initial functional requirements, with the electronics design supporting control of more actuators, sensors and cameras than was thought needed. Therefore, no change in the design is required.

The first version of the electronics system PCBs have been designed, sent off for manufacture, populated and tested. The faults and issues with the first version are currently being addressed with the second version designs.

## 2. Project Progression

### 2.1. Benjamin Griffiths

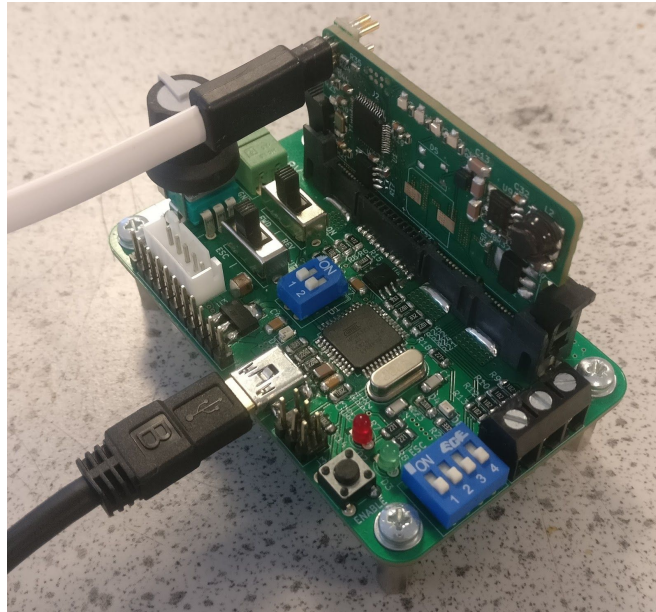
The first revision of the interface PCBs, responsible for interfacing the data and power PCBs to the external underwater connectors, and the ESC unit testing PCB, have been ordered, populated and tested.

The power end PCB, responsible for connecting the thruster and power connections, meets the technical requirements, hence no further revision is needed. The full power end-cap assembly, containing the PCB, underwater connectors and mounting plate is shown in Appendix Figure x.

The data end PCB, responsible for connecting the cameras, thrusters, communication lines and sensors, does not meet the technical requirements, due to not including USB connections for digital

video feeds, and incorrect ethernet routing. This PCB design is currently being revised to meet the requirements.

The ESC unit testing PCB, responsible for testing the ESC modules independently from the rest of the electronics system, has been fully tested and performs all the required functionality. No further design revision is required. The final PCB is shown in [Figure 2](#).



*Figure 2: ESC Breakout Board For ESC Testing*

The software aspect of the project has had excellent progress, both with the embedded C code running on the ROVs microcontroller, as well as the Python pilot control interface program.

The pilot control program, developed in Python and PyQt5 takes the form of a fully customisable, easy to use yet powerful graphical user interface. The following list explains the current key features of the program:

- View and switch between digital camera feeds
- Receive control inputs from an XBOX controller
- Reconfigurable key bindings for ROV controls
- Automatically connects to correct COM port to communicate with ROV
- Request and display sensors readings from the ROV at 100Hz refresh rate
- Toggle the ROV actuators
- Independently control speed of each ROV thruster
- Allow direction of each thruster and its position on the ROV to be specified
- Launch the various machine vision tasks
- Change controller sensitivity to perform precise movements
- Change ROV control orientation to drive in reverse

The program in its current state is able to control most of the required functionality to control the ROV at the competition, and can be easily configured to adapt to future ROV designs.

The thrusters on the ROV are arranged so that each thruster is offset by  $45^\circ$  to the X, Y and Z axis, as seen in Figure x. This means that each thruster has a contribution to the ROV thrust in all 3 axes. A

thrust vectoring algorithm has been developed to convert the XBOX controller joystick positions into speed values for all 8 thrusters, allowing control of the ROVs pitch, yaw and roll, as well as up/down, right/left and forward/backward movements. This was achieved by analysing each thruster in turn, to see whether it has a positive or negative contribution to roll or pitch etc. when the thruster is being driven forward. This generates an array with 8 speed values for each thruster. These values are then normalised to the highest speed value and joystick position, so that the values are in the range 1 - 999 to be sent to the ROV via serial communication.

This algorithm has been tested on a small prototype ROV in a water tank and is able to control the ROVs movement and rotation in all 3 axes. However, the ability to precisely control the ROVs position can only properly be tested in a large body of water, so fine tuning of the algorithm may be required in the future.

The C code running on the ROV in the Arduino environment has also progressed, with a simple and reliable serial interface that uses ASCII commands to control the thrusters, actuators, camera signal switches and sensors. The commands start with '?' followed by an alphabetical character (acts like an address) that indicates which aspect of the ROV the command is trying to control, followed by the required data. This makes serial communication with the ROV simple human readable, allowing the ROVs basic functions to be tested via command line without needing to use the GUI program. The commands currently implemented are shown in Appendix Ben.

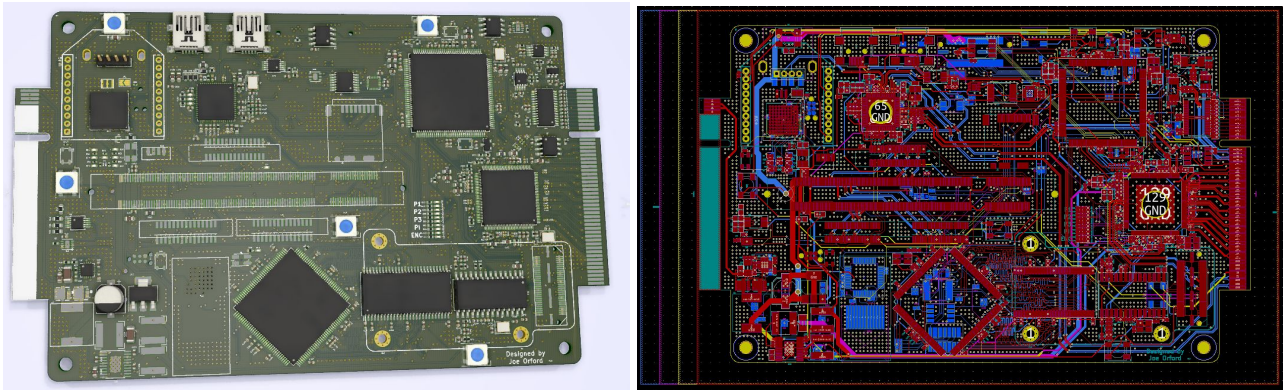
## 2.2. Joseph Orford

This PCB is responsible for the data processing of the project. This includes the main microcontroller and microprocessors for doing the processing of the control system, control signals and camera processing. The board takes 48V from the main supply and regulates it to 5v, 3.3v, 2.5v, 1.8v and 1.2v for all of the systems on board at varying power levels. The board can take USB, ethernet, CSI and analog camera inputs which can be sent up the tether differentially or via the fibre optic connection. The on board microprocessors allow for image processing as well as server hosting for a backup communications system with the surface. This board is responsible for all the communications with the surface and mini-ROV and has multiple differential transceivers.

The board is designed to have multiple redundancy elements, such that if one system was to fail, there is another which can be switched to within seconds. This has been achieved with the implementation of at least two methods of achieving the same sensor reading communication method. This is because the PCB will be in hot, humid conditions which can lead to failures of the PCB. The PCB will be conformally coated to help alleviate this issue, with limited effect as components such as connectors cannot be conformally coated.

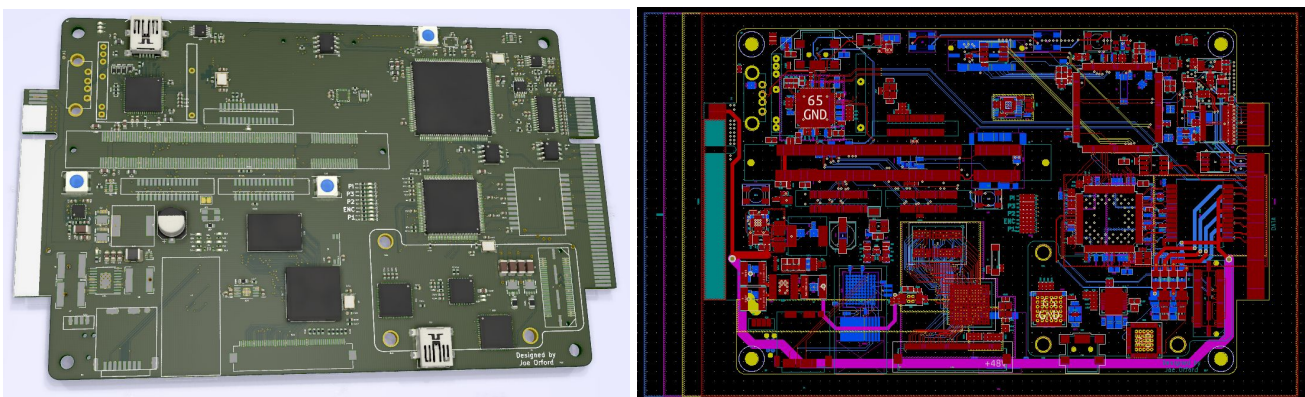
The first revision of the PCB was completed and tested, as shown in figure [JOE1]. There were several errors on this PCB, most notably the interconnections between two Physical Ethernet Layers (PHYs) were incorrect and resulted in multiple modifications for the next revision. Further potential errors were found with the 3v3 power supply unit in that it couldn't supply enough current for sustained usage with all elements being used. Brownouts could occur if all features were active at the same time. The ethernet switch and fibre optics were a success, achieving speeds over 100 Mbps. This is significantly less than the datasheet specification, so work will be done to remove the bottlenecks.

There were other issues with the usage of certain on board communications. In an oversight, it was discovered that the cameras could not be used at the same time as they shared the same control lines, and also the USB hub could not function at the same time as the cameras whilst the Arduino was communicating with it. These issues require a minor rearrangement of components and changes to the pins connected.



*Joe 1 showing the first revision PCB and layout*

Revision 2, shown in figure X, looks to optimise the design and add extra features. The components have been placed and routing has begun. Power over Ethernet (PoE) has been added so that ethernet cameras can be powered conveniently. This has resulted in the addition of ethernet magnetics to isolate each connection. The FPGA has been removed and has been replaced with a microchip Microprocessor Unit (MPU) which is using DDR3 memory and will be designed to run a linux distribution. This module is for redundancy in the event of the Raspberry Pi hanging during operation. This MPU connects to the system via the ethernet switch and via USB.



*Joe 2 showing the latest PCB render and PCB layout*

### 2.3. Henry O'Keeffe

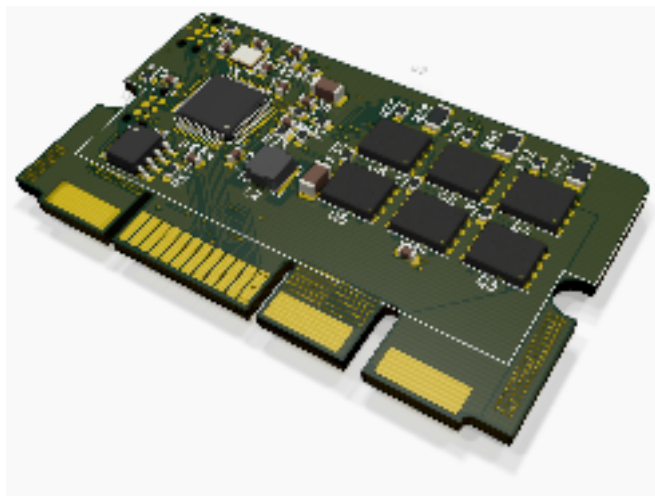
The first revision of the Electronic Speed Controllers have been designed, the PCBs made, and the boards populated. A program has been developed, but not yet tested that will allow motor control with Field Oriented Control (FOC).

Figure HENRY 1 and figure 2 (ben) shows the ESC designed with LMG5200 Gallium Nitride (GaN) MOSFET half-bridge modules. This design has a maximum current of 10 A, and can operate at very high PWM frequencies (>100 kHz) with negligible switching loss. The GaN ESC is equipped with 4 LEDs for debugging and status.



*Henry 1*

Figure HENRY 2 shows the ESC designed with traditional Silicon MOSFETs. This design has a higher maximum current than the GaN device at 20 A, however they cannot achieve as high frequencies, with switching losses becoming significant above 25 kHz. Due to additional I/O required for the more advanced gate driver, the Si ESC features only one microcontroller debugging LED and two driver fault/status LEDs.



*Henry 2*

Both ESCs function are designed to accept 48 V DC nominal, feature on-board DC/DC converters to power the dual-core dsPIC33CH512MP505 microcontroller ( $\mu\text{C}$ ). They both run similar programmes on the cores, one core acting as a master responsible for the communications (RS-485 with I2C, analogue and PWM as backups) with the slave running the FOC algorithm and PLL rotor position estimator, controlling the inputs of the LMG5200 GaN half-bridge modules or DRV8301 gate driver directly.

The basic functionality of the GaN PCB has been proven working, with the exception of the current sense amplifier. Due to the extra complexity of the Si MOSFET driver (the requirement for an SPI setup routine), the Si ESC will require extra programme complexity, so will be tested after the Si ESC programme development is underway.

In addition to the GaN and Si ESCs, a third is being developed to act as a backup. This will house a commercial ESC, adapting the interface from RS-485 on the signal input side to a single pin servo Pulse-Position Modulation with an ATmega4809. This PCB also provides a 48 V to 12 V DC/DC converter, as the commercial ESCs are designed to run at a lower voltage than the 48 V available.

All three ESCs will be produced in quantity after redesign if necessary, and their performance evaluated and compared with each other, however the design of the third ESC is currently stalled, awaiting the footprint of the commercial ESC to be designed which depends on the arrival of the commercial ESCs, expected the week of the 10th of February.

#### 2.4. George Osmond

As discussed in the initial project report, the power board is needed to provide the power for all the external components of the ROV: any components that are outside of the control enclosure such as the thrusters, solenoid valves, cameras and any required actuators in order to complete the tasks set out by the MATE ROV competition specification. The power management must be done on a separate board to the control board due to high-impedance signals on the control board that can easily be interfered with by high current traces running in close proximity. A separate PCB for high currents prevents this. This also allows for the PCBs to fit easily within the enclosure as they can be stacked and interfaced by the end cap boards. Appendix A shows the overall system flowchart for all the components required on the power board.



*Figure George 1: Render of Revision 1 Power PCB*

The first revision (*shown in George 1*) of the power board utilised 2oz thick copper to allow for high current carrying traces that could be made thinner and easier to route. This made soldering small components difficult as the board required a lot of power to melt the solder due to the copper's high thermal capacity. The initial decision behind using 2oz copper was to ensure that each trace for each thruster phase was capable of carrying enough current for all thrusters to be running on full load. This meant the traces must be able to carry roughly 7 A for a sustained period of time, in order for this to be possible the traces needed to be a minimum of 1.6mm wide. This made routing the PCB difficult due to components on the PCB creating narrow paths for the traces to run through.

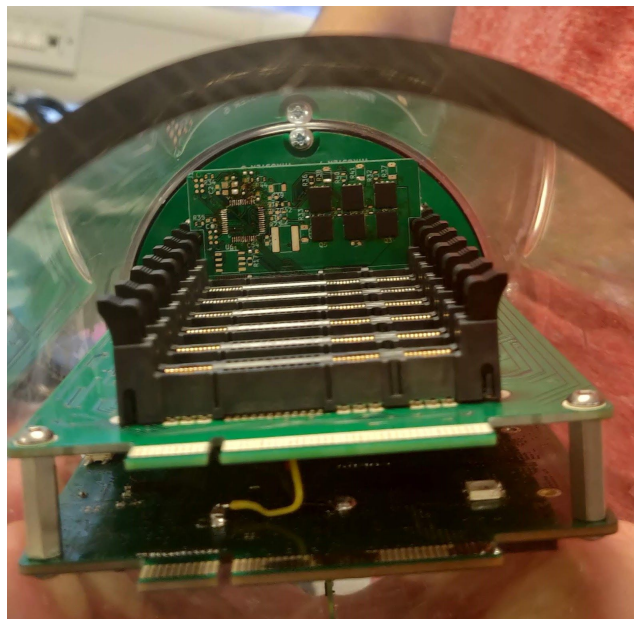
For the 12 V regulator a Texas Instruments L5146-Q1 was used, which is a synchronous buck controller rated to up to 100 V. This was used to provide 12 V at 10 A to the cameras and h-bridges which are used to control any external motors or solenoid valves that will be used. This regulator came in a 20-pin VQFN package that proved difficult to solder due to the 2oz copper traces used as the package had no visible legs to solder to, only small pads on the underside of the chip with wettable flanks.

The second regulator used on the power board is the 5 V at 5 A regulator which is used to feed the ESCs with 5 V for on board logic. This is also connected to the data board 5 V rail through a jumper and then the board to board connector. The 5 V regulator used was the microchip MIC2128 which comes in a 16-pin QFN package, which, similarly to the LM5146-Q1, uses pads on the underside of the chip rather than legs which proved difficult to solder due to the 2oz copper layer.



*George 2: Showing the board-to-board connector between the data and power board*

The connectors which are mounted to the PCB to allow for interfacing between the ESCs and the data board were tested. Figure George 2 shows the data board and the power board connected together as they will be inside the capsule with the board-to-board connector allowing for signals to be sent throughout the entire control system. Figure George 3 shows the ESC connectors which allow for easy removal and replacement of ESC's in the case of a fault.



*George 3: Showing the Modular ESC Connectors*



Revision 2 of the power board design will use more suitable packages that are easier to solder and easier to fault find as the pins and pads will be visible and easier to probe on to for unit tests and a full system test. The 12 V regulator will use Texas Instruments LM5088-Q1 which comes in a HTSSOP package and also requires fewer components to achieve the desired output which will also make routing easier. As well as this the 5 V regulator that will be used is the LM5085 which comes in a VSSOP package and will allow for much easier soldering and testing. Along with the better selection of components the PCB will be redesigned using 10z copper traces and a 4 layer board which will allow for a ground and 48 V plane to be put in place which will increase the ease of routing. The 10z copper will make for much easier soldering due to the lower thermal mass of the copper traces. One downside to 10z copper traces is the fact that the traces would need to be roughly 4mm wide in order to carry the same amount of current as the previous 20z traces. The easiest way around this is to remove the solder mask from the motor traces and solder directly onto the traces to increase the thickness of the trace. This is an industry standard method of creating high current traces on a low weight copper board. These changes should allow for the board to be fully working, ready for a full system test aligning with the timescale set out in the Gantt chart.

### **3. Review of Project Schedule (GO)**

The Gantt chart has proven to be an accurate representation of the current progress of the project and all aspects are on track and meeting any deadlines set. In order to ensure that project progress stays within the current deadlines and is set to meet the final deadline for the competition, a close eye will be kept on timings and the team will ensure that all efforts are made to keep the project on track. The initial Gantt chart is shown in Appendix X and shows that the current state of project is testing and redesign, which has been explained in the previous sections of this report.

As the project approaches completion it is of high importance that the team keeps within the proposed timeline to ensure that the final deadline is met. The initial plan allowed for some overflow to occur and allow for extra time if needed for final tweaks and tests to ensure that the project is ready for the competition.

### **4. Review of Risk Register (HO)**

Out of the applicable risks at this stage of the project, only No. 4, “delays due to late / slow ordering of components” presented an issue. (See Appendix C for the Risk Register). The Commercial ESCs, critical for the backup system, still have not yet arrived, despite ordering them 3 months ago though our budget with the Multidisciplinary Engineering Education department. Several attempts to speed up the process have been carried out, and apparently the ESCs have been ordered, however they have not arrived. During the writing of the Risk Register, the impact of poor communications in the near-side supply chain was not considered in Risk No. 4. Instead, the focus was on delays at the supplier level.

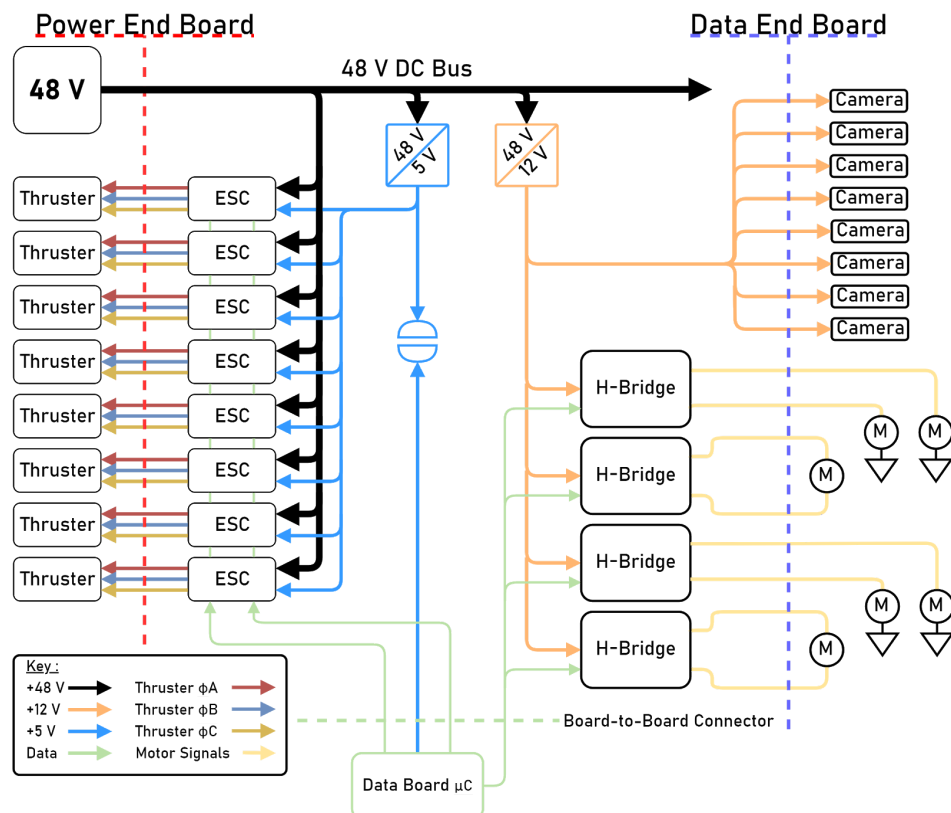
Unfortunately, there is little that can be done within the scope of the project, so the only alteration the the risk factors is to increase the likelihood after mitigation to 2, and to acknowledge and accept the high risk factor of 10.

### 5. Appendix

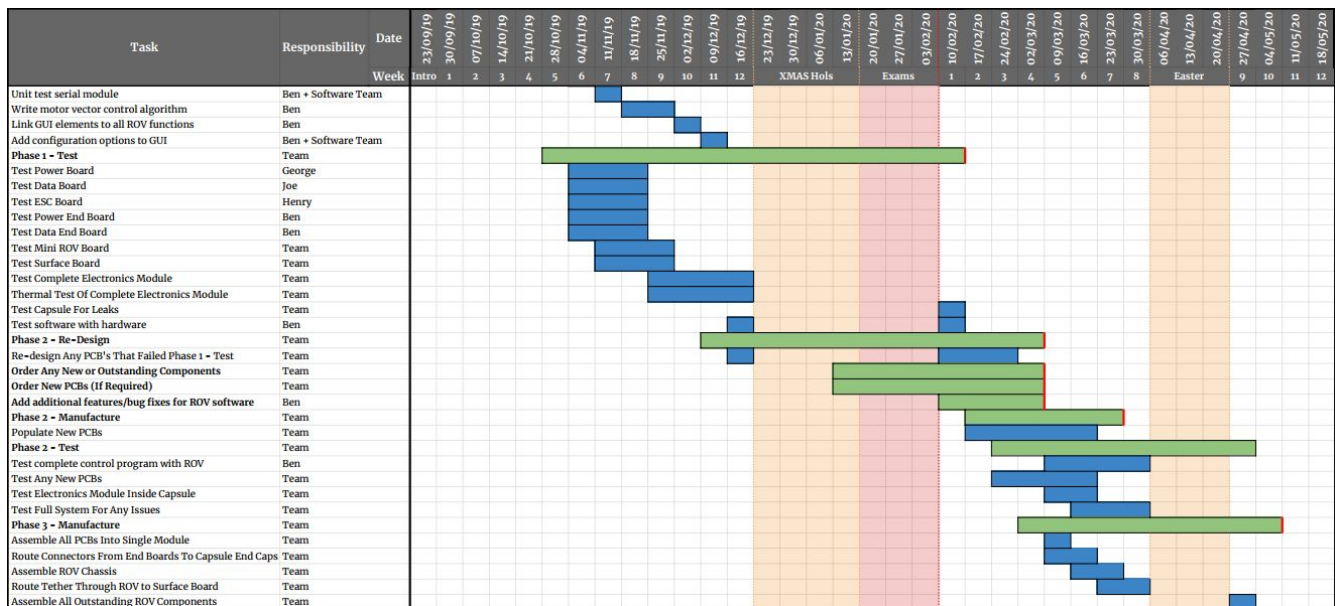
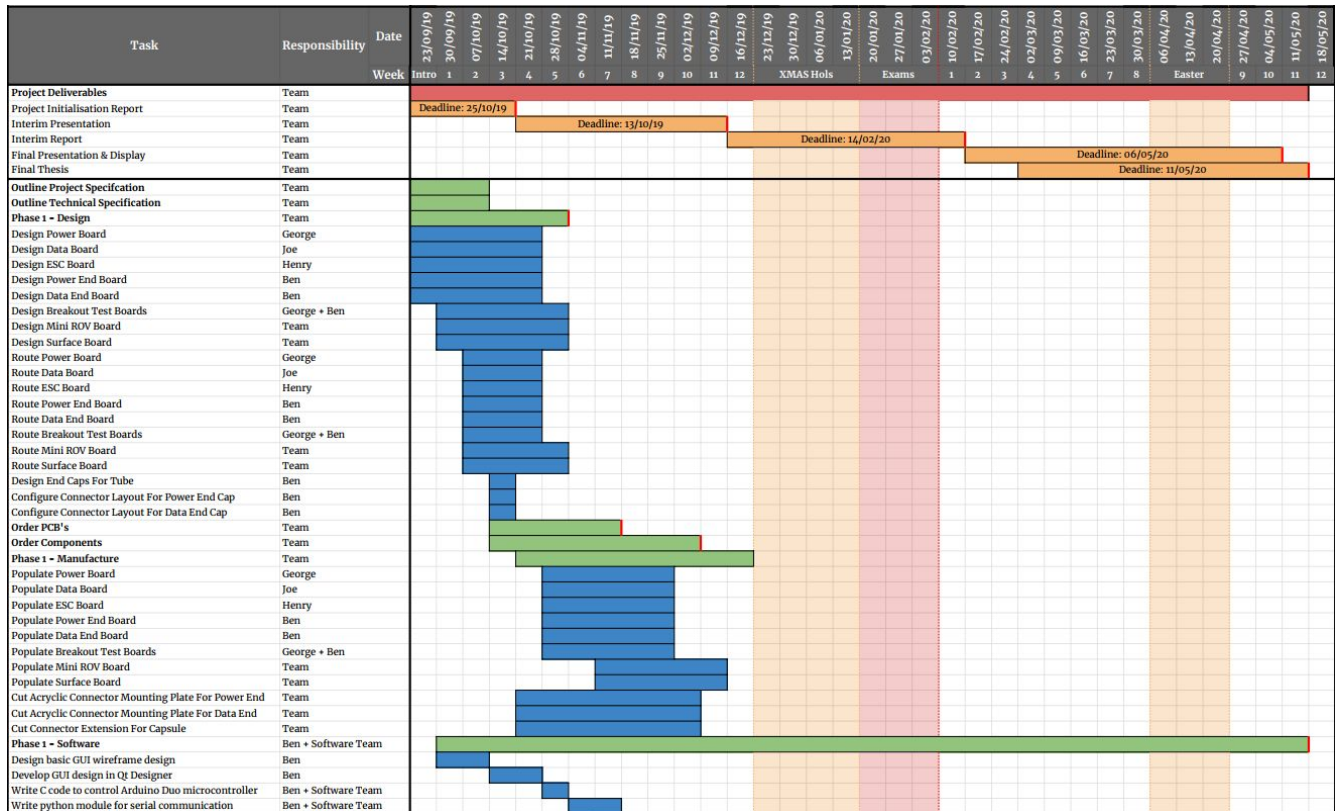
Command Initialiser	Command Function	Data	Description
?I	-	-	Requests the identity of the ROV, responds with 'AVALONROV'.
?R	T	aaabbbcccddeefffggghhh	Sets the speed of each thruster. 'Aaa' represents the speed of thruster 1 from '001' - '999'.
	X	-	Arms the thruster electronics speeds controllers (ESC's).
	A	abcdefgh	Sets the state of each actuator. 'A' represents the state of actuator 1, either '0' or '1'.
	C	aabbccdd	Sets the analog camera switches to display the 4 desired camera feeds. 'Aa' represents the address of camera 1, from '01' - '99'.
?M	X	a	Activate the mini-ROV, arm the thruster ESC and turn the headlights on. Where '1' is ON and '0' is OFF.
	T	aaa	Sets the speed of the mini-ROV thruster. 'Aaa' represents the speed from '001' - '999'.

For example, if the pilot wanted to set thruster 1 to maximum speed, the command would be, “?RT999500500500500500500”, or to toggle actuator 3, the command would be “?RA0010”.

#### Appendix A: ROV ASCII commands.



#### Appendix B: System Flow Chart For Power Board Operation



Appendix C: Gantt Chart for Project Planning and Timescale Management

No.	Risk to Project	Severity	Likelihood	Risk Rating	Mitigation	Updated Severity	Updated Likelihood	Final Risk
1	Scope Creep increasing workload, causing delays in task completion.	4	4	16	Properly define a fixed specification at the initialisation of the project (in this document) and refer to it frequently.	4	2	8
2	Poor understanding of project requirements.	5	3	15	Spend additional time ensuring the project requirements, then write the specification to ensure full coverage.	5	1	5
3	Pressures from other projects and exams.	4	4	16	Ensure other events (exams, etc.) are accounted for in the project planning phase.	4	1	4
4	Delays due to late or slow ordering of components / PCBs.	5	3	15	Use the schedule to plan ahead component ordering once requirements have been identified. After final checks, order PCBs at the next available opportunity.	5	1	5
5	One or more tasks are not known at the planning stage.	4	3	12	Ensure full coverage by cross-checking specification against aims.	4	1	4
6	Communication between team members breaks down, causing task duplication or loss.	4	4	16	Conduct regular meetings in person and avoid the use of social media to conduct important conversations.	4	1	4
7	Time pressure due to nearing deliverable deadlines causes non-functioning / poor quality work.	3	4	12	Adhere to the project plan, completing work earlier if possible to ensure an acceptable workload immediately before deadlines.	3	1	3
8	Knock-on delays build such that the lost time is unrecoverable.	5	4	20	Plan extra time into the schedule to act as contingency for any unexpected delays.	5	1	5

9	MATE Specification, on release, reveals incorrect assumptions about tasks, leading to a lack of requirement planning.	5	3	15	Design for additional features in the electronic systems to cover all possible specification variations; ensure system is expandable.	5	1	5
10	Testing does not cover the boundary conditions of the electrical system, and discrepancies with the specification are not noticed.	3	4	12	Use unit testing, where tests (especially for software) are built before the module concerned. This ensures that, provided the test is accurate, the product meets the specification.	3	2	6
11	Data loss due to individual poor backup regime causes project delays.	5	4	20	Use online services such as google drive to synchronise personal data.	5	1	5

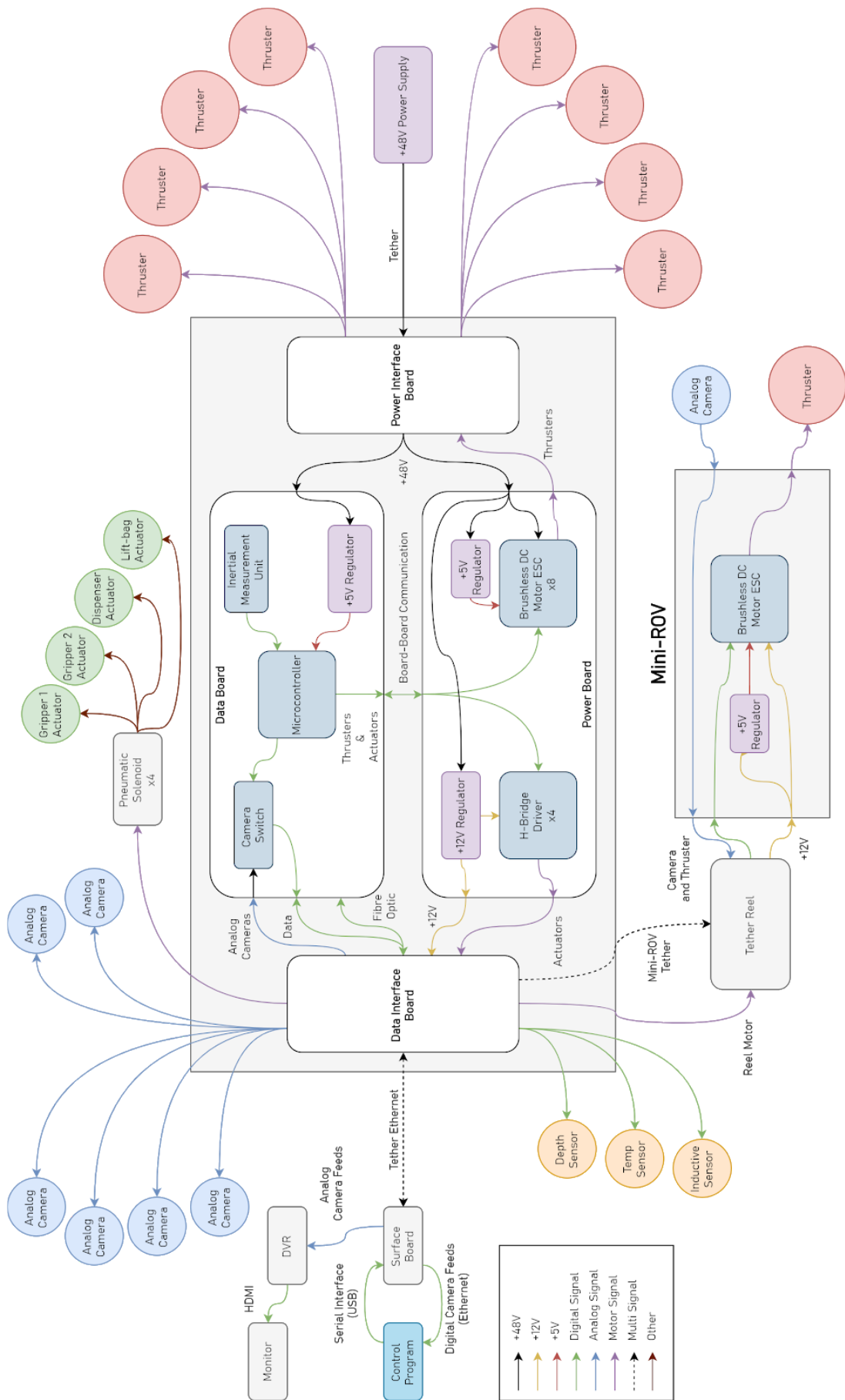
Appendix D: Risk Register Showing Major Risks and Attempted Risk Mitigation

		Likelihood				
		1	2	3	4	5
Impact	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Appendix E: Risk Rating Based on Likelihood & Impact of Risk

Risk Rating	Description
1-2	Low priority risk - risks we are willing to take and won't affect project progress.
3-6	Moderate risk - risk will need monitoring but not a large threat to project completion.
8-12	High risk - risk will need monitoring and action will need to be taken to prevent risk from affecting project progress.
15-25	Critical risk - risk is detrimental to project progress and processes must be put in place to prevent it.

Appendix F: Description of Risk Rating



Appendix G: Overall System Flowchart For ROV Control System