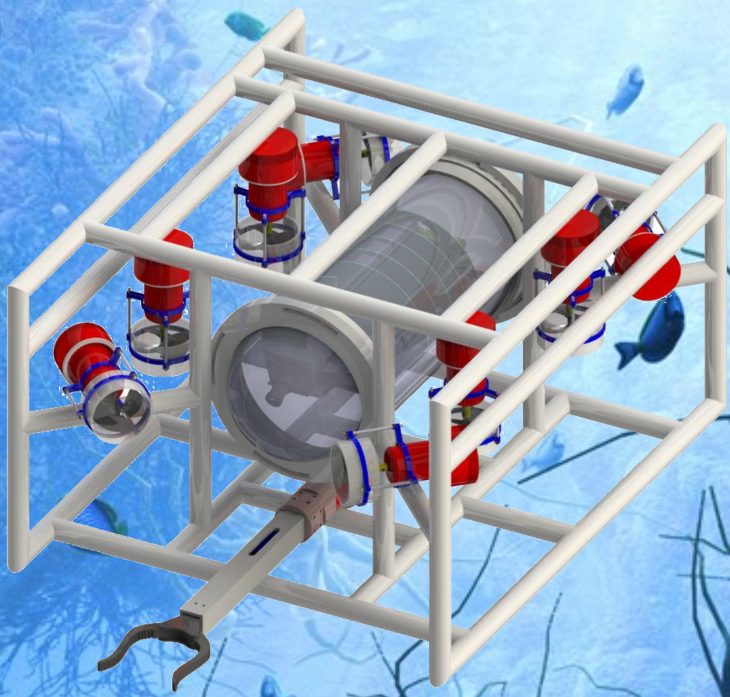
RGU SUBSEA ROBOTICS



RGU ABERDEEN

TECHNICAL DOCUMENTATION

COMPANY MEMBERS

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COMPANY INFORMATION

Explorer Class Team for the 2015 MATE International Student ROV Competition: Science and Industry in the Arctic. St John's, Newfoundland and Labrador, Canada.

VEHICLE NAME

Versatile **I**nspection **P**latform for **E**xploration and **R**ecovery Mark. III (**VIPER** Mk. III)

UNIVERSITY

School of Engineering,

Robert Gordon University,

Aberdeen, Scotland

MENTORS

Graeme Dunbar, John Still, Steve Allardyce

1 ABSTRACT

RGU Subsea Robotics is a company consisting of eight students studying for an engineering degree at the Robert Gordon University in Aberdeen, Scotland.

The company was founded in October 2012, when its five founding members had just started their degree course. The main purpose of the company was to design and build a Remotely Operated Vehicle (ROV) to compete in the International MATE ROV Competition. Since then, the company has grown and developed a total of three ROVs, which they have named "Versatile Inspection Platform for Exploration and Recovery" (VIPER).

2015 sees the company travelling to St. John's, Canada to compete in the Explorer Class of the annual MATE ROV International Competition, for the first time. They aim to demonstrate their latest product, VIPER Mk. III, by successfully completing a series of timed missions with themes of science under the polar seas and oil and gas operations along the North Atlantic continental shelf.

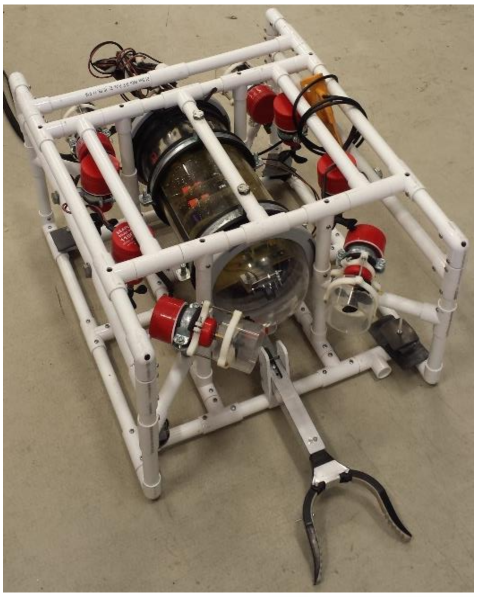

Figure 1. VIPER Mk. III

The product was designed and developed entirely using a final budget of £902.95 ($1386.84 USD). The project started at the beginning of the academic year in September 2014 and by the MATE Scotland ROV Challenge, in April 2015, the company had developed an Explorer Class ROV, VIPER Mk. III. The team re-used components from previous builds i.e. VIPER Mk. I and Mk.II.

VIPER Mk. III incorporates various tooling such as a multi-purpose manipulator used to complete tasks ranging from deploying passive acoustic sensors to replacing wellheads. Other features which will be discussed in further detail through the course of this report.

Figure 2. Company photograph taken by RGU student Bruce Mackenzie.
[Left to right standing: Donald, Amanda, Scott, Matthew, Elias and Ross; Left to right kneeling: James and Rulston]

CONTENTS

2 DEVELOPMENT PLAN

The company planned to organised itself into two main divisions, which were mechanical and electrical, and there would be a leader for each division. Each division lead would focus on organising their divisions work and personnel to complete required tasks and meet deadlines set by the CEO. For larger divisions it would be more effective to develop sub-divisions and delegate work.

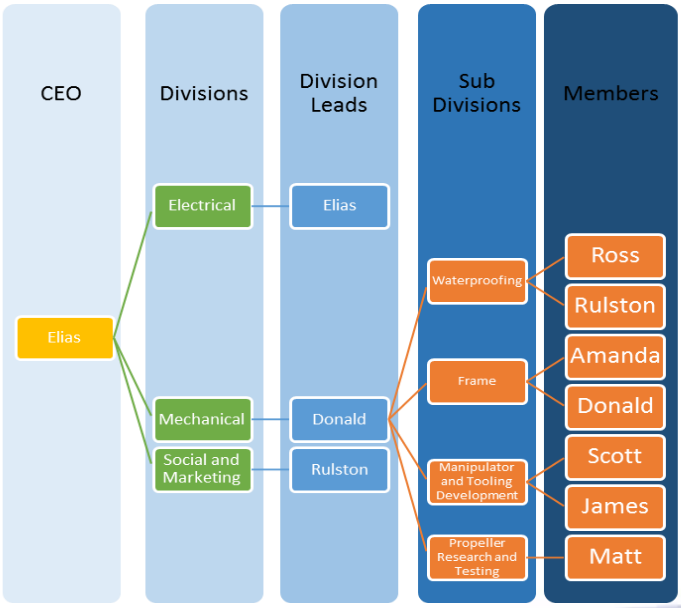

Figure 3. General company structure.

By assessing member skill sets, positions for people within the company were allocated and a general layout is shown in Figure 3. The layout describes the main roles assigned to members initially however as the project progressed, company fluidity was necessary which meant members assisted in other divisions and members gained other roles due to various conditions. The general steps followed for developing designs was to research other solutions and relevant content, design a basic solution, present the solution to other members, if majority of members agree with the solution then produce more detailed design, manufacture and test solution.

Since the company was divided into organisations, fortnightly progress meetings were held where each division and subdivision would present the progress made, problems encountered or suggestions made over the two weeks since the last meeting. This allowed the company to work separately but also to keep all members updated on global project progress and events.

The company also had a logbook system, enforced by the CEO, which was used to record developments in detail for future reference. A template logbook was made and company members would fill this in after each session as a group, then all logbooks would be uploaded to the company Google Drive account where any member could access the information at a later date. The suggested initial development plan for the project is shown in Figure 4.

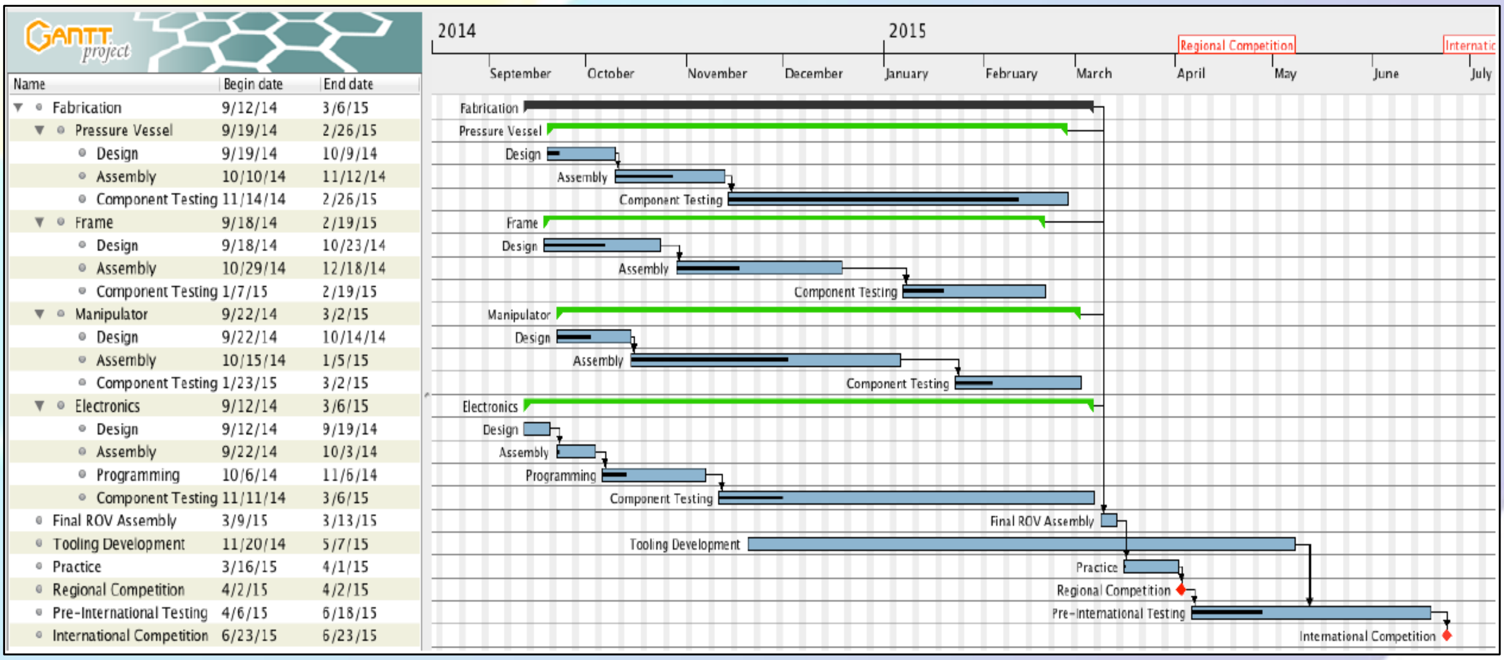

Figure 4. Initial project plan Gantt chart (created using GanttProject).

However the company did not manage to follow this plan strictly due to problems encountered which are described further in the Challenges section (Section 6, pg.15)

3 DESIGN RATIONALE

3.1 SAFETY

Overview: Through the course of this project, safety was the most important factor in the company's code. Therefore, the company ensured that the correct safety measures were maintained at all times by employing policies and procedures to alleviate human error and maintain rigorous safety of personnel, equipment and the mission environment.


Figure 5. Matt and Rulston wearing lifejackets to test pressure vessel.

Procedural: During the fabrication stage of the VIPER Mk. III, all appropriate risk assessments were conducted members of the company wore the appropriate personal protective equipment (PPE) for each task undertaken. For example, safety specs were worn when soldering of components on PCB boards and full personal protective equipment was worn including lab coats, safety goggles and latex gloves when using any solvents or adhesives e.g. when assembling the pressure vessel. Furthermore, when conducting electrical testing upon the ROV, the company maintained standard procedures whereby notifying everyone in the vicinity to stand clear, therefore minimising the risk of electrocution. Life jackets were also mandatory PPE for personnel performing work involving the pool. The ROV safety procedures are shown in Appendix A.

Electrical: Due to the modular design and the use of a board dedicated to cable connections, setting up and operating the system was safer as there was no chance of user miswiring accidents occurring and connecting/disconnecting systems was simple.

Status LEDs to indicate power and general operation were also incorporated on boards, were possible. This assisted in monitoring and diagnosing the system and generally showing a user if the boards were powered so they know whether they were safe to touch. 20mm fuse holders were also incorporated on the main input power line for all modules that handled high voltages, i.e. 48V, and appropriately sized fuses installed. The system was also designed such that, generally, the high voltage (e.g. motor power) and low voltage (e.g. Arduino operations) PCB tracks were separated to the right and left (of the ROV) respectively. This meant if there was a short due to a conductor over the tracks, low power components (such as an Arduino) were less likely to get damaged from voltages within their operating range than +48V.

The control box was made of plastic, which is an insulator, hence there was little to no change a person could get an electric shock. The software for the vehicle was also designed with fail safes such as if there is an error with communications all motors are switched off and before motor strengths are applied, the program ensures they are within set limits for a 50% duty cycle at least, in case an error or a bug causes values to spike. Power safety features that the control box provided were 1) miswiring protection, which involved placing a 40A diode (in forward direction for correct wiring) on the negative line which meant when power was reversed no current flowed; 2) current and voltage supply monitoring achieved by using a car battery monitor to measure and display the values.

The electrical system also included an inline Maxi blade fuse holder, which holds a 40A fuse, and an inline battery cut off switch rated to 300A (Carpoint, 2015). The fuse provided protection in overcurrent conditions and the switch provided control to quickly power off the system without disconnecting from the supply.

Mechanical: The company implemented the following mechanical safety features in order to coincide with the company's safety policies. Safety shrouds were fitted around each propeller to prevent damage from any incoming debris, obstacles or the vehicles tether and each motor operated within the frame. The correct length of bolts were also used with edges filled down so they were smooth and cable ties cut to appropriate lengths to reduce the chance of any exposed sharp objects on the vehicle, which would be considered dangerous.

3.2 MECHANICAL

3.2.1 *Design Approach/ Design Philosophy*

The design approach to the ROV with regard to Mechanical components was to make cost effective, simple and innovative ideas. The design philosophy was to try and generate solutions which did not rely on expensive, complicated and demanding components. Due to constraints set forth by the budget, it was decided to keep costs to a minimum by manufacturing components and solutions in-house, using readily available components and easy to manufacture solutions. As a result of this, maintenance of components is simple and can be undertaken by all members of the team. Furthermore, it would be possible to quickly service components in the event of failure, which reduces down time. Safety considerations are discussed in the safety section.

When mechanical components were to be manufactured by the company they would first be designed as a CAD model in Solidworks. They would then be stress evaluated and mounted on a CAD assembly of the full vehicle to determine if the design was suitable and to show how it would fit on the overall design. If the design seemed suitable then it would be manufactured. All CAD models and rendered images were made in Solidworks, however some components in the models were given different colours so they could be differentiated better.

3.2.2 *Frame*

The frame of the vehicle is constructed from 21.5mm plumbing waste overflow piping and connectors. These are secured together with self-tapping screws, allowing parts to be swapped-out should they become damaged, as opposed to a permanent adhesive connection. The pipe provides a strong frame with minimal mass. The frame is free-flooding, whereby water enters the frame as the ROV submerges. This means that there is never any pressure difference between the internal/external pipe walls. A sealed pipe design would be susceptible to leaks and would create buoyancy issues. Additionally, the frame houses the power cables for the thrusters, reducing the risk of damage to them.

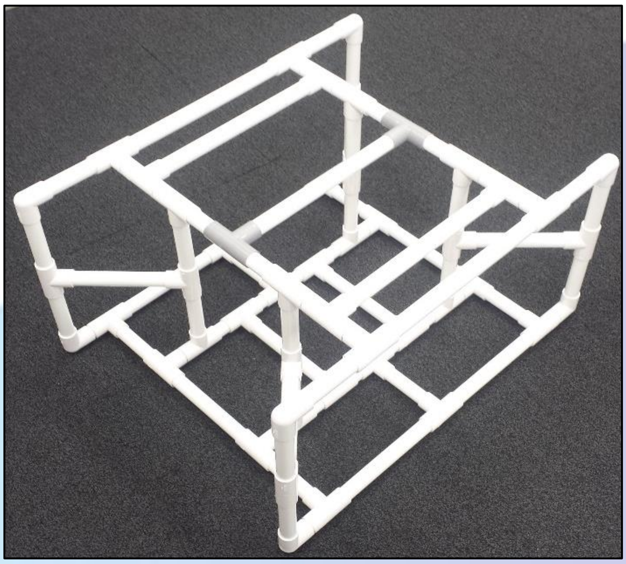

Figure 6. Frame design with no mounted components.

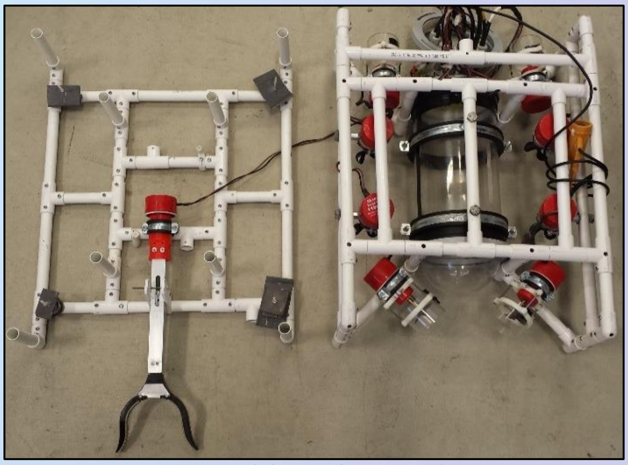

Figure 7. Frame modules, with mounted components.

The frame was designed primarily as an exo-skeleton containing the pressure vessel and vital components, mounting other components was also considered. For this reason it was built to the maximum dimensions possible, limited by the university flight case, which would allow most components to fit inside and have less parts exposed minimising potential hazards. Final frame dimensions were 590 x 480 x 330 mm, excluding tooling.

An effective and cheap method to hold the pressure was made using 2 x 250 MACROFIX 159-162MM clamps (Hoses Direct, 2015). Compared to previously used designs, these proved a great improvement with massively reduced slippage and an easy method of mounting the pressure vessel. Similar but smaller clamps were used to fasten the motors to the frame as they were effective.

The frame was also made modular when components were added, to make access to mounted components easier. The frame splits into two main modules which are the top ‘main module’ which holds essential systems i.e. thrust motors and the pressure vessel and the bottom ‘tooling module’ which holds the required tooling. Hence new tooling can be added easily without disrupting the essential components.

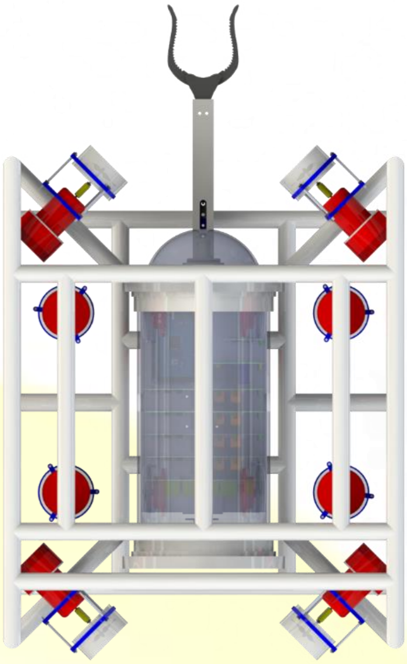

Figure 8. Solidworks rendered top view of motor arrangement on frame.

3.2.3 *Propulsion*

The ROV used motors from 24V bilge pumps, rated for 1100GPH, with propellers attached to the motor shafts to produce thrust. These motors were chosen because a high rated voltage would mean less voltage regulation is required to run the motors from a 48 V supply and 24 V was the highest voltage rating available. They were cheap, light with a mass of 0.25 kg in air (Stainless Direct, 2013), had a relatively low rated current draw of 1.5 Amps and a high rated head of 4 m compared to other bilge pumps. Hence the motor specifications suggested it would be quite effective in terms of producing high thrust, due to the high head, with a low price, mass and power draw which is why they were chosen.

For selecting the propellers to use, the company conducted tests on three different propeller designs. The requirements for propellers were maximum thrust and preferably similar performance in forward and backwards thrust operation. The test was conducted in a test tank by mounting a motor such that it could only move linearly, up and down, then attaching a digital weight scale to the motor and to a fixed surface. A propeller was then attached to the motor shaft and the motor powered at 24 V. The motor had a polarity such that it thrusted downwards and so the force exerted by the motor thrust was measured using the digital scale in kg. This was how the thrust performance of various propellers was measured and the chosen propeller had a performance of 0.8 kg and 0.4 kg thrust in forward and reverse respectively.

Figure 9. Motor mounted in propeller test arrangement.

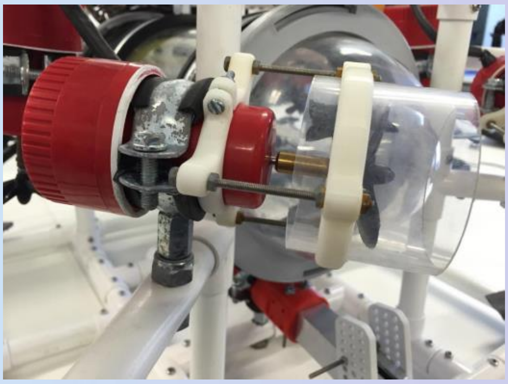

Figure 10. Motor with shroud mounted on frame via pipe clamp.

To accurately control the motion of the ROV, eight motors were used with four being horizontal thrust and the other four being vertical thrust (lift) motors. The horizontal thrust motors were mounted at angles in a vectored thrust arrangement to the frame which allowed more for finer control and the ability to turn on the spot compared to straight, right angled motor arrangements. The vertical motors were arranged symmetrically about the geometric centre planes at the furthest reasonable distance from the centre, for stability, to provide an evenly distributed vertical thrust to the frame. The vertical thrusters were mounted such that maximum thrust would be produced in lift direction and could produce a maximum total lift of 3.2kg, using propeller test results.

3.2.4 *Pressure Vessel*

The pressure vessel houses all the on-board electrical systems including the motherboard, motor driver circuits and video cameras. The main body of the pressure vessel is a 160mm diameter transparent acrylic pipe. This diameter was chosen as it allowed for industry standard plumbing parts to be used. The transparent pressure vessel allows us to monitor the electronics visually during set-up and troubleshooting.

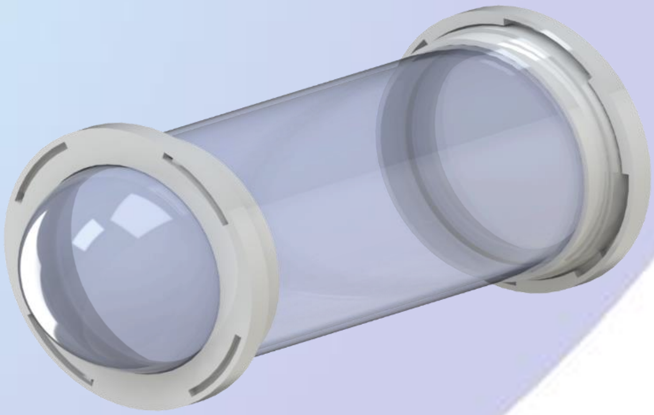

Figure 11. Solidworks rendered image of assembled pressure vessel.

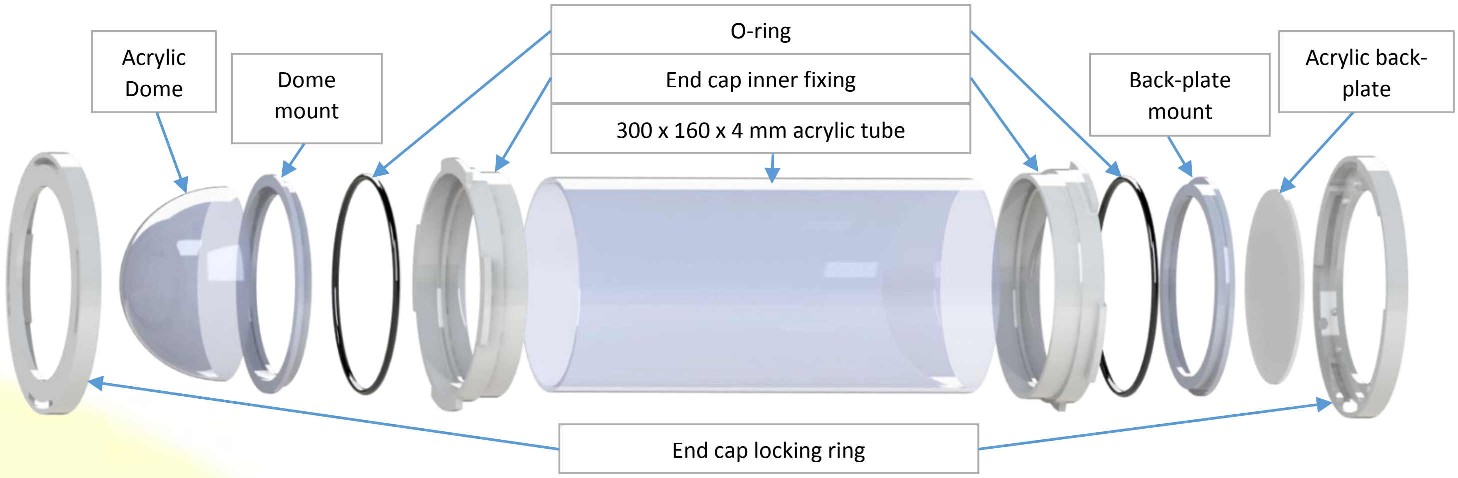

Figure 12. Solidworks rendered image of pressure vessel components, exploded view.

Each end cap inner fixing was bonded to the acrylic tube with solvent cement. The acrylic frontal dome was also adhered to its mount with solvent cement. The O-ring formed a seal between the dome mount and end cap inner fixing. The end cap locking ring, when tightened, presses against the dome mount forming a tight seal with the O-ring. The same process was used for the back-plate, with a flat acrylic cut-out in-place of the dome. The vessel can be opened at both the ends and the whole motherboard assembly fully removed. All cables enter the pressure vessel through the back-plate via nine cable glands. Four core cable (i.e. four insulated cables within a larger outer insulation) was used to minimise the number of vessel penetration points. Cable glands used on the back plate were SIB brand Polyamide 6 glassfiber reinforced with a Tefablock seal, rated at IP68 and suitable for underwater applications. They are rated to 5 Bar, equivalent to approximately 50 meters of water depth.

Due to the use of four core cables, there existed gaps between the cores and these were found to allow water into the pressure vessel when the cables were exposed to water at depth. This was a serious issue as a water leak could seriously damage the electrical system when powered. To solve this the company developed a two layer sealing process which involved using araldite resin to seal areas were the cores were exposed and heat shrinking over them such that the resin set in a cylindrical shape. Then an additional layer of araldite was added to cover any gaps on the heat shrink then self-amalgamating tape was used to seal over the resin. The pressure vessel has undergone extensive testing, including a 72 hour test at three meters depth, which was successful which shows the waterproofing method was effective.

3.2.5 *Manipulator*

A device capable of interacting with objects and mechanisms was to be designed and built utilising easily sourced materials. The designed device was powered by a 24V bilge pump motor, the same as the thrust motors. A manipulator claw mechanism was sourced from a hand litter grabber, which was cheap and easily adapted. The claw mechanism was actuated by converting the rotary output from the motor to a linear motion which pushed/pulls the claw mechanism control wire.

This angular to linear motion conversion was developed using a brass threaded rod fastened to the output from the motor via a brass coupling. This threaded rod rotated within the internal thread of a square boss (shown in blue in Figure 13) which sits inside a square aluminium duct fixed to the motor so permits linear motion of the boss, sliding up and down within the duct. The square boss slides since it sits within the confines of the duct and when the motor rotates, it is unable to spin and therefore produces a linear reaction force such that it slides along the inside of the duct. The boss was fastened to the control cord (shown in green in Figure 13) of the claw mechanism via a piece of Meccano, hence the linear motion of the boss opened/closed the claw mechanism. This device can be used in a variety of tasks for the competition. The simple design allowed for easy maintainability should the company encounter any troubleshooting. The versatility of the claw allows it to carry out tasks efficiently in numerous environments and to a high standard.

Due to the rotary output from the motor, numerous challenges were faced in the design of the system. There were vibrations initially and it was discovered that many points on the design were too weak to sustain the manipulator's operating stresses and subsequently did not perform adequately. As such, these challenges were addressed as explained below.

One such challenge which had to be overcome presented itself in the fastening of the motor to the aluminium tube. It was documented in previous designs that use of adhesives to fasten the duct to the motor was insufficient as the torque exerted by the motor was too great, and subsequently, sheared the adhesive surface. Adhesives also did not offer easy access to the internal mechanism.

Hence it was decided to discard adhesives in favour of utilising more secure mechanical methods to hold the entire design together. This was achieved by employing a combination of a 3D printed manipulator mount piece which was bolted to the duct and a pipe clamp, same as those used to fasten the thrust motors, was used to securely fasten the motor to the aluminium tube. The pipe clamps also provided an easy method to mount the manipulator to the frame and permit rotation of the motor shaft, whilst inhibiting rotation of the duct.

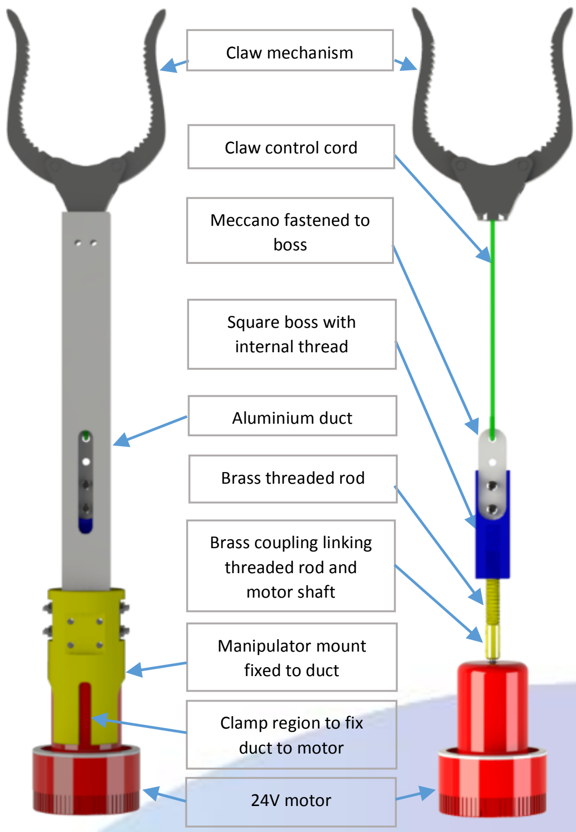

Figure 13. Manipulator as viewed and with mechanism visible respectively.

It was similarly determined that a more secure fastening method, than adhesives used previously, of the litter picker mechanism to the aluminium duct was needed. This was achieved by drilling holes at appropriate points on the mechanism and the duct and bolting them together, which gave us a secure and reliable connection. Some plastic components of the mechanism were also replaced with in-house designed and manufactured equivalent aluminium components which were stronger to increase the reliability. Aluminium brass material was used for in-house manufactured components to prevent corrosion in water. The final design was effective, reliable and functioned smoothly with minimal vibrations.

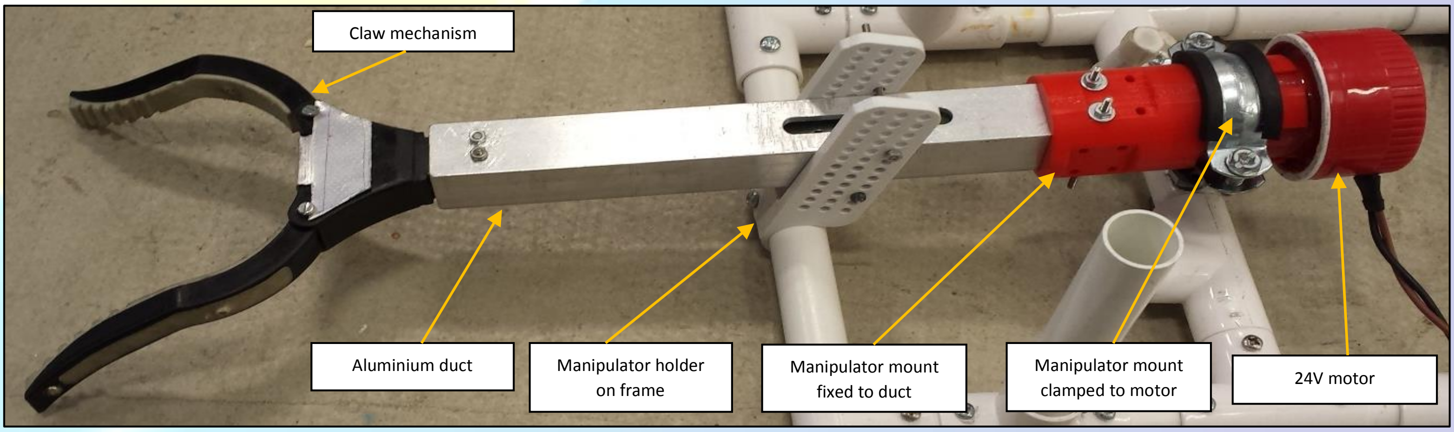

Figure 14. Manipulator mounted on frame.

3.2.6 *Buoyancy/Ballast*

The components mounted on the frame and the frame itself were relatively light, approximately 4kg in air, and the pressure vessel volume displaced water to produce a calculated approximate positive buoyancy force equivalent to 6kg. Hence the frame with final components was significantly positively buoyant. Neutral or slightly positive buoyancy would be most preferable for ROVs hence ballasts were added to the frame to counteract the buoyancy force for a near neutral buoyancy. Ballasts were lead plates which were added in the lower four corners of the frame. The weights at each corner were determined by trial and error. The ballasts were placed at the lowest points of the frame to lower the overall centre of gravity of the vehicle and produce the maximum metacentric height for maximum stability against overturning (CodeCogs, 2011).

3.2.7 *Task Tooling*

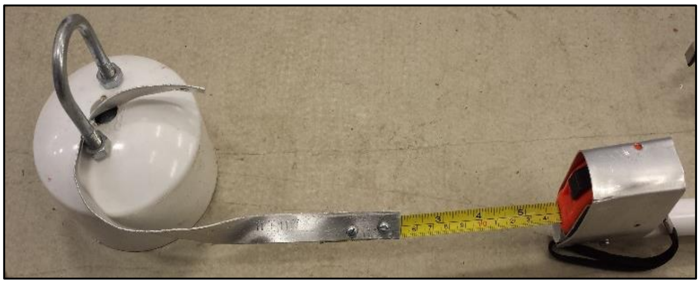

Figure 15. Tape measure in mount.

Measuring: A measuring device was required for the some of the tasks and was designed by employing our design philosophies. It was decided that we would utilise a measuring tape to complete measuring tasks. In order to do this, the tape measure would be mounted to the frame. This was achieved by manufacturing a mount to house the tape measure, which was fastened to the frame using self-tapping screws. The device measures distance by hooking on to the item being measured, and drawing the scale out by moving the ROV. The distance travelled between the hook point and the final point is recorded via a camera, and so, shows the measured dimension of the object.

Turning valves: In order to complete the tasks involving the turning of valves, it was necessary to design a tool which would allow us to complete the task quickly and easily. One such solution devised involved the manufacturing of a set of arms which drop down below the bottom of the ROV when required, but have the ability to retract when not. This gave the system the ability to rest on the bottom of the tank when needed, and when risen, the arms drop below which allows a valve to be turned by landing on top of a valve and rotating the ROV. This gave us the ability to complete the valve tasks without the need to remove the ROV from the water and adjust the frame, saving time and energy.

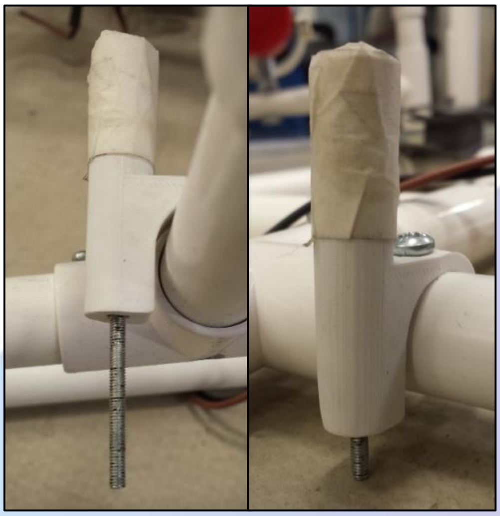

Figure 16. Telescopic valve turner, frame off the ground and frame on the ground respectively.

3.3 ELECTRICAL

3.3.1 *Design Approach/ Design Philosophy*

The electrical system for the ROV was designed, building on experience from VIPER Mk. I and Mk. II to be safe; versatile; and easy to set-up, monitor and diagnose. To achieve this, a modular approach to designing the system was taken, which meant circuits with specific functions were designed as individual boards which could be interfaced with a mother board to produce the overall system. This meant sections of the overall system could be built and tested individually which made diagnosing problems easier. Safety considerations for the system are discussed in the safety section. All PCBs designed using EAGLE PCB.

3.3.2 *Overall System Summary*

The overall system satisfies initial conditions as it is safe; versatile; and easy to use, monitor and diagnose due to its features. For the full allowable load, determined by fuses, the load on the system would be mainly from five dual motor driver modules drawing 6 Amps each and one 12V regulator module drawing 3 Amps, which is a total of 33 Amps. This shows the system, at its limits, operates within the 40 Amps limit with 7 Amps to spare. The System Integration Diagram (SID) for the full system is shown in Appendix B.

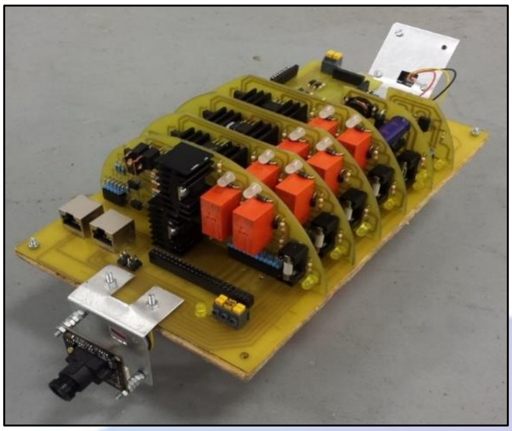

Figure 17. Fully assembled ROV motherboard.

The general operation of the system involves an Arduino in a surface control box receiving input from a user via a controller. The surface Arduino then calculates the thrust values for the motors to produce the required input motion and sends these values to an Arduino on the ROV. The ROV Arduino then implements the thrust values by actuating motors, via motor drivers, using pulse width modulation (PWM) signals. The duty cycle of the PWM signals represents the magnitude of the thrust and is proportional to the received thrust values from the surface Arduino and hence the user input. Three internal cameras were included in the pressure vessel and these were displayed using a 4 channel video processor.

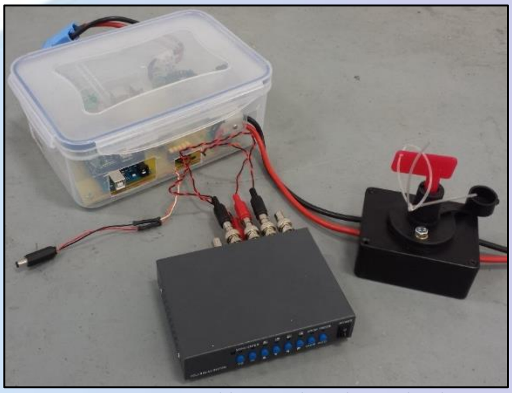

Figure 18. Control box with 4 channel video processor and switch.

3.3.3 *Motor Drivers*

The motor drivers were required to provide control over the operation of a motor in terms of direction and magnitude of shaft rotation. To achieve this a circuit with an H-Bridge using a DPDT relay, driving the motor, in series with an N-Channel MOSFET was designed which produced the required control. The MOSFET controlled whether current flowed through the H-Bridge and hence the motor and the H-Bridge controlled the direction of current flow through the motor. To provide analog control of the supplied voltage, the MOSFET gate was controlled using a pulse width modulation (PWM) signal from an Arduino which meant the motor speed could be controlled by varying the duty cycle of the PWM signal.

To control the motor driver circuit, direction (DIR) and PWM signal from Arduino pins were used to control the H-Bridge relays and MOSFET respectively. To protect the Arduino from high voltage faults, the input signal PCB tracks were electrically isolated via optical isolators. To make the system compact, two identical circuits as described above were placed on the same PCB and routed. A fuse holder for a 20mm 6A fuse was also added to each dual motor driver.

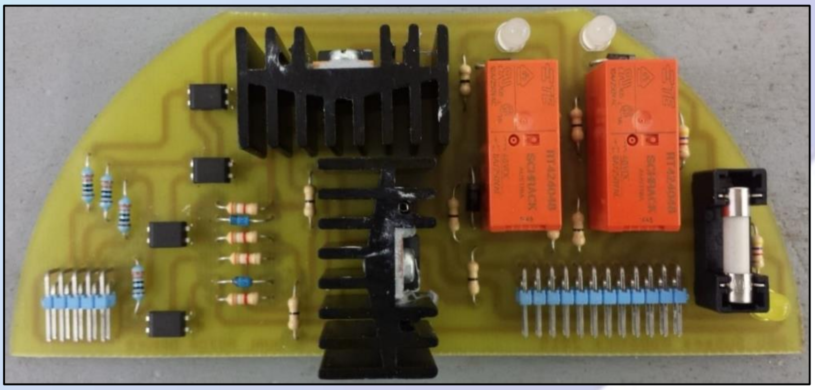

Figure 19. Dual motor driver module.

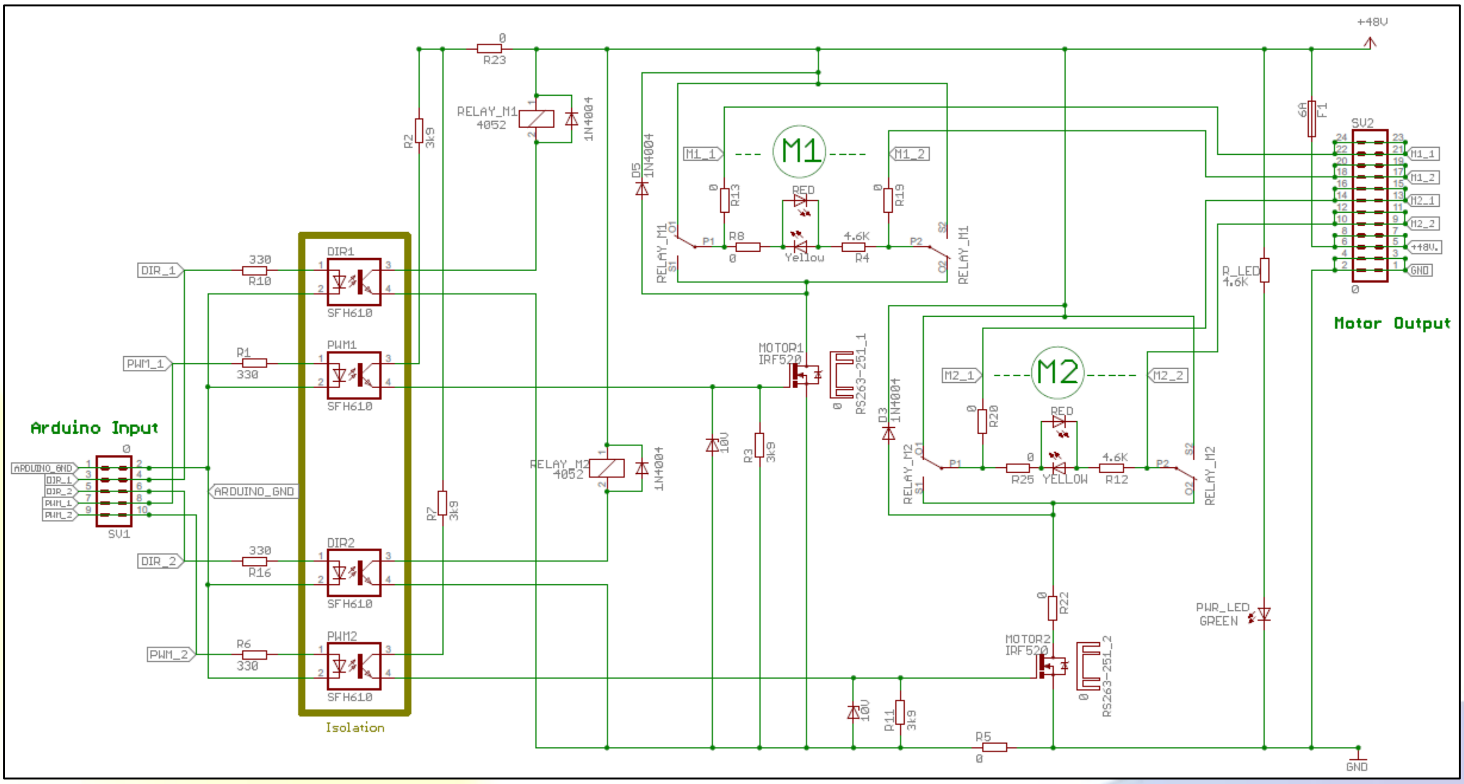

Figure 20. Dual motor driver module, schematic.

3.3.4 *Voltage Regulation*

PWM voltage regulation was used to reduce the +48V to power 24V motors, by operating the motors at a maximum 50% duty cycle. This solution was used because it did not require any extra components as it was a software solution and it allowed easy control of the voltage supplied to, and hence speed of, the motors.

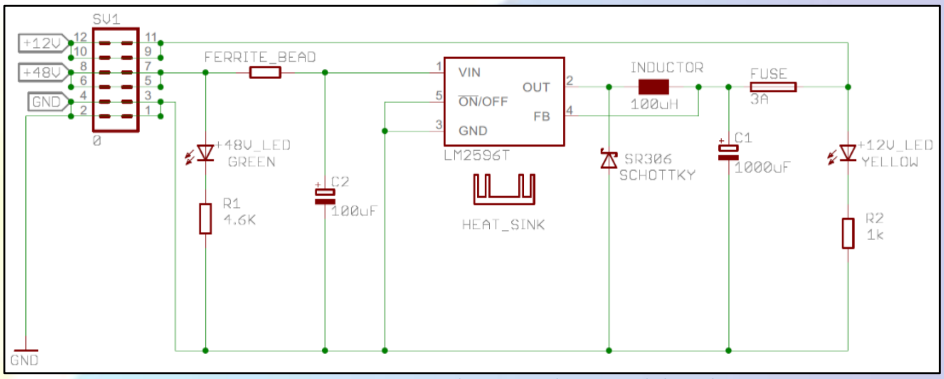

Figure 21. 48V to 12V DC step-down regulator module, schematic.

For components such as Arduinos, cameras and lights, the PWM voltage regulation method used for motors would damage the components, hence it was not suitable. For these components a step down voltage regulator board was designed to step down the 48V supply to 12V. The board used a circuit with a LM2576, 12V switching regulator IC, which was rated for a maximum load of 3A and input voltage of 60V (Texas Instruments, 2015), hence it was appropriate for the application. A fuse holder for a 20mm 3A fuse was added to the output of the regulator module. The 12V regulator module powered all non-motor electrical systems including the surface control box.

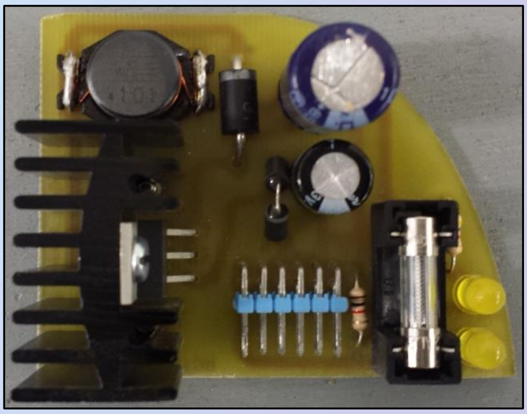

Figure 22. 12V regulator module.

3.3.5 *Control*

Communication: To control the ROV from a distance through the umbilical, two Arduinos were used which communicated with each other. One was in the surface control box and would receive input from the user then communicate instructions to the second Arduino in the ROV which controlled thrusters.

This method was used rather than wires directly from surface to the motor drivers because it required a small number of wires to communicate large amounts of data. A hardware only system would require long wires for each component that needs controlling to be installed which would be expensive and difficult to implement.

More wires also means more holes in the pressure vessel for the wires, which increases the chances of leaks occurring and so the Arduino communication method was safer.
Arduino Megas were used for this application because they had more PWM pins for controlling motor drivers and more memory which allowed greater freedom in terms of maximum size of programs compared to Arduino Unos. For communicating between the two Arduinos, the 'Inter Integrated Circuit Communications (I2C)' communication protocol was chosen. The alternatives, such as Serial, were mostly suited to point-to-point communications between two devices whereas I2C allowed fast and simple communications for a master device to up to 112 slave devices on the I2C bus (Sparkfun, no date). I2C hence allowed the system to be more versatile for future developments such as adding sensors and more tooling, which is why it was chosen. I2C however had one major disadvantage for this application which was that it has a very short operating range in terms of cables between devices. To solve this issue, P82B715 I2C-Bus Buffer modules were made which allowed for reliable communications through a 20m umbilical.

***Programming**:* The control program for the ROV was split between the surface (master) Arduino and the ROV (slave) Arduino. The surface code acquired user input data from a controller and calculated required motor thrusts as signed numbers, where the size of the number described the magnitude and the sign (negative/positive) described the thrust direction. These numbers were referred to as 'motor strengths' and were sent to the ROV Arduino via I2C, at a rate of approx. 125Hz (loops/sec), which then converted them to equivalent PWM and DIR pin values and applied to the motor drivers.

The program was made such that the master device did all of the motor strength calculations and the slave Arduino simply implemented the values it received without modifying. This setup meant the operation of the whole ROV could be adjusted by just changing the master code and so there would be no need to open the pressure vessel regularly. The master and slave programs also included watchdog timers, which meant the system would automatically reset itself and continue if an error occurred and so the system was robust. The master program also included non-essential extra features such as support for multiple controllers; namely PlayStation 4 (PS4), PlayStation 3 (PS3) and Xbox 360; which made the system more versatile for users who prefer different controllers; and "six-axis motion control" for PS4 and PS3 controllers which allowed the pilot to move the vehicle using hand motions. Flow charts of the programs are shown on in Appendix C.

3.3.6 *Cameras*

The ROV used Charged Coupling Device (CCD) board cameras with a resolution of 700TVL, equivalent to 976 x 582 pixels (eLine Technology, 2014). The alternative to CCD cameras are Complementary Metal Oxide Semiconductor (CMOS) cameras, which weren't chosen for this application because they produce lower quality images and are not as good for low light conditions compared to CCD cameras (Steve's Digicams, no date). Better image quality and better low light performance would benefit the pilot for missions under the ice, where the environment would be darker.

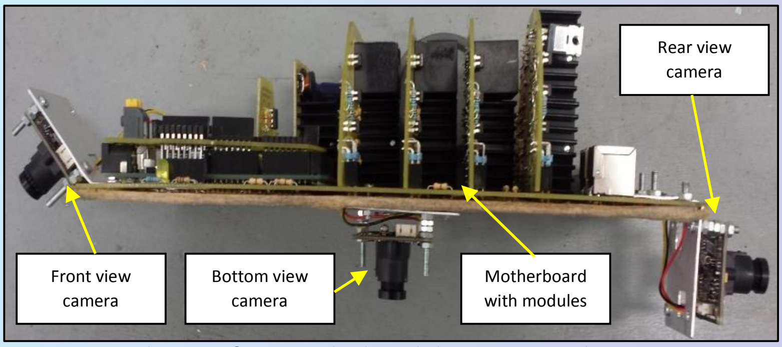

Figure 23. Side view of ROV motherboard showing internal camera positions.

Three board cameras were mounted on the motherboard in the pressure vessel to provide front (with a downward angle), bottom and rear views. A commercial underwater camera was used as the fourth external camera which had an adjustable position on the frame. A commercial camera was chosen because it would have been more reliable underwater than an in-house construction. The external camera greatly influenced the effectiveness of the pilot at certain tasks, such as the hot stab task, and so it had to be reliable. Another important factor for this decision was that the camera was donated by RGU and so it was cheaper than buying the components and materials to make an original design. To display the video feeds at surface, a commercial 4 Channel Video Processor was used because this could display all four video feeds simultaneously. Alternatives to this were to use video multiplexers which switched between video feeds, however this would greatly affect the effectiveness of the pilot during missions. There was no company member with the skills to create a reliable in-house built system to simultaneously display all four video feeds, hence a commercial system was used.

3.3.7 *Umbilical and Cable Connections*

The umbilical for the ROV was 20m long and consisted of five cables which were CAT6 for I2C communications and 12V power for the control box from the ROV, CAT6 for the three internal camera feeds, two 4.5mm^2 cross sectional area (approx. 11 AWG) cables for main 48V power and the umbilical for the external camera. The CAT6 cables were connected via RJ45 terminals at both the ROV and surface control box whereas the power cables were connected via screw terminals to the ROV boards and via Anderson power connectors to the surface control box.

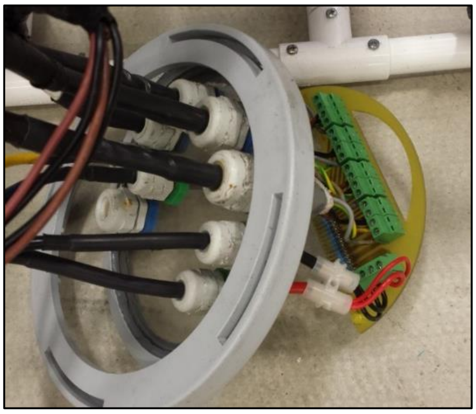

Figure 24. Motherboard connector module with motor cables attached.

On the ROV, screw terminals were used for interfacing the main power cables and motor power cables to the motherboard. Instead of having the user screw/unscrew cables every time the boards were to be removed, all of the screw terminals were placed on a detachable board, named the motherboard connector. This meant cables were screwed in one time on the connector board, which stayed on the ROV, and this provided a quick an easy way to connect/disconnect the rest of the boards from the vehicle.

3.3.8 *Control Box*

The control box used a modular design with a motherboard but with only two modules i.e. the Arduino and an I2C bus buffer. The motherboard received 12V power from the ROV through the I2C communications Cat6 cable over two pairs of strands. The motherboard was housed in a plastic Tupperware box with holes cut out for cables, which was cheaper to implement than making our own box. The Tupperware box was also used because it had advantages such as being made of insulator material, to protect people from electrical shocks, and it had a lid which could be locked on securely and removed easily.

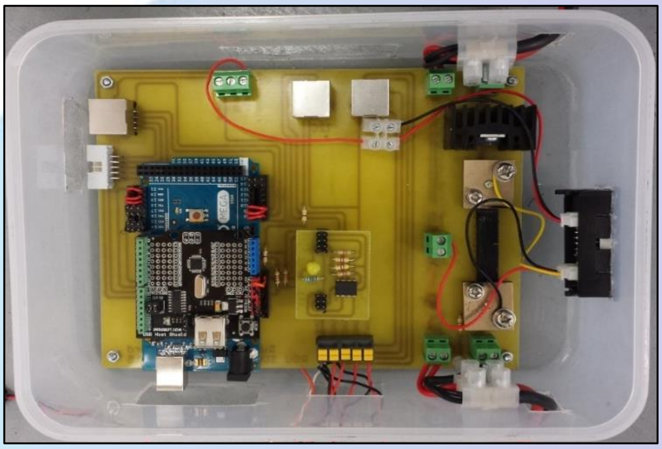

Figure 25. Control box without lid.

The surface control box was made for two main functions, which were interfacing the surface Arduino with the I2C bus and applying safety features to the ROV main power lines. The Arduino-I2C interface was achieved by linking the SDA, SCL and GND from the appropriate CAT6 through an I2C bus buffer to the Arduino.

3.3.9 *Task Systems*

Flow Meter: For the 'flow rate measurement' task in the offshore oilfield production and maintenance mission, the chosen solution was to use a Hall effect flowmeter mounted on a mount that allowed it to rotate with low friction. The mount had a vertical flat plate, referred to as a 'fin', whose centre point was a distance away from the centre of mass of the flow meter and the mount. This meant that as water flowed, the plate would produce a drag reaction force and this drag would produce a moment on the low friction mount, turning it until it faced the flow i.e. where drag would be minimum. With the flow meter and mount facing the flow, the device could accurately measure the flow rate to within 0.5L/min which is an equivalent of 0.06m/s, for the flow meter's inlet and outlet diameter of 13.5mm.

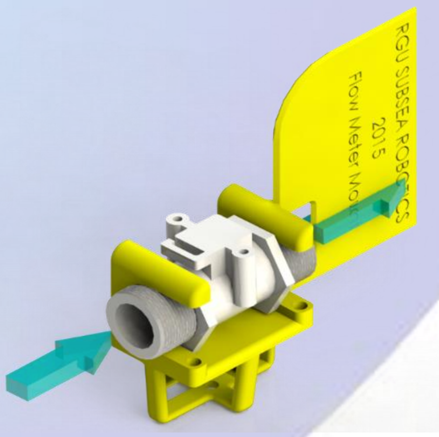

Figure 26. Flow meter on mount, showing water flow.

Anode Tester: for the 'testing grounding of anodes' task in the offshore oilfield production and maintenance mission, the chosen solution was to make a manipulator fitting, named the 'anode tester' which had two conductive pads. The conductive pads would be inputs to a diode full rectifier circuit which fixes the output polarity, which would be connected to the Arduino ground and an analog pin, and produces a 1.4V drop over the diodes which means the 6V would be reduced to 4.6V.

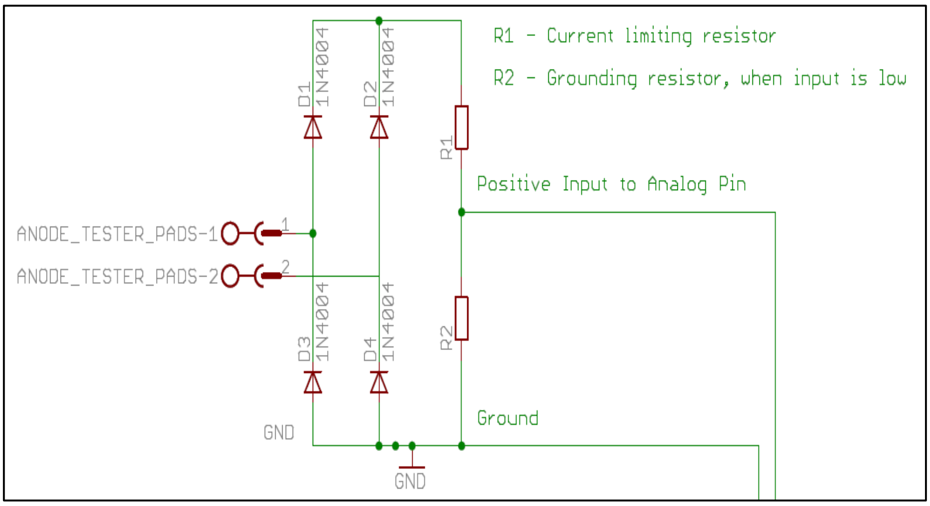

Figure 27. Anode tester, full diode rectifier circuit schematic.

The anode tester was mounted on the manipulator and the pilot would grip the platform leg such that the two conductive pads were in contact with an anode and the common ground. If there is a potential difference at the pads, the rectifier circuit would ensure the polarity is such that the positive is linked to an Arduino analog pin and the common ground to the Arduino ground and it would also reduce the voltage to 4.6V which is within the Arduino input range. The value of the analog pin would be sent to the surface and read by the user to determine if there is conduction i.e. high values mean conduction and vice versa.

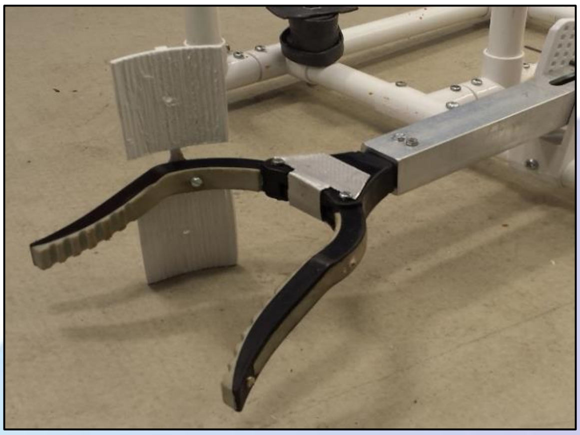

Figure 28. Anode tester mounted on manipulator.

4 Budget and Project Costing

The complete list of all the accounts spent on VIPER Mk. III can be found in Appendix D. The team spent £902.95 ($1386.84 USD) developing the vehicle (due to a previous accounting error, the total spend given for the previously submitted Spec Sheet is incorrect and different than that declared in this document). The company's initial approach to dividing the allocated budget of £1000 from the university was to draw up a list of required components. After which, the company liaised with the project mentors to determine whether the School of Engineering had any of the required components on the list readily available in-house, to reduce expenses. Any items from the list not readily available were then placed for order, after a group discussion.

5 Troubleshooting Techniques

Electrical: The ROV and control box software was made with two operating modes which were practical and debug mode. In practical mode the system works at a fast frequency, approx. 125Hz, for smooth response and operation and does not print operating data on the Arduino serial monitor as it would slow down the system. Debug mode works at a slower frequency of 5Hz and displays all appropriate operating data in terms of received user input, calculated motor strength, successful I2C data transmission/reception, errors etc. hence the program operation can be monitored to find the cause of errors. The slower frequency allows a user to read the operating data. Debug mode was used several times when software was being developed or improved as it served as a safe way to test new code and monitor what the program actually does.

The electrical hardware could be tested for faults easily due to the modular design. Each module and the motherboard could be tested individually for faults and this was done every time a new module was made. Testing involved testing the function of that board directly e.g. motor drivers had voltmeter put across the motor connections and the voltage measured when DIR and PWM pins were high or low, it passed the test if the expected results matched the actual results. So all the boards in the system were tested right after populating them, which meant they were reliable and because of this the company did not experience problems due to faulty boards. The modular design also allowed isolating particular systems for testing i.e. partially assembling the system by leaving out some modules, e.g. removing motor drivers and leaving only the horizontal thrust boards to test the horizontal motors.

Mechanical: When developing pressure vessel waterproofing methods, tissue was used to determine the origin of leaks. Tissues were wrapped around cables where they had been sealed and the tissue was sealed using latex glove fingers or electrical tape such that if there was a leak on a cable, the leak would not make the other cables wet and defeat the purpose of the test. Tissue was also inserted into cable glands from the inside of the pressure vessel. This tissue method was very useful in determining leaks and allowed us to achieve a reliable pressure vessel that stayed dry for over 70 hours, at a 3m depth. Figure 29 shows tissue that we still include to monitor leaks through cables.

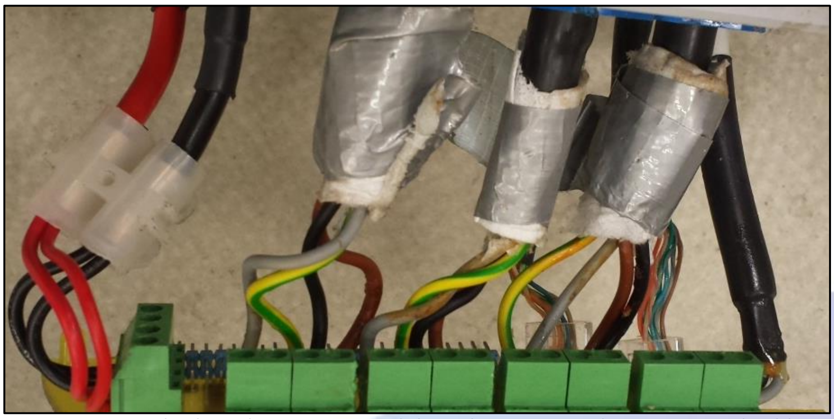

Figure 29. Motherboard connector module with tissue taped motor around cables.

6 CHALLENGES

Technical: In terms of technical difficulties encountered through the course of this project, one major issue the company had to deal with was the struggle in achieving a completely watertight pressure vessel. Many methods were attempted in hope of a solution but unfortunately most were unsuccessful. The team's first response in addressing this issue was to determine the source of the leak. Methods used to locate the leak involved securely attaching the back plate to the pressure vessel, with the cables and cable glands fully tightened, and partially submerging it in 1000 litre Intermediate Bulk Container, i.e. test tank, and then looking through the other end to see where water seeped through from.

Another method used to locate leaks, which was also used, was a full body submersion in the test pool. Before conducting this test, sheets of absorbent paper were inserted inside the pressure vessel and wrapped around the cables and cable glands on the inside of the pressure vessel. This way, the company was able to accurately determine which cables and/or cable glands were leaking. After extensive trial and error testing, various leaks were determined. The first was the biggest leak, which was found to occur in all cable glands and this was due to the cables not being thick enough to achieve a tight enough fit in the glands. The team's solution to this was to heat shrink the parts of the cables which would sit in the cable glands, this added an extra layer of thickness, allowing the cables to fit securely in the cable glands in minimal air gap.

Another source of leak was identified to be in the Cat5 cables. It was discovered that there was a small cut somewhere along the 20m cable, which allowed water to pass through the air gap, between the strands in the cable, and penetrate the inside of the pressure vessel. After extensive research and trial and error of various solvents and sealants, the optimum solution was determined to be an araldite resin. This was applied directly to the air gap in the Cat5 cables and seemed to perfectly resolve leakage issues. This was the same method used for the air gaps in four core cables.

Furthermore, another technical difficulty encountered through the course of this project, was whilst developing the manipulator. This is explained in the manipulator section of the design rationale (section 3.2.5 pg.7).

Non-Technical: The company encountered a few counts of non-technical difficulties. One of the biggest of which was that due to third year university coursework constraints, the company struggled to find the perfect balance between their university studies and the project. Also, at Robert Gordon University (RGU) during the second semester of the third year in an Engineering Degree, students partake in a group project which involves designing and developing a land yacht from scratch. This then meant that during the second semester, the company members were involved in two projects operating simultaneously, as well as other coursework and exams. This altogether caused for a lack in communication since different company members had different pieces of coursework to focus on at different times.

After realising the severity of this issue, company CEO Elias Mangoro decided to call an emergency company meeting to revaluate the initial Gantt chart and determine a solution by which the company were able to spend equal amounts of time on each component of their third year studies, including the ROV project. The solution determined was the use of a schedule, where at least a few members would work on the ROV build every day possible on a rotation basis. After each work session, the members involved in the session would ensure that the group log book was updated accurately. This provided sound results and the company were able to successfully complete all pieces of their third year coursework as well as the ROV project, in time for the regional demonstration run, which they aced. However the basic vehicle was completed and fully assembled later than planned, nearer to the end of March than the beginning which did not give the company a great deal of time to practice for the regional.

7 Future Improvements

The vehicle works well however improvements can be made. One improvement would be acquiring more powerful thrusters to increase the speed and lift of the vehicle to make it more effective and faster at completing tasks.

Another potential improvement would be to add more autonomy to the vehicle function, namely in the form of self-stabilisation. An I2C inertial measurement unit (IMU) could be included in the vehicle which would produce orientation and motion data. This data could then be used to let the system automatically control thrusters, on a reduced level, to keep the vehicle level if required. This could also be used to account for factors that cause the user input motion of the vehicle to be different to the actual motion of the vehicle such as water currents, flaws in geometric arrangement and direction of thrusters, drag, inertia etc. This would alleviate the work the pilot needs to do just to keep the vehicle steady and allow him to focus more on performing tasks.

8 Reflections and Skills gained

It has been difficult to acquire experience in the field of the oil and gas industry, thus the MATE ROV competition has been an invaluable opportunity; both allowing each member of the company to gain an insight into the engineering discipline as well as providing hands-on experience. This opportunity has also provided the company with first-hand experience in project management and seeing ideas evolve from concept through to completion, within project parameters such as timescale and budget. This project has also allowed the company to apply various theoretical models studied in a class-room environment, demonstrating the importance and significance of the team's degree programmes. Each member of RGU Subsea Robotics would consider this opportunity to have been very beneficial to their prospective career.

RGU Subsea Robotics is comprised of students of various engineering disciplines and experiences. These core qualities nurtured a dynamic approach to the development of VIPER Mk. III, the company's ROV, as the development plan involved a hierarchy of various divisions and subdivisions which catered to each company member's individual skills set and experience. Although this type of development plan was used, the major team decisions were made as a group, so each member was allowed the chance to voice their own opinion. In terms of team bonding, all members of the company were previously close colleagues before adventuring into the path of this project. This played to the company's strengths as team working, which is an important factor of any project, was at a maximum resulting in the success achieved by the team.

The team's general philosophy for the course of this project was to keep the vehicle build as simple as possible, whilst ensuring that the fundamentals were strong. The reason for this was to minimise the risk of failure of the project and vehicle and maximise productivity, resulting in a sound vehicle. RGU Subsea Robotics was fortunate enough to be granted a range of incredible facilities and support, such as the underwater testing pool, which the company made excellent use of. This allowed the company to conduct solid testing of the vehicle, to ensure the project deliverables were accurately met, as per the mission brief.

The company feels that one of the main skills gained through this experience, was the ability properly research new subject matters, with no prior experience and to then conduct technical development in that field. Before embarking on VIPER Mk. III, the majority of the company had limited ROV experience. Only through going out and researching the information required from a first-hand principle and then extracting the appropriate information and using a trial and error method to determine successful solutions, were the company able to develop a keen sense of knowledge in the development and uses of ROVs.

During the course of project, the company considered the outreach component of the MATE ROV Competition of great importance. This was because it allowed the company to raise its profile, as well as the profile of the university, MATE, the competition and engineering to a wider community around Aberdeen. Therefore, the company embarked on many corporate social responsibility events.

The company's biggest event to date was the Discovery Day event, which took place at the Satrosphere Science Centre during the National British Science Week. As part of this event, the company hosted a workshop and set up a MATE stand. The workshop involved some talks and presentations on the science behind ROVs and the MATE ROV Competition. Also two activities were set up involving tanks of water and mini-ROVs used to allow the attendees a chance at piloting an ROV. The first activity was 'ROV Football' and the second was a 'Christmas-Tree' workshop, where the attendees got some first-hand experience in completing ROV missions based on real life scenarios. This event, which ran for 6 hours, had been attended by 735 visitors.

Figure 30. Scott and Ross stumped by a puzzle at Satrosphere.

Overall, the team feels that participating in the MATE ROV Competition has been one of the best experiences of their university studies. The company are really grateful for the opportunity and feels that they have learnt a great deal, whilst gaining exposure to an important aspect in the oil and gas industry and industry professionals whom they aspire to emulate upon graduating.

9 Acknowledgements and Sponsors

RGU Subsea Robotics would like to acknowledge and personally thank the following people for their efforts assisting in manufacturing some of the components the company designed, allowing the company to access to certain tools and general advice that assisted the company to achieve its goals.

University Staff: Graeme Dunbar, Alan McLean, John Still, Martin Johnston, Stephen Allardyce, David Howie, David Smith, Andy Ross, Margaret Craig, Les McLaren, Gavin Murison and Phil Chaplain.

They would also like to acknowledge and thank the companies that sponsor the MATE ROV Competition, without which none of this would have been possible.

Table 1. Table of Sponsors.

Sponsors			
BP	**FUGRO**	**ROVOP**	**Marine Advanced Technology Education**
Sponsored travel expenses and MATE Scotland ROV Challenge	Sponsored MATE Scotland ROV Challenge.	Sponsored MATE Scotland ROV Challenge.	Hosted the MATE competition.
DOF Subsea	**SubseaUK**	***Dassault Systemes: Solidworks***	***Robert Gordon University***
Sponsored MATE Scotland ROV Challenge.	Sponsored travel expenses and MATE Scotland ROV Challenge	Sponsored the company with free Solidworks licenses.	Provided funding, facilities and material for the company.

Also the company would like to acknowledge software used during the project which was significant to the team.

Software used: Solidworks, EAGLE PCB, Arduino, Adobe Photoshop, WordPress, Draw.io, GanttProject, Microsoft Office and Google Drive.

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11 APPENDICES

APPENDIX A – ROV SAFETY PROCEDURES

The safety checklist and procedure for the vehicle is shown below for different functions, where general descriptions for procedures are shown in bold with more descriptive sub-steps shown.

A. *Pre-dive setup procedure:*

Ensure vehicle boards and cables are inserted correctly, motors are shrouded and pressure vessel is sealed correctly (Perform if pressure vessel has been opened and needs sealing):

1) Check cables are securely fastened in motherboard connector board in correct positions.
2) Check all boards are inserted fully at correct positions on motherboard.
3) Check Cat6 cables are connected in correct ports on motherboard and control box.
4) Check O-ring was greased and insert on pressure vessel end cap.
5) Check pressure vessel was properly sealed i.e. locking ring is fully locked on inner end cap fixing.
6) Check pressure vessel is sealed correctly i.e. O-ring is in correct position and cannot be seen from the inside or outside of the pressure vessel.
7) Check cable glands are tight and no cables are loose.
8) Check all propellers are properly shrouded.
9) Check motors are at correct angles and within frame.

Ensure correct control box connections are made:

1) Connect ROV umbilical main power to control box main power Anderson connector, on correct end.
2) Check board and cable connections in control box are correct and secure.
3) Check controller is connected.
4) Check camera phono plugs are plugged into video processor.
5) Switch on monitor and video processor and ensure display cable is between them, such that screen showing blank channel feeds is shown.
6) Plug in control box main power Anderson connector to 48V supply.

B. *Mission Safety Checklist:*

These are checks conducted prior to ROV launch.

Table 2. Mission safety checklist table

	Check list	Tick Boxes
1.	ROV System Pre-dive checks complete, as per pre-dive setup procedure:	
2.	Toolbox talk of the mission plan	
3.	Each company member briefed and clear on mission roles	
4.	Site cleared of all obstructions	
5.	Site cleared of all non-critical personnel	
6.	Full required PPE checks complete	
7.	Completed all checks	
8.	If check 7 is ticked, power ready to be switched on	

C. ROV pre-dive test procedure:

1) Check overall system for any anomalies.
2) Check all controller inputs are zero, i.e. no input to system to do anything.
3) Turn battery isolator key to power system and check control box power LED is YELLOW.
4) Check supplied voltage is approximately 48V using voltmeter on control box.
5) Check camera feeds on all four channels show video from ROV on monitor.
6) Wait for LEDs on controller to come one, indicating program is running.
7) Test that ROV communications are working by, lightly, testing thrust input and waiting for a response.
8) Switch

D. ROV launch procedure:

1) Ensure system is powered down i.e. battery isolator key removed.
2) Lift vehicle and place in pool, gently, and keep one personnel at side of pool near ROV.
3) Switch battery isolator key on, to power system.
4) Check bottom camera for any indication of a water leak inside the pressure vessel, if water leak is visible switch power off and remove vehicle from pool IMMEDIATELY.
5) If no leak visible then ROV was setup successfully and is ready for use.

E. Vehicle recovery procedure:

1) Manoeuvre ROV to surface and against a wall near a company member.
2) Power down ROV by completely removing power key.
3) Carefully lift ROV out of water.

Appendix B – System Integration Diagram (SID)

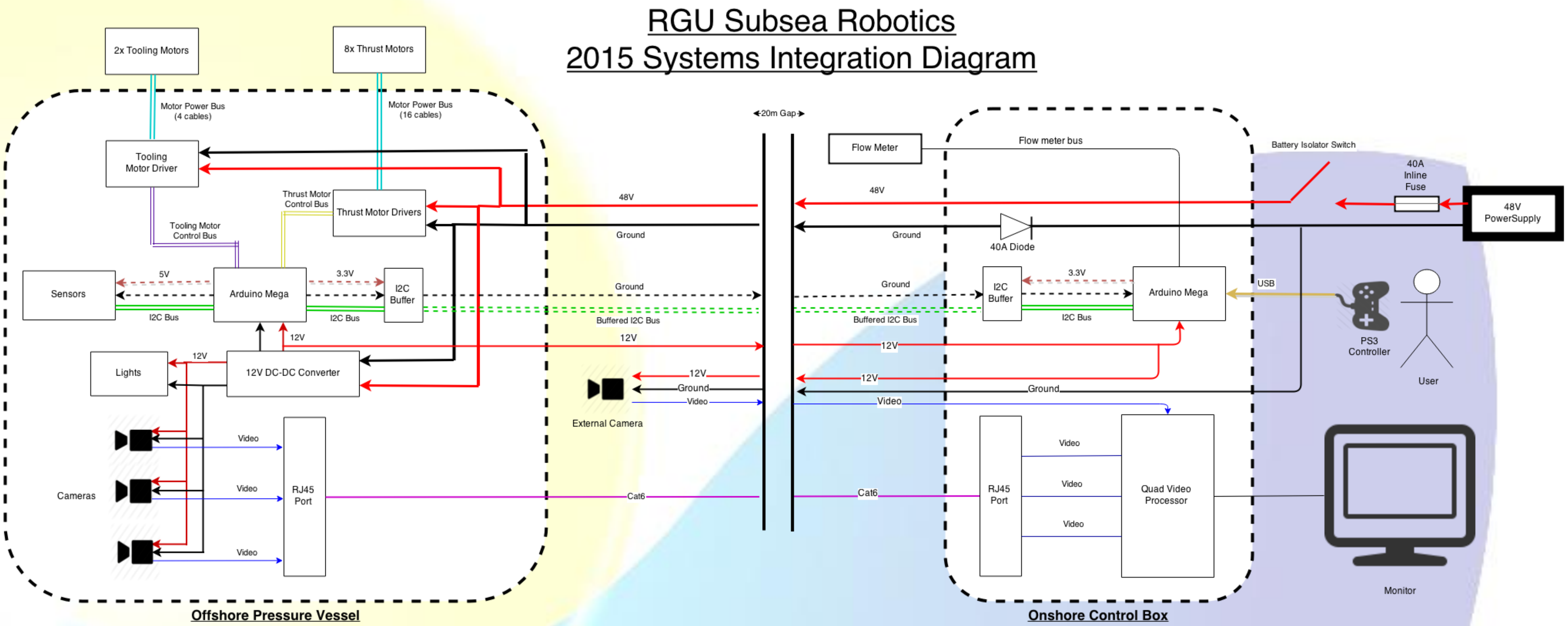

Figure 31. Systems Integration Diagram (SID)

APPENDIX C – SOFTWARE FLOW CHARTS

Master Arduino Software Flow Chart

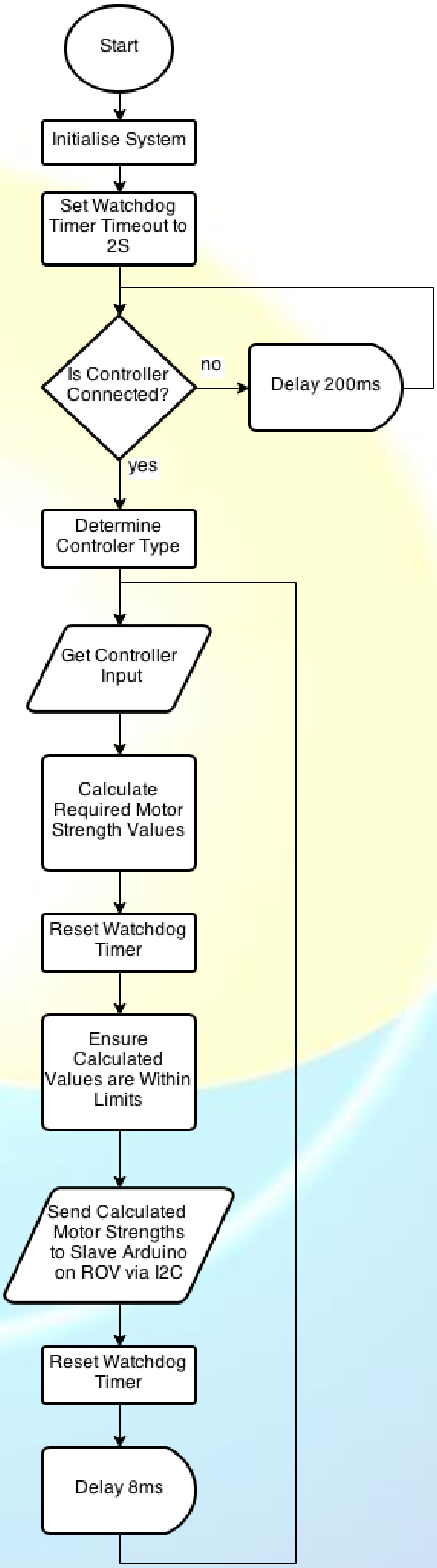

Figure 32. Surface (Master) Arduino Software Flow Chart

Slave Arduino Software Flow Chart

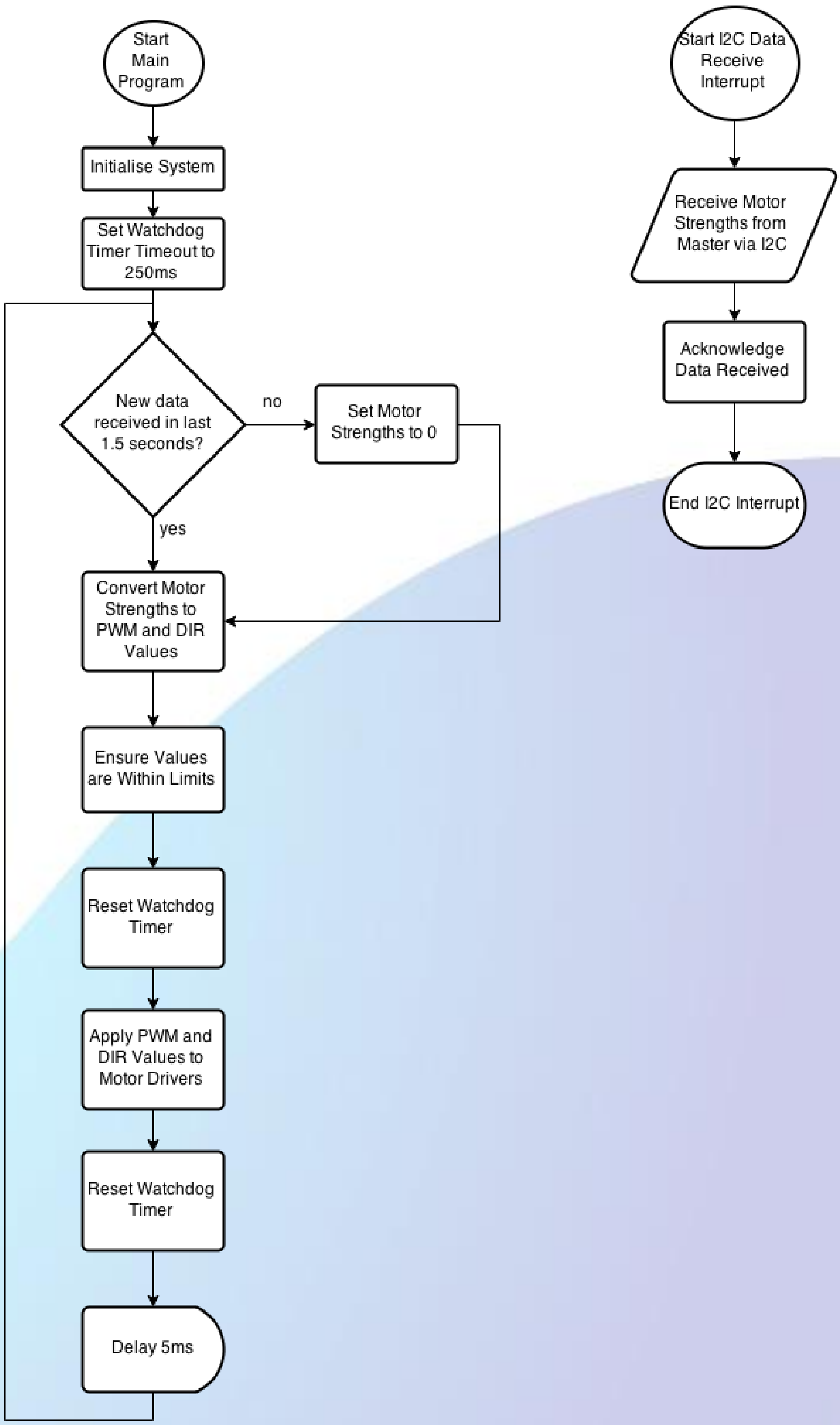

Figure 33. ROV (Slave) Arduino Software Flow Chart

Appendix D - Project Costings: Income and Expenses

RGU:Subsea Robotics - Robert Gordon University Mentor: Graeme Dunbar Reporting: 22 SEPT 2014 - 25 MAY 2015

Purchase Date DD/MM/YY	Type	Departmental Expense	Parts Description	Original Supplier	Qty.	Unit cost	Total Cost	Running Balance
22/09/2014	Donated	Grant	University Project Grant	Robert Gordon University	1	£1,000.00	£1,000.00	£1,000.00
30/10/2013	Re-Used	Frame	21.5mm Waste Overflow Pipe 3m - Pack of 10	Screwfix	1	-£12.90	-£12.90	£987.10
30/10/2013	Re-Used	Frame	21.5mm Waste Overflow 90 Degree Bend - Pack of 5	Screwfix	4	-£2.69	-£10.76	£976.34
30/10/2013	Re-Used	Frame	21.5mm Waste Overflow T Join - Pack of 5	Screwfix	9	-£2.69	-£24.21	£952.13
04/12/2013	Re-Used	Electrical Part	N-Channel MOSFET	RS Components	18	-£0.88	-£15.84	£936.29
07/01/2014	Donated	Thrusters	Brass Coupling W/ Grub	University Storerooms	10	-£0.30	-£3.00	£933.29
07/01/2014	Re-Used	Thrusters	Bilge Pump	Stainless Direct	10	-£18.99	-£189.90	£743.39
10/01/2014	Re-Used	Camera Systems	HD 700-TVL Colour Board Camera 3.6mm Lens	Securitycamera2000	3	-£16.41	-£49.23	£694.16
10/01/2014	Re-Used	Camera Systems	HD 700-TVL Colour Board Camera 2.8mm Lens	Securitycamera2000	2	-£18.23	-£36.46	£657.70
10/01/2014	Re-Used	Camera Systems	Video Calliber to Line Cable Jack	Securitycamera2000	5	-£2.43	-£12.15	£645.55
10/01/2014	Re-Used	Camera Systems	2.8mm CCTV Board Surveillance Camera	Securitycamera2000	3	-£3.65	-£10.95	£634.60
10/01/2014	Re-Used	Camera Systems	3.6mm CCTV Video Camera Lens - for Security	Securitycamera2000	1	-£3.34	-£3.34	£631.26
10/01/2014	Re-Used	Camera Systems	4 CH Camera Video Quad Processor Splitter	Securitycamera2000	1	-£53.29	-£53.29	£577.97
10/01/2014	Re-Used	Camera Systems	4 CH Passive Long Distance Twisted Pair Video Ballun	Securitycamera2000	2	-£7.00	-£14.00	£563.97
03/02/2014	Re-Used	Pressure Vessel	Clear Acrylic Tube	KM Wholesale	1	-£11.70	-£11.70	£552.27
03/02/2014	Re-Used	Pressure Vessel	Hemispherical Dome	KM Wholesale	1	-£12.25	-£12.25	£540.02
10/02/2014	Re-Used	Tether	CAT6 Cable Blue 20m	Cabling4less	1	-£11.88	-£11.88	£528.14
10/02/2014	Re-Used	Tether	CAT6 Cable Yellow 20m	Cabling4less	1	-£11.88	-£11.88	£516.26
25/02/2014	Re-Used	Manipulator	Draper Litter Picker	Amazon UK	1	-£5.17	-£5.17	£511.09
25/02/2014	Re-Used	Electrical Addition	Arctic Cooling Thermal Compound	Amazon UK	1	-£3.79	-£3.79	£507.30
25/02/2014	Re-Used	Thrusters	Bilge Pump	Stainless Direct	2	-£18.99	-£37.98	£469.32
25/02/2014	Re-Used	Electrcial Part	8 PIN I/O Expander	RS Components	3	-£3.07	-£9.21	£460.11
25/02/2014	Re-Used	Electrcial Part	PCB Relay DPDT	RS Components	2	-£2.30	-£4.60	£455.51
25/02/2014	Re-Used	Propeller	3 Blade Model Boat Propellers - Pack of 2	HobyKing	5	-£1.08	-£5.40	£450.11
10/03/2014	Re-Used	Thurster Shroud	3D Print Production Shroud Assembly - 4 Unit Runs	Gray's School of Art	1	-£111.95	-£111.95	£338.16
10/03/2014	Re-Used	Tether	Standard Cable 5.0mm OD - Black - 1m	Auto Electric Supplies	20	-£0.95	-£19.00	£319.16
10/03/2014	Re-Used	Tether	Standard Cable 5.0mm OD - Red - 1m	Auto Electric Supplies	20	-£0.95	-£19.00	£300.16
19/03/2014	Re-Used	Electrical Part	Switching Diode	RS Components	2	-£2.54	-£5.08	£295.08
19/03/2014	Re-Used	Electrical Part	Phototransistor Output Optocoupler	RS Components	20	-£0.29	-£5.80	£289.28
19/03/2014	Re-Used	Electrical Part	4-Pole Straight Cable Mount Circular Connector Male	RS Components	1	-£4.10	-£4.10	£285.18
19/03/2014	Re-Used	Electrical Part	4-Pole Straight Cable Mount Circular Connector Female	RS Components	1	-£4.10	-£4.10	£281.08
19/03/2014	Re-Used	Electrical Part	PCB Mount Non-Latching Relay	RS Components	6	-£2.15	-£12.90	£268.18
19/03/2014	Re-Used	Electrical Part	Extruded Heat Sink	RS Components	10	-£0.82	-£8.20	£259.98
03/10/2014	Re-Used	Electrical Part	8 Pin Stackable Header for Arduino	Amazon UK	10	-£0.90	-£9.00	£250.98
03/10/2014	Re-Used	Electrical Part	Splashproof In-line 40A Fuse Holder	Amazon UK	2	-£1.48	-£2.96	£248.02
03/10/2014	Re-Used	Electrical Part	40A Standard Fuse - Pack of 20	Amazon UK	1	-£2.49	-£2.49	£245.53
03/10/2014	Purchased	Electrical Part	Arduino Mega 2560 R3 UNO	Amazon UK	1	-£18.50	-£18.50	£227.03
03/11/2014	Purchased	Manipulator	Aluminium Hollow Bar	Ebay	1	-£6.12	-£6.12	£220.91
09/11/2014	Purchased	Pressure Vessel	M16 SIB Cable Gland (Pack of 5)	RS Components	2	-£2.80	-£5.60	£215.31
09/11/2014	Purchased	Pressure Vessel	M20 SIB Cable Glands (Pack of 5)	RS Components	2	-£3.17	-£6.34	£208.97
09/11/2014	Purchased	Teather	White Flex Cable - Four Core - per meter	TLC - Direct	5	-£0.70	-£3.50	£205.47
09/11/2014	Purchased	Motor Mounts	Insulated Pipe Clamps	Hoses Direct	12	-£1.52	-£18.24	£187.23
09/11/2014	Purchased	Frame	Macrofix Pipe Mounting Bracket	Hoses Direct	2	-£5.08	-£10.16	£177.07
14/02/2015	Donated	Ballast	Assorted Lead Plates	University Storerooms	1	-£2.00	-£2.00	£175.07
14/02/2015	Donated	Tether	CAT5 Connection Head - Manual Install	University Storerooms	6	-£0.06	-£0.36	£174.71
14/02/2015	Donated	Frame	Self-Tpping Screw No. 4	University Storerooms	50	-£0.01	-£0.50	£174.21
16/02/2015	Donated	Manipulator	3mm Aluminium Sheet - 4x4cm	University Storerooms	1	-£0.32	-£0.32	£173.89
09/03/2015	Purchased	Electrical Part	Heavy Duty Power Connectors (Anderson)	Mouser Electronics	8	-£2.03	-£16.24	£157.65
09/03/2015	Purchased	Electrical Part	Heavy Duty Power Connectors (Anderson) Housing	Mouser Electronics	4	-£1.43	-£5.72	£151.93
19/03/2015	Purchased	Tether Cover	Braided Sleave	Amazon UK	4	-£3.95	-£15.80	£136.13
19/03/2015	Purchased	Electrical Part	Car Battery Monitor - Voltmeter/Ammeter	Amazon UK	1	-£12.50	-£12.50	£123.63
19/03/2015	Purchased	Electrical Part	Battery Isolator Switch	Amazon UK	1	-£6.94	-£6.94	£116.69
19/03/2015	Purchased	Electrical Part	Battery Isolator Switch	Amazon UK	1	-£6.94	-£6.94	£109.75
20/05/2015	Purchased	Manipulator	Printed Manipulator Support Mount - White	University 3D Printer	1	-£5.50	-£5.50	£104.25
20/05/2015	Purchased	Manipulator	Printed Manipulator Support Surrond Linkage - Red	University 3D Printer	1	-£7.20	-£7.20	£97.05
							Remaining budget	**£97.05**

All values given above are in British Pounds Sterling (GBP). Exchange rates shown are correct as of 15:00 BST 27 May 2015. (1 GBP = 1.9094 CAD) (1 GBP = 1.5359 USD) (1 CAD = 0.8037 USD). Travel and Transit costs are not included in the above accounts.

Currency Equivalents	GBP	CAD	USD
Total Funds Recived - University Grant	1000.00	1909.39	1535.89
Total Funds Spend - Construction Costs	902.95	1724.09	1386.84
Total Funds Remaining - Returned to University	97.05	185.31	149.06
Travel to International Competition	4800.00	9165.00	7372.00
Total project spend (Spend + travel)	5702.95	10889.09	8758.84