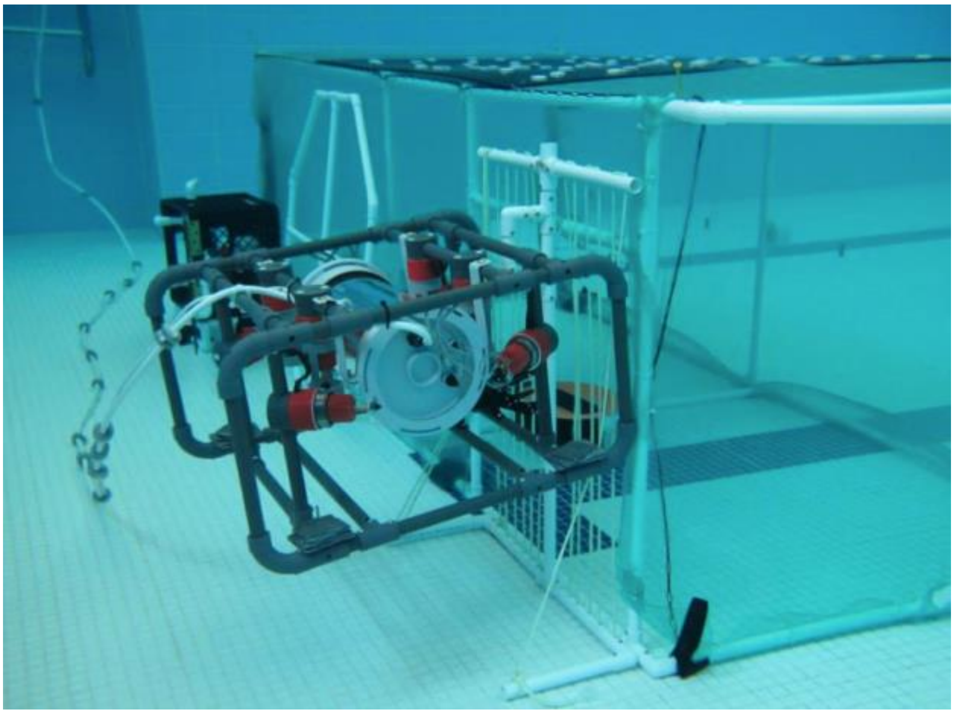
MATE International Student ROV Competition 2014 – EXPLORER Class

RGU Special R.O.V Service

Technical Report

Swimming Haggis MKII



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Distance Travelled: 3442 Miles

Abstract

RGU's Special R.O.V Service (RGU SRS) is a company comprising of 3rd year engineering students from Robert Gordon University (RGU) in Aberdeen Scotland who are building an EXPLORER Class ROV for the 2014 MATE International Student ROV Competition to carry out scientific, archaeological and conservation tasks at the Thunder Bay National Marine Sanctuary in Alpena, MI, USA.

The company had a budget of £1000 ($1687) to design and build a ROV from a blank sheet starting at the beginning of the new academic year in September 2013, to being fully operational by the regional competition in April 2014. The ROV system fits into standard airline baggage allowance size flight cases to minimise transportation costs.

The ROV created by the company is called the Swimming Haggis MKII. It evolved from lessons learned from the company's first ROV, the Swimming Haggis MKI, which was built to RANGER Class specification for an internal RGU competition in 2013.

The Swimming Haggis MKII is built in accordance to a, 'keep it simple,' design ethos. Every part of the ROV has been thought out and considered to be able to carry out the tasks in the most efficient way possible without the need for any unnecessary complication.

The Swimming Haggis MKII is a compact manoeuvrable ROV with precision control. This lets it do the basics well. With the addition of effective tooling it can complete tasks with ease.

The team. from left to right: Robbie Williams, Bruce Bob Mackenzie, Matthew Head, Ross Templeton and Matthew Downie

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1. Design Rationale

1.1. Design overview

Special ROV Service's design motivation was to build a simple and effective ROV with the philosophy of doing the basics well. We focussed on simplicity and reliability without adding any unnecessarily complicated design features and tooling. This, 'keep it simple,' philosophy is born out of the need to maximise the company's £1000 ($1687) budget. Every aspect of the Swimming Haggis MKII has been considered and rationalised to deliver the most effective solution with the minimum of fuss and complexity. This allows the company to deliver on the set mission tasks in the best way possible. The ROV size was determined at the outset by airline baggage limits to minimise shipping costs.

The ROV is modular which allows for easy interchangeability of various system components. This is to allow for any upgrades or change in designs to be easily implemented. With nearly all components built in-house by the company using the facilities at Robert Gordon University, the Swimming Haggis MKII is fully customised to meet the challenge of the mission tasks.

Controllability of the ROV is of high priority to the company. This led to a design that has good stability due to the large metacentric height. The control software allows for full analogue control of the ROV in all planes and gives very fine control that allows the pilot to easily and effectively carry out mission tasks.

1.2. Subsystems

1.2.1. Frame

In the previous academic session, Special R.O.V Service built a proof of concept ROV to 2013 RANGER Class specifications called The Swimming Haggis MKI. As can be seen in Figure 1, it consists of a rectangular frame which is made up of an inner square frame to hold the motors in position, with the outer rectangle protecting the ROV systems. With the decision to use vectored thrust the most effective way of implementation is to have all four vector motors equally spaced apart in all directions. This was however slightly compromised in order to incorporate other parts of the design but overall the Swimming haggis MKI frame design did not deviate from its initial concept. Upon water testing the MKI it was shown to be very stable and manoeuvrable in the water. This led to the design of the swimming haggis MKII frame being an evolution of the tried and tested design of the MKI.

Figure 1 the swimming Haggis MKI frame

Figure 2 The Swimming Haggis MKII frame

As can be seen in Figure 2 the frame of the Swimming Haggis MKII is taller than the MKI's frame which allows for the on-board pressure vessel and also improves the stability of the vehicle. The pressure vessel consists of two standard drainpipe inspection covers fitted to the end of a clear Perspex tube.

The drainpipe inspection covers were chosen due to their ability to provide simple access and a good watertight seal. A clear Perspex tube is used so both the ROV cameras can be housed within it negating the need to develop secondary waterproofing for the camera system. This also allows easy visual inspection of the circuits of the ROV. The pressure vessel is mounted transversely on the ROV as this improves its left-to-right stability while also allowing the tilt function of the ROV to perform more efficiently. Furthermore the main camera is able to tilt therefore giving a 180° view around the ROV; if the pressure vessel was mounted longitudinally part of the mounting points would be in the view of the camera.

1.2.2. Propulsion

The ROV consists of 8 Rule 1100 GPA 24 V bilge pumps which are rated at 2.5 A. These pumps were chosen due to their already watertight housing while being easy to modify for the purpose. Furthermore the motors are cost effective relative to the source of power they provide. The motors are modified by taking the outer housings off and removing the impeller. Brass couplings are fitted with an M4 thread that the propeller bolts onto.

2 Blade Racing Propeller 32.5 mm diameter right handed M4 are used on all 4 motors. The 2 blade propeller is used because compared to 3 or 4 blade propeller designs they are the most effective when being driven in reverse direction. Although a 3 blade propeller design offers more thrust in the forward direction this is reduced by 75% when it is operated in reverse; on the other hand a 2 blade propeller produces 50% less thrust in reverse. This trait is of particular advantage on the lift motors is all motors are mounted in the same direction so there is always a reduction of power in one particular direction. (1)

32.5mm blade size was used as this best suits the characteristics of the bilge pump motor. This propeller size allows the motor to run at its maximum efficiency under full power, this means that the stress is placed upon the ROV drives system is kept at manageable levels therefore making for a reliable system. Upon testing the ROV the company was happy with speed and performance that these propeller blades give the ROV. (1)

In early tests the lift motors were installed facing upwards and at the bottom of the ROV. This meant there was more thrust while going down then was to lift the ROV. Upon testing the ROV it become apparent that more upward thrust would be beneficial and the ROV could be trimmed to be slightly negatively buoyant if it needed to descend at a faster rate. This led to the repositioning of the vertical thrusters to the upper part of the ROV.

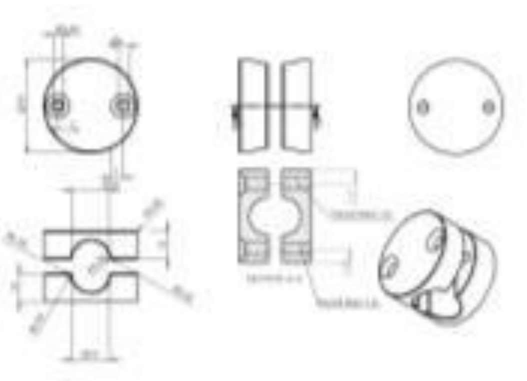

Figure 3 design drawing for motor mounts

The horizontal motors are positioned to allow for vector thrust controls to be used. This means the pilot has complete control of the ROV and is able to send it in any direction that they require. Therefore having the fine control to be able to carry out the missions.

The motors themselves are mounted to the frame with plastic motor mounts that are designed by the company and constructed in Robert Gordon University's workshop (Figure 3). The reason for this choice of mounts is to give a tidier neater

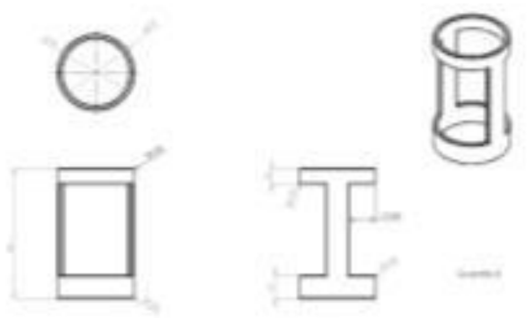

Figure 4 design drawing for propeller guard

looking way of fitting a motor without using any metal parts. Another feature these mounts have is that they allow the position of the motor to be adjusted easily.

A safety feature of the propulsion system is the Perspex guards (Figure 4) that surround the propellers. These have been designed to be easily removable and not block too much of the water thrust flow from the motors propeller. A variety of tooling and subsystems are required in order for the ROV to complete the tasks. The great lakes theme provides both a challenging and a thoroughly invigorating challenge in order to seek out and explore a shipwreck.

1.2.3. Tooling

1.2.3.1. The Claw

The claw manipulator is the main subsystem comprising the Swimming Haggis MKII. The “claw” as it is affectionately known comprises of a modular gripping system, which can be adapted to have either 2, 3 or 4 configurations depending on the environment and more importantly, the shape of the objects. The 3 gripping configuration is achieved by the fitment of two bosses designed by the company and 3D printed at RGU. A 12 V waterproof DC motor is geared in order to spin a M4 threaded bar, this in turn moves a threaded boss up and down. This boss is attached to the grips bringing them in or out depending on the rotation of the motor. One configuration of the claw can be seen in Figure 5.

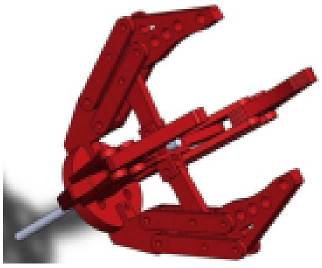

Figure 5 Claw Configuration

It can be used in any number of tasks such as the removing of the debris on the sea floor and the anchor system. It is important for all ROVs to have a manipulator system in order to affect the environment round it and the design must be as versatile and effective as possible in a changing environment in order to complete the tasks required. We believe that the claw that we have designed will be an effective and versatile instrument.

1.2.3.2. Measuring System

Part of the Great Lakes challenge is to identify an underwater wreckage of a ship. This requires measurements and observations to be made such as the type of cargo it was carrying, type of ship, homeport, build year and the ships dimensions. For the ship dimensions task the company decided that a simple solution would be the most effective. In this case a simple measuring tape (Figure 6) within an aluminium frame. It is stated in the rules that bolts would be protruding from the frame of the shipwreck which meant that a protrusion of sorts must be used in order to minimise the amount of time to hook the bolt. In this case a large wardens keyring was used and attached to the tape measure.

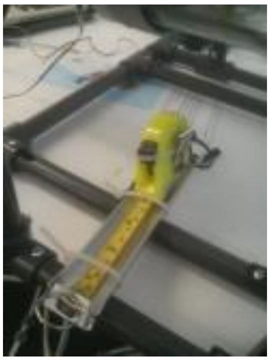

Figure 6 Measuring Device

The aluminium base also has a rounded edge for the tape measure so that it can operate in both the horizontal and vertical planes.

1.2.3.3. Plate Skid

Another of the shipwreck challenges is to be able to identify the home port which the ship came from. This is done by picking up a plate inside the shipwreck and returning it to the surface. For this the company implemented a skid which will drag along the pool floor and hold the plate underneath the ROV. The design rationale behind this is to be able to get underneath the plate with relative ease using the skids regardless of the difficulty to get leverage with the plate sitting on the pool floor. By having the skids a set distance apart the plate is locked into place as the Haggis moves forward having the curvature of the plate protruding out. In order to stop the plate from slipping out the tilt function of the ROV is implemented so that is slightly back heavy and the other side of the skid is sealed so the plate cannot escape.

1.2.4. Cameras

Figure 8 Camera System

It is important to RGU SRS that visibility around the Swimming Haggis is maximised whilst minimising the number of cameras on-board therefore reducing the number of wires required for the tether. In order to achieve this a tilting camera with a wide angle lens using a servo configuration as seen in Figure 8 was implemented taking advantage of the clear Perspex pressure vessel. The servo is capable of moving 270 degrees however this was restricted to 180 degrees as shown in Figure 7 so that the camera does not interfere with the motherboard. In addition to the tilting camera another camera faces the rear of the Swimming Haggis allowing us to monitor the tether.

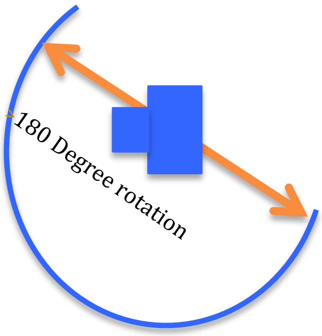

Figure 7 Full range of view

A second camera board was also implemented that has the sole purpose of monitoring the tether and would use a wide angle lens in order to maximise its angle of view.

1.2.5. Circuit Design

Throughout the design and build of the Swimming Haggis MKII the team philosophy has been to keep everything simple. In accordance with this the electronic systems onboard the ROV have been designed to be non-complicated.

The electronics are all contained in a single pressure vessel on the ROV. This includes the microprocessor and shield, several voltage regulators, motor controllers for both the propulsion and the manipulator, cameras and the servo to provide the tilt function for the main camera.

With the exception of the voltage regulators and microprocessor, all the circuits featured in the Swimming Haggis MKII were designed, populated and tested by members of our company. We also had the opportunity to fabricate the printed circuit boards ourselves.

1.2.5.1. Electronics

Figures 9 and 10 and the show the ROV circuit boards with the major subsystems labelled.

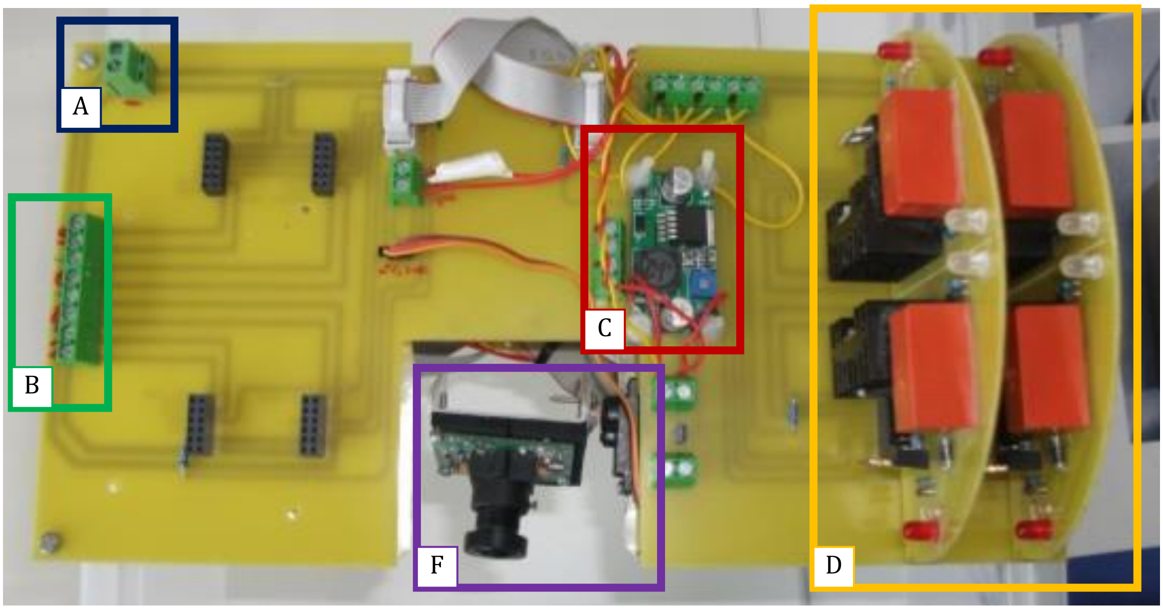

Figure 9 Motherboard Plan View with Two Dual Motor Drivers

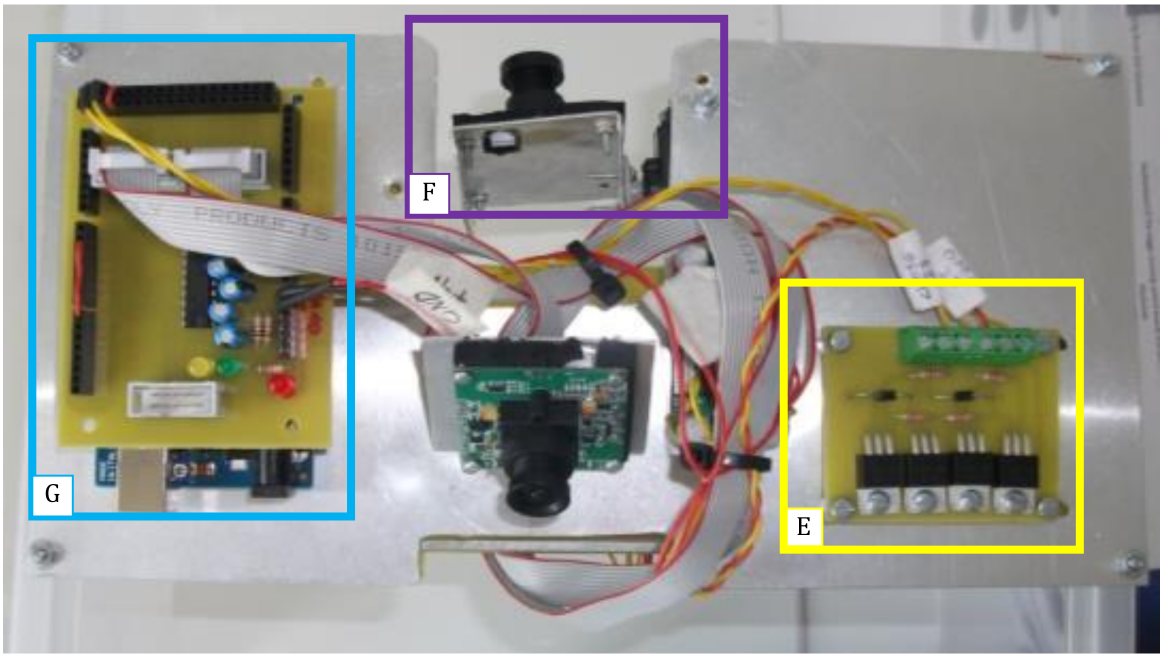

Figure 10 Underside of Motherboard

A - Power Input Connection 48 V
B - Motor Output Connection
C - Voltage Regulators dropping 48 V to 5, 9 and 12 V
D - Propulsion Motor Control Circuits (H bridge relay)
E - Manipulator Motor Control Circuit (H bridge Darlington)
F - Tilt Camera and Servo
G - Arduino Mega Microprocessor with Shield

1.2.5.2. Motherboard

The motherboard is used to connect the electrical systems on the ROV together. It is the largest circuit board in the ROV and has been attached to a reinforcing bracket. This then forms a base for all the other circuits to be connected to. By connecting all the electronics to this one board it can all be removed from the pressure vessel as a single unit. As well as providing a structure to attach the circuitry to, the motherboard also organises the power connections and control signals within the pressure vessel. See Figures 9 and 10.

1.2.5.3. Power

The 48 V supply and ground from the tether is connected directly to the motherboard. These are then connected to each of the eight motor control circuits through pin header terminals. These allow the motor driver circuits to be easily removed and swapped. The 48 V supply is also connected to the three voltage regulator boards using screw terminal connectors. These hold the wires connected to the regulators securely while still allowing them to be disconnected if necessary. The output of the 9 V regulator is then connected directly to the Arduino Microprocessor, while the 12 V and 5 V outputs are returned to the motherboard to be redistributed to the tooling, cameras, lights and servo.

1.2.5.4. Signals

The control signals from the Arduino are connected to the motherboard in the form of two 10 way ribbon cables. These contain the motor speed and direction control signals as well as control signals for both the lighting and servo. The ribbon cables provide the link to ports on the motherboard which send each individual signal to the appropriate destination. This method provides a neater way to organise the wiring inside the pressure vessel rather than using a separate wire for every connection.

1.2.5.5. Voltage Regulators

The electronic systems on the Swimming Haggis require 4 different voltage levels. The Arduino microprocessor operates on 9 V, the cameras and tooling use 12 V and the servo and line drivers operate on 5 V. In order to produce all the required voltage levels three separate voltage regulator circuits are included.

As they are of critical importance we elected to purchase pre-built voltage regulators rather than design and build our own as we had with the other circuitry. The Swimming Haggis uses the LM2596HV step down power supply module. This is not only more efficient but most importantly much more reliable than a homemade voltage regulator circuit. See Figure 9.

1.2.5.6. Microprocessor

The Swimming Haggis MKII uses a pair of Arduino microprocessors. These were selected for this purpose as they are easy to use and members of our company had had prior experience in using Arduino microprocessors and the associated software development environment.

An Arduino Mega is contained in the pressure vessel on the ROV itself to store and run the main control program. It was selected for this task because it has a large number of pins that can provide both digital and pulse width modulation outputs. An Arduino Uno is also included in the control box to take the controller inputs and transmit them to the ROV using serial communications.

1.2.5.7. Arduino Shields

The shield circuits (Figure 11) provide connections for all inputs and outputs to both the Arduino Mega onboard the ROV and the Uno in the control box. This provides more secure connections to the microprocessors to reduce the risk of wires becoming loose. It also allows the control signals to be collected and sent to the other circuits through a ribbon cable rather than individual wires, further organising the connections.

Figure 11 Arduino Mega with Shield

The Shields have been produced by the company for both the Arduino Uno in the control box and the Mega onboard the ROV itself. Fortunately due to certain similarities in the pin layout of these microprocessors it was easy to adapt the design of the shields to fit both.

The shields plug in to the microprocessor using stackable board connectors. These allow the circuits to be connected to the microprocessor easily and also allow multiple shields to be stacked on top of each other while still being able to access every pin on the microprocessor. This also allows for the possibility of additional shields to be connected if they are required to provide additional functionality.

1.2.5.7.1. RS232 Line Drivers

In order to send serial communication signals up the tether a line driver circuit is used at each end which converts the serial communication data from and to RS232 levels for transmission.

Due to the length of the tether and the proximity of the serial communication lines and camera feeds within the tether cable the line drivers have been included to improve the quality of the transmitted signals and reduce the possibility of communications being lost or corrupted.

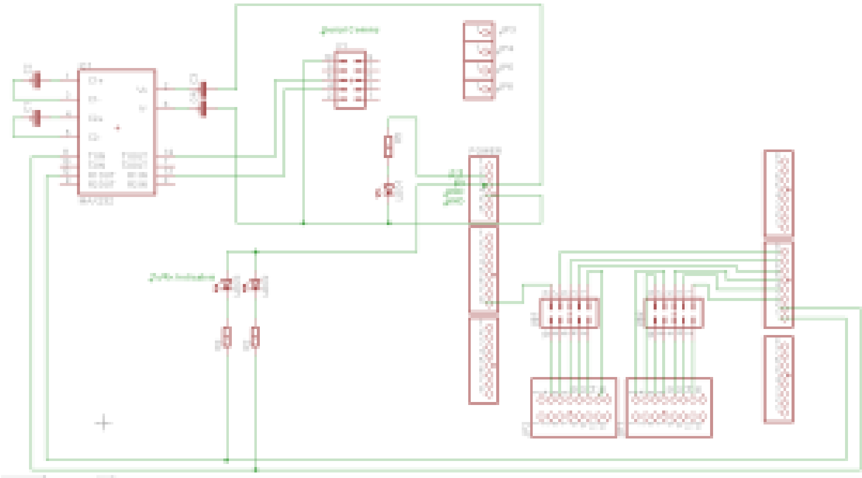

Figure 12 Arduino Mega Shield Schematic

The line drivers consist of a MAX232 chip integrated into the microprocessor shield circuits (Figure 12). By including this circuit on the shield the chip can be powered through the Arduino's inbuilt 5 V regulator, and the, 'transmit,' and, 'receive,' signal lines are directly connected to the serial communication pins on the microprocessor.

The shields also include LED indicators to assist with testing and troubleshooting. One has been included on each shield as a power indicator and two are used as transmit and receive indicators to show the communications between the two microprocessors.

1.2.5.8. Propulsion Motor Driver Circuit

The Swimming Haggis MKII has been designed to have full analogue speed control in all directions. In order to achieve this, the motor control circuits (Figure 13,14,15)were required to accommodate both pulse width modulation to control the speed of each motor and the ability to reverse the direction of each motor.

In order to control the speed of each motor a PWM output from the microprocessor is connected to the gate of an N-Channel MOSFET. This MOSFET is connected in series with the motor and will switch on or off at a high speed depending on the PWM signal, effectively reducing the voltage across the motor. Because this MOSFET will be switching very quickly a heatsink has been included to prevent it from overheating.

The directional control is achieved through the use of a DPDT relay to reverse the polarity of the current flow to the motor. The coil of the relay is energised through an N-channel MOSFET which is driven from a digital pin of the Arduino. When the direction signal goes high the MOSFET switches on. This energises the coil and switches the relay reversing the polarity of the motor terminals.

Figure 13 Dual Motor Driver Circuit

LED indicators have also been included in each motor control circuit. One LED is connected between the voltage supply and ground lines to show when the control board is powered. A red/green bi-directional LED is connected across the terminals of the motor. This will change colour according to the direction of the current flow and also change brightness due to the pulse width modulation.

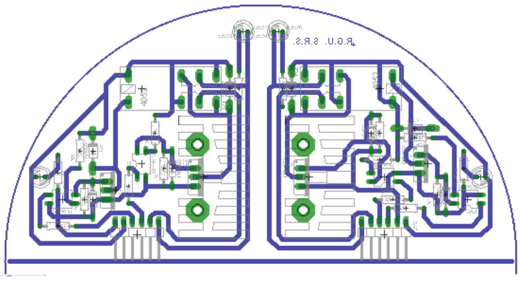

Figure 14 Dual Motor Driver Board Layout

In order to make the most efficient use of the space in the pressure vessel the 8 motor driver circuits have been arranged in pairs as four semi-circular circuit boards containing a pair of circuits. These are connected vertically to the motherboard by pin header connectors allowing them to be easily inserted and removed. In the case of one of these circuits failing a line of holes have been drilled to allow the semi-circular board to be spit into two separate circuits so the damaged half can be replaced.

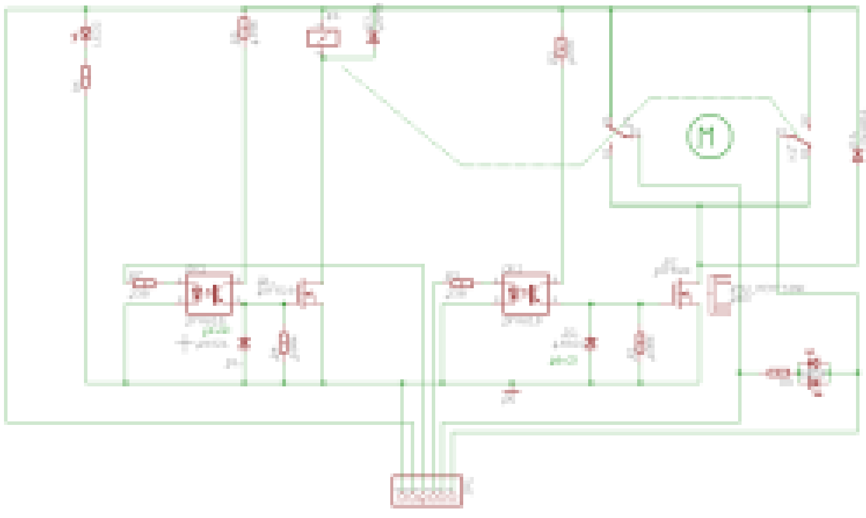

Figure 15 Motor Driver Circuit Schematic

1.2.5.9. Manipulator Motor Driver Circuit

The manipulator claw on the Swimming Haggis MK.II uses a 12 V DC motor. This motor is controlled using a Darlington H-bridge circuit. The circuit designed for this is uses the same schematic as the propulsion motor drivers from the Swimming Haggis MKI. The layout of the circuit has then been slightly compressed to fit on a smaller PCB (Figure 16, 17).

Figure 17 Manipulator Motor Driver Circuit

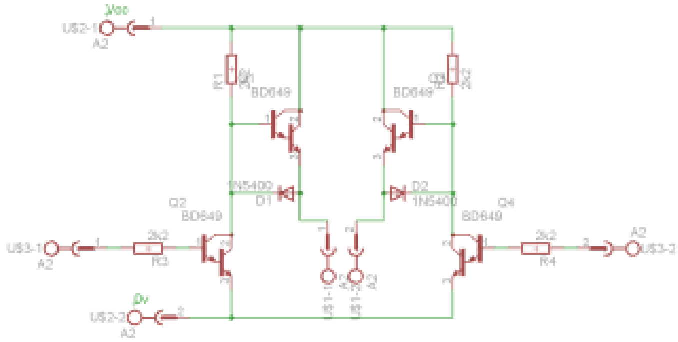

Figure 16 Manipulator Motor Driver Circuit Schematic

1.2.5.10. LED Light Board

1.2.5.10.1. Board design and calculations

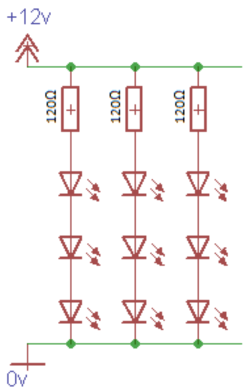

Figure 18 LED circuit design

The LED light boards are the forward and backwards light source for the ROV and were designed and built in house with simplicity at the core of the design. The board comprises of Brightek 5050 surface mount LED units which have three LEDs contained within along with current limiting resistors as shown in Figure 18.

The typical forward voltage for the LED unit is 3.2 V and the maximum rated current for the LED unit is 30 mA. As such it was decided that it would be preferable to run the LED unit below rated current and 25 mA was selected.

With reference to Equation 1 it can be seen that the required resistor size would have been 100 Ω however with testing it was found that the forward voltage of the LED was 3 V therefore to maintain the current at 25 mA it was decided to use 120 Ω resistors.

$$V_s = 12V \quad Vf = 3.2\,V$$
$$V_R = Vs - (3 * Vs)$$
$$V_R = 12 - 9.6$$
$$V_R = 2.4\,V$$

$$R = \frac{V_R}{I_R} = \frac{2.4}{25 * 10^{-3}} = 96\,\Omega$$

Equation 1 Resistor value calculations

1.2.5.10.2. Board Construction

The steps involved in creating the LED PCB board are detailed with reference to the flowchart shown in Figure 20. The same process was followed for other boards.

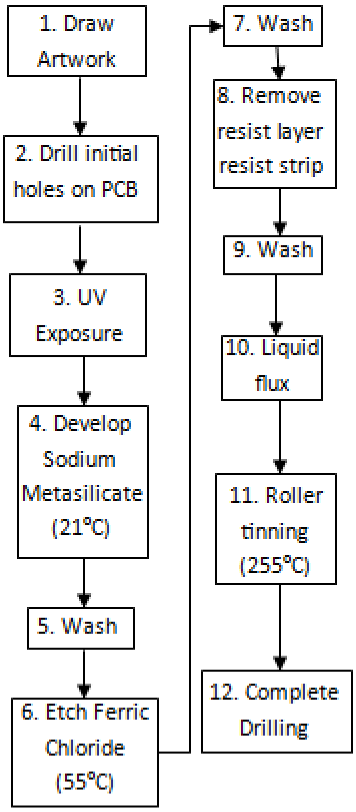

Figure 20 PCB manufacture flowchart

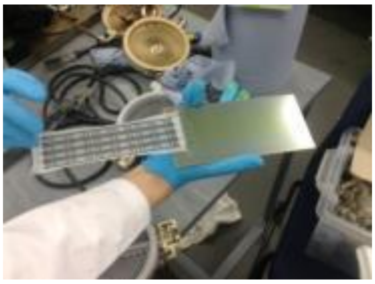
Figure 21 UV exposure


Figure 22 CNC drill machine

1. The circuit design shown in Figure 18 was produced in the CAD program Eagle v6.5 leading to the board design that can be seen in Figure 19. This design was then printed out on tracing paper and a suitably sized piece of PCB was cut to size.

2. The PCB board was placed in the CNC Drill Machine and the six large outer holes drilled for orientation required in step 12.

3. The tracing paper copy of Figure 19 was affixed to the PCB board and then exposed to UV for three minutes. This turns the exposed photo/etch resist acidic in preparation for step 4. See Figure 21.

4. The board is developed by immersing it in the alkaline solution Sodium Metasilicate at a temperature of 21ºC. This destroys the unwanted photo resist exposing copper underneath.

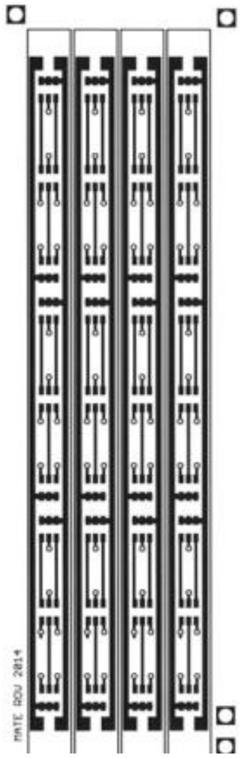
Figure 19 PCB artwork

5. The board is thoroughly rinsed.

6. The board is spray etched with Ferric Chloride at a temperature of 55ºC. After four minutes the process is complete and the copper exposed in step 4 has been removed.

7. The board is thoroughly rinsed.

8. To improve the solderability of the copper remaining under the photo resist that was protected by the trace the remaining photo resist must be removed. The board was immersed in Resist Strip until all copper is exposed.

9. The board is thoroughly rinsed.

10. Liquid flux is applied to the board in order to help solder cling to the exposed copper by removing oxide build up.

11. The PCB board is then passed through the Roller Tinner as shown in which applies a thin layer of molten solder to the exposed copper. This protects the copper tracks from corrosion and improves its solderability.

12. The PCB is placed in the CNC Drill Machine and the holes for the components are drilled ready for population as shown in Figure 22.

With the LED units and resistors soldered on, the boards have been coated in RS Insulating Varnish (2) in order to create a watertight coating so that the board may be exposed to water. The power wire has been soldered onto the board and then sealed with Araldite Rapid epoxy (3) isolating the electrical power from the water.

1.2.5.11. Tether

During discussions with the previous year's team it became apparent that one of the things they struggled with was the weight of their ROV tether. In order to reduce this weight the Swimming Haggis MKII uses only two cables; a power cable and a single length of stranded CAT5 cable for all required data transmission, both control signals and camera outputs.

Of the 8 cores of the CAT5 cable, one twisted pair is required for each camera. Three of the remaining four cores are used for serial communication, two for transmit and receive and one to provide a common ground connecting the two microprocessors.

1.2.6. Control system

1.2.6.1. MKI Control System

The control system requirements for the Swimming Haggis MKI were that the ROV was simple to control and would quickly respond to controller input changes. The company wanted Vector Thrust because of its wide use in modern day Work Class ROVs. A digital control system was implemented. Switches with 3 states (forward, reverse and stationery) were used to control motors directly. A digital joystick was used for controlling the horizontal motors to give vector thrust. Inside the control box as shown in Figure 23 there is a single microcontroller; an Arduino UNO. The UNO took in the reading from the digital joystick. The reading then determined the values at the digital output pins which were connected to 4 H-Bridges.

Figure 23 MKI control box

1.2.6.2. MKII Control System Design

For the MKII, we had a few of the same design requirements. We wanted a quick response from the vehicle and for it to be simple to fly.

For the MKII we wanted even more control. Instead of switches and a digital joysticks to control the motors, slide potentiometers and an analogue joystick were used. The data read from the analogue inputs is used to calculate pulse-width modulation and polarity values for each motor driver circuit. The use of sliders allows the operator to hold the ROV's position in the water.

Along with sending data for the motor values, a potentiometer value to control a camera servo and the state of a switch to control a claw is also sent down as shown in Figure 24.

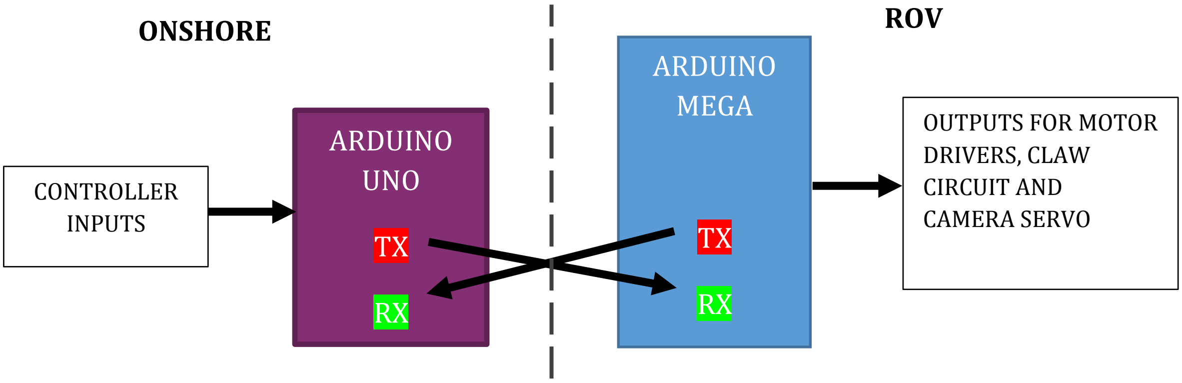

Figure 24 Data transmission

1.3. Software

1.3.1. Flow Diagrams

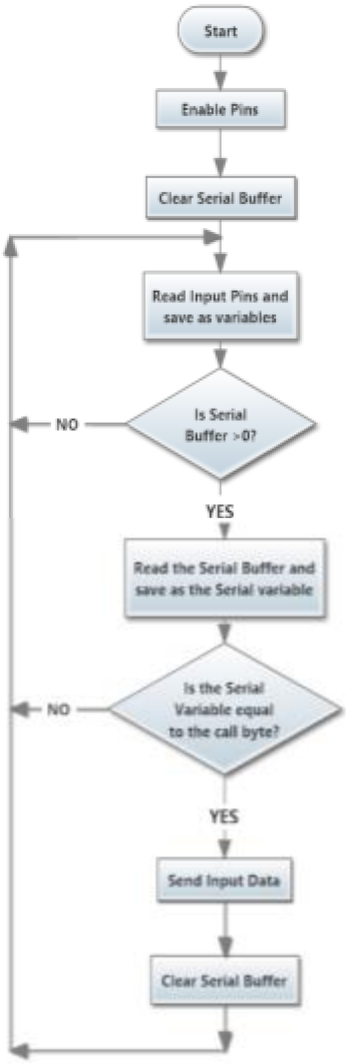

Figure 25 Controller UNO Program

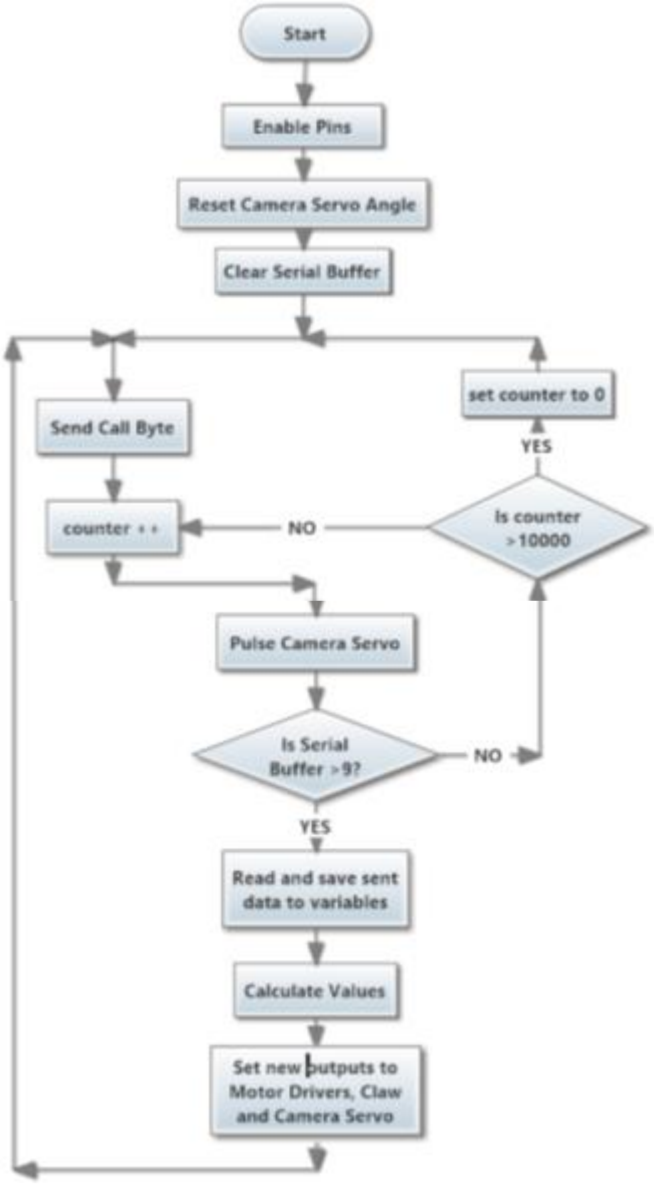

Figure 26 ***ROV MEGA Program***

1.3.2. Controller Inputs

The ROV operator uses the interface shown in Figure 27 to control the ROV. The modules X, Y, Rotate, Vertical and Tilt are used to control the motors. The position of the slide potentiometers and the joystick are read via the analogue input pins. A value between 0 and 1023 is saved for each of them. The value is then scaled down so it can be saved in byte form.

Figure 27 Controller Interface

The joystick returns to the middle position when not in use, but the slides will stay in the position the operator leaves them at. Each slider has a centre detent and will click and stay in the middle zone when not in use. For each value, a dead zone is set. The values for each module will not stay completely constant so the motors are programmed to not move for a range of values in the middle.

A potentiometer is used to move a camera by controlling a servo that is attached. The potentiometer turns 260° but the camera only moves about 150°. This allows the operator to have a lot more control over the angle of the camera.

A momentary switch is used to control the claw. The claw has three states; close, open and stationery. When the operator releases the switch from the open or close position the switch will automatically move back to the middle. This is in case the operator leaves the switch opening or closing and will save the DC Motor from burning out.

1.3.3. Communication

The two Arduinos send data back and forth via serial communication using the Call and Response method. The ROV microcontroller writes the ASCII character "C" on the transmit line (TX) when it wants to receive new data. The onshore microcontroller will receive this character on the receive line (RX) and will respond by sending down the motor, camera servo and claw data in the form of bytes. A start byte (ASCII character "S") and an end byte (ASCII character "E") are sent along with the transmission. This is a form of error checking. If "S" and "E" are not read at the ROV, the message has been corrupted and that data will be discarded.

1.3.4. Calculations and Outputs

Once new data has been sent to the ROV, the equations in Equation 2 are used to convert the operator inputs into useful PWM and polarity values for the motor drivers. These equations create output values that will not cancel out a movement. For example, if the operator wished to lift an object and take it to the surface the tilt slider will be pushed fully down and the vertical thrust slider fully up. The equations will ensure the ROV will act accordingly and not just tilt or just rise.

```
M1 = -Y + X - R;
M2 = -Y - X + R;
M3 = Y + X + R;
M4 = Y - X - R;
M56 = V + T;
M78 = V - T;
```

Equation 2 ***Motor Equations***

Since the camera potentiometer is 260 degrees and the servo can only rotate 180 degrees, the value is scaled down to match this. The camera servo signal cannot just be set; it needs to be continuously pulsed. The MEGA is programmed to pulse the servo even if new data is not coming through.

The Claw is controlled from an H-Bridge circuit. The claw can be in one of three states; open, close and stationery. It is programmed so that if the switch breaks or the pins are faulty the motor will not turn in either direction. This is so the DC Motor used to open and close the claw will not burn out.

1.3.5. Control Box

A Tupperware box from ASDA (Walmart) was chosen to house the controller parts. The components were bolted onto aluminium sheets and secured using screw bar (Figure 28).

To keep the control box reliable and easy to repair, another shield was developed for the inputs. The live, neutral and signal lines from each module plug into this shield.

Three cores of the Cat 5 cable are used for the serial communications; Transmit, Receive and Ground. The 2 cameras also share the same data cable and use four of the cores. The data cable plug in is a DB9 connector.

Figure 28 The control box

2. System Integration Diagram (SID)

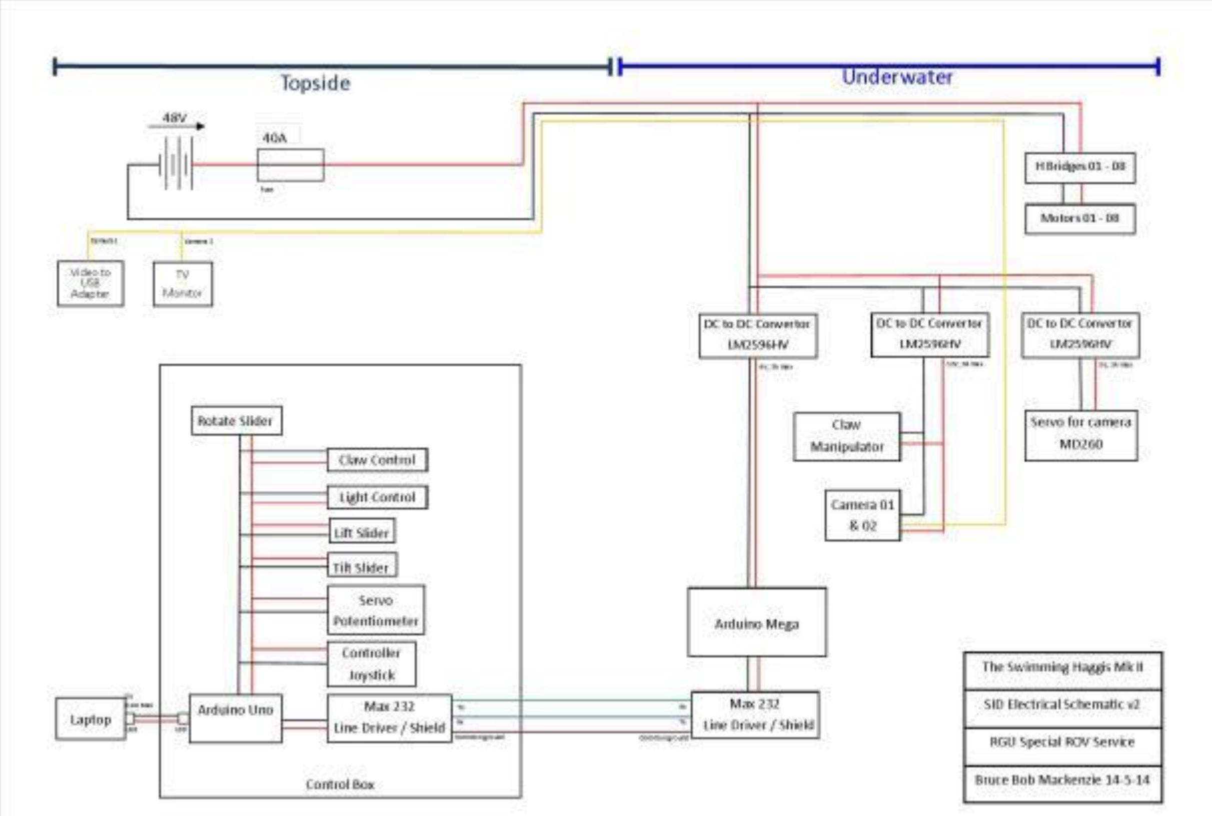

Figure 29 System Integration Diagram

3. Lessons Learned

RGU SRS had a build schedule that had dictated that the Haggis MKII would be completed and ready for tank testing by the start of 2014 however we had underestimated just how long it would take to complete the Haggis. Tank testing occurred on the 26th of March 2014 three months behind the date that we had intended. This has been a useful learning experience whereby projects to be completed which are initially out with the scope of knowledge currently held may take longer than anticipated to complete.

Furthermore RGU SRS feels that i its parts ordering regime could have been more efficient as we have been ordering parts close to the regional competition date. It seems far more sensible to have ordered everything in one order so that we had all the parts awaiting progression of the project to a suitable time whereby we would utilise them in our project. It seems sensible to note however that due to the build schedule falling behind the timetable that we had anticipated then the realisation of requirement of parts was subsequently delayed. As such the two issues are related and would be something not having the experience of the build that we could improve upon.

4. Future Improvements

While the Swimming haggis MKII does a lot very well, there are always further improvements which could be made.

For example, dismantling and reassembling the electronics in the pressure vessel was originally intended to be a quick and simple task. However, as it stands it is quite time consuming to disconnect or reconnect everything.

There are far too many steps involved in the process and as such we have had to resort to the use of a checklist in order to ensure every wire has been connected in the correct order. Having two or three block connectors which could be connected and unplugged would be a better solution

This has a knock on effect on the ease of access to the circuits contained in the pressure vessel. The initial idea was to be able to access any of the circuits quickly and replace them easily. However, as it stands it is a time consuming process to access the electronics. The result of this is although the motor control boards and Arduino shields can be attached or removed easily replacing the voltage regulator, Microprocessor, servo or cameras remains a fairly major operation.

5. Budget Sheet

1 GBP(£) = 1.68 USD($) correct as of 13th May 2014

Date	Expense	Amount	Balance	Amount (US)	Balance (US)
Initial Funding					
01/09/2013	Funding	**£1,000.00**	£1,000.00	$ 1,680.00	$ 1,680.00
22/11/2013	Voltage Regulator	£ 9.09	£ 990.91	$ 15.27	$ 1,664.73
22/11/2013	260 Degree Servo	£ 16.00	£ 974.91	$ 26.88	$ 1,637.85
05/12/2013	Arduino Mega 2560 R3 Microcontroller	£ 28.00	£ 946.91	$ 47.04	$ 1,590.81
05/12/2013	Arduino Uno R3	£ 14.45	£ 932.46	$ 24.28	$ 1,566.53
04/12/2013	SONY CCD 1/3inch Camera	£ 20.73	£ 911.73	$ 34.83	$ 1,531.71
22/11/2013	Joystick	£ 2.39	£ 909.34	$ 4.02	$ 1,527.69
22/11/2013	Slide Potentiometers	£ 16.53	£ 892.81	$ 27.77	$ 1,499.92
27/11/2013	PVC Pipe and Joints	£ 50.63	£ 842.18	$ 85.06	$ 1,414.86
17/12/2013	Countersunk screws	£ 5.96	£ 836.22	$ 10.01	$ 1,404.85
22/11/2013	Rule Bilge pump	£ 286.87	£ 549.35	$ 481.94	$ 922.91
27/11/2013	Polypipe Pipe Bracket Pvc Coated Steel	£ 18.56	£ 530.79	$ 31.18	$ 891.73

22/01/2014	In-line Coupling 3mm - 4mm	£ 44.60	£ 486.19	$ 74.93	$ 816.80
25/02/2014	6x2 PCB socket	£ 14.00	£ 472.19	$ 23.52	$ 793.28
25/02/2014	2x1 screw terminal	£ 3.24	£ 468.95	$ 5.44	$ 787.84
25/02/2014	8x1 screw terminal	£ 4.32	£ 464.63	$ 7.26	$ 780.58
25/02/2014	Max232 transciever	£ 2.42	£ 462.21	$ 4.07	$ 776.51
25/02/2014	20x1 Stackable header	£ 2.37	£ 459.84	$ 3.98	$ 772.53
25/02/2014	8x1 Stackable header	£ 3.70	£ 456.14	$ 6.22	$ 766.32
25/02/2014	6x1 Stackable header	£ 1.08	£ 455.06	$ 1.81	$ 764.50
22/01/2014	power relay,10A 48Vdc	£ 3.42	£ 451.64	$ 5.75	$ 758.76
23/01/2014	1N4004 diode	£ 0.13	£ 451.51	$ 0.22	$ 758.54
24/01/2014	Zener Diode 6.2V	£ 0.11	£ 451.40	$ 0.18	$ 758.35
25/01/2014	Terminal right angle	£ 0.86	£ 450.54	$ 1.44	$ 756.91
25/01/2014	Heatsink 263-251	£ 4.97	£ 445.57	$ 8.35	$ 748.56
25/01/2014	MOSFET IRF520N	£ 12.32	£ 433.25	$ 20.70	$ 727.87
25/01/2014	Relay RT424048	£ 13.38	£ 419.87	$ 22.48	$ 705.39
25/01/2014	Optoisolator SFH610A-4	£ 2.98	£ 416.89	$ 5.01	$ 700.38
25/01/2014	Connectors 6x2	£ 6.85	£ 410.04	$ 11.51	$ 688.87
03/03/2014	2 Blade Racing Propeller 32.5mm right hand M4	£ 37.90	£ 372.14	$ 63.67	$ 625.20
03/03/2014	Metal Servo Horn	£ 6.78	£ 365.36	$ 11.39	$ 613.81
03/03/2014	SIB Cable Gland PA 6 IP68 3 to 6mm	£ 7.89	£ 357.47	$ 13.26	$ 600.56
03/03/2014	0.5 mm 2182Y Grey Cable	£ 36.19	£ 321.28	$ 60.80	$ 539.76
03/03/2014	SIB Cable Gland PA 6 IP68 7 to 12mm	£ 3.07	£ 318.21	$ 5.16	$ 534.60
13/03/2014	TIP120 Darlington Transistor	£ 2.13	£ 316.08	$ 3.58	$ 531.02
13/03/2014	IRF520N Mosfet	£ 4.40	£ 311.68	$ 7.39	$ 523.63
13/03/2014	RS Black Polyolefin Heat Shrink Cable Sleeve, Yes Shrink Ratio: 3:1, 3mm Dia., 1.2m Length	£ 3.27	£ 308.41	$ 5.49	$ 518.14
16/03/2014	LITTELFUSE - 01520001.TXN940 - FUSE HOLDER, MAXI FUSE	£ 5.95	£ 302.46	$ 10.00	$ 508.14
16/03/2014	LITTELFUSE - 01520900XX832 - COVER, MAXI FUSE HOLDER	£ 1.14	£ 301.32	$ 1.92	$ 506.22
16/03/2014	LITTELFUSE - 0299040.ZXNV - FUSE, SLOW BLOW, 40A, MAXI	£ 8.90	£ 292.42	$ 14.95	$ 491.27
16/03/2014	NEUTRIK - NL2FX - SPEAKON PLUG, 2 POLE	£ 4.36	£ 288.06	$ 7.32	$ 483.95
16/03/2014	NEUTRIK - NL2MP - SPEAKON SOCKET - 2 POLE	£ 3.12	£ 284.94	$ 5.24	$ 478.71
16/03/2014	Optocoupler Transistor O/P 1-CH	£ 4.26	£ 280.68	$ 7.16	$ 471.55
16/03/2014	RS Silicone Grease, 100g Tube	£ 4.79	£ 275.89	$ 8.05	$ 463.50
24/03/2014	Relay RT424048	£ 23.00	£ 252.89	$ 38.64	$ 424.86
19/03/2014	Arduino Mega 2560 R3 Microcontroller	£ 45.00	£ 207.89	$ 75.60	$ 349.26
07/04/2014	Robot World Acrylic Board Strong Robot Gripper -- 76mm	£ 26.99	£ 180.90	$ 45.34	$ 303.92
07/04/2014	RS Nitrile Rubber O-Ring, Mar-32in Thick , -30 to +120°C	£ 2.59	£ 178.31	$ 4.35	$ 299.57

07/04/2014	SIB Cable Gland PA 6, IP68 PG7, 3 to 6mm Cable Dia Range	£ 7.89	£ 170.42	$ 13.26	$ 286.31
23/04/2014	M3 Nylon studding 1000mm	£ 2.80	£ 167.62	$ 4.70	$ 281.61
23/04/2014	M3 Nylon Full Nuts	£ 1.56	£ 166.06	$ 2.62	$ 278.99
23/04/2014	M3 Washers	£ 0.39	£ 165.67	$ 0.66	$ 278.33
23/04/2014	2.1mm 1/3" 150 Degree Camera Lens	£ 2.96	£ 162.71	$ 4.97	$ 273.36
23/04/2014	3.6mm 1/3" 92 Degree Camera	£ 1.21	£ 161.50	$ 2.03	$ 271.33
23/04/2014	TO220 extruded heat sink	£ 7.81	£ 153.69	$ 13.12	$ 258.21
23/04/2014	IRF520N Mosfet	£ 17.60	£ 136.09	$ 29.57	$ 228.64
23/04/2014	Terminal right angle	£ 7.80	£ 128.29	$ 13.10	$ 215.53
23/04/2014	Swimming Noodles (buoyancy aid)	£ 14.97	£ 113.32	$ 25.15	$ 190.38

Total Spent: £ 886.68 ($1489.62)

6. Safety

6.1. Overview

Safety is a fundamental pillar of the operating ethos of RGU SRS. It is of paramount importance that we maintain the safety of members of RGU SRS and the public at large by implementing designs and procedures that mitigate human error.

6.1.1. Procedural

When working upon the Swimming Haggis all members of the company would wear the appropriate personal protective equipment for the task that they were undertaking. Safety goggles were worn when soldering components on PCB boards. A lab coat was worn in conjunction with safety goggles and latex gloves when making PCB boards and handling dangerous chemicals.

Furthermore, when conducting electrical testing upon the Haggis it was standard procedure for a shout to be made that electrical power was being applied with the phrase, 'power on, stand clear!' This warned all company members to stand clear so that there was not a risk of electrocution.

6.1.2. Mechanical

Within the mechanical build design the following safety features were implemented. Guards were fitted around the propellers to prevent objects from entering that could be dangerous. This could be human body parts, debris or the tether that can create danger as a result. All elements of the outside of the Haggis have rounded edges so that people do not cut themselves accidently whilst handling the ROV. Another feature of the Haggis is that it is positively buoyant meaning that should there be a failure of on-board control it will return to the surface for collection. This minimises the risk of retrieving the Haggis in such a case.

6.1.3. Electrical

Within the electrical build design the following safety features were implemented. The system is protected by a 40 A fuse so that if the Haggis draws beyond its rated current, damage and potentially fire risks can be averted. Within the pressure vessel of the Haggis voltage regulators are affixed to the main motherboard using plastic bolts and nuts. This isolates the regulator form the rest of the board preventing any part of the system being exposed to a higher voltage than is designed for. The pressure vessel is clear and therefore exposes all the indicator lights on the motherboard giving clear indication from a distance that the system is live.

7. Challenges

7.1. Technical

The company suffered many setbacks on the way. One of the major challenges was the unpredictable nature of the Arduino microcontroller. Through the entire time building the Swimming Haggis three different Ardunio Megas decided to no longer function due to a variety of problems. The first being an unresponsive COM port, the second a blown chip and finally on the last Arduino two of the pin outputs decided to no longer give any PWM. The team responded by purchasing backups, making sure there was a minimum of two in reserve. However, this affected both our budget and project plan.

Further problems were created by the limited space within the pressure vessel itself. In order to counter this special circuit boards where designed and printed in half moon shapes to try and accommodate.

Previous Robert Gordon University teams suffered from leakage problems with the pressure vessel due to poor design and implementation. From the outset the team decided that a lot of time and effort would be made to counter this problem with the simplest design as possible. Using plumbing pipe with O-ring sealed end caps the team rigorously tested the pressure vessel for leaks taking it out and resealed the end caps until it was watertight. The next major challenge was to allow the cables to flow in and out of the vessel without letting water in. Glands were purchased and glue heat shrink was used so that no water travelled down the insulation of the cables. The glands were also O-ringed and these were fitted in countersunk holes on the ends caps.

7.2. Non-technical

In the summer of 2013 the engineering department of Robert Gordon University moved site from Aberdeen city centre to the newly built Riverside East building located on Garthdee campus. This change in location presented challenges which were not initially anticipated by the team beforehand of which we had to adapt to and seek resolution.

Upon moving to the new facility at Garthdee we had to acquaint ourselves with the layout of the new building as well as our new campus. We did not know where labs, workshops and stores were as well as where the offices of staff members were. Furthermore to this items of equipment that we may require such as connection leads for Arduinos were now stowed away in boxes to be unpacked and were no longer easily to hand. Learning the layout of the building, where to locate staff and where to obtain consumables introduced time delays meaning that as a team we had to be even more organised. It was essential that we would anticipate our needs in order to mitigate loss of time due to unfamiliarity of our new working environment.

At our old facility in Aberdeen city centre the ROV team had a dedicated work space kitted out with tooling and equipment required for the building of a ROV. Upon our arrival at Riverside

East, Garthdee we discovered that this had not yet been established and had to make arrangements to organise this. We managed to temporarily secure a room and borrow equipment from the main lab but had to move after a couple of months to another room. Having to establish a working environment, and source the necessary equipment required to develop the Swimming Haggis added further time delay which we had to overcome and adapt to of which we did with professionalism.

One of the facilities at Riverside East that was to be at our disposal was a water tank where we could test and develop the ROV that we were building. However due to error on the part of the contractor responsible for constructing our new facility the test tank was left incomplete and unfit for such purposes. To this end we had to secure alternate facilities for testing. CEO Matthew Head was able to obtain an 1,000 litre Intermediate Bulk Container as a gift to the university from his part-time employer in order that we could perform waterproofing tests and get limited testing on the performance of the Haggis.

However, whilst the IBC suffices for limited testing we required a larger test tank in order to properly test and obtain pilot training hours. We approached local companies that could assist us by allowing us to use test tanks on their industrial premises. To that end Subsea 7 i-Tech 7kindly invited to their site so that we could to do testing in their ten metre deep tank which allowed us to pressure test the Haggis to a depth deeper than what would have been possible should the RGU test tank had been complete. At the time of writing we are discussing with Kongsberg Maritime if we can have use of their onsite pool so that we can undertake pilot training essential to our success prior to the competition.

Whilst not having a pool for testing presented a challenge for us we as a company adapted by reaching out to local companies for assistance and have as such made valuable relationships and connections with members of industry. It has allowed us to hone our networking, organisational and managerial skills to the benefit of the project, and our own skill set. It has proven to be a beneficial experience for the team despite initially being viewed upon as a problem.

8. Team Reflection

RGU SRS comprises of a multi-disciplinary team of mechanical, electrical and electronics engineers ranging in age from early school leavers to mature students with previous vocational experience within and outwith engineering. These range of perspectives have fostered a dynamic approach to the mission and has encouraged an excellent inter-team relationship. Attention to detail and recognition that we are representing Robert Gordon University and the engineering community of Aberdeen have driven us to push the bar and strive for ultimate success.

The team ethos has been to keep the build simple and to do the basics well to ensure an avoidance of convoluted and overly complex designs which may look impressive yet has more likelihood of failure. The team has made excellent use of the resources available to us such as academic mentoring, the support of RGU administrative staff and facilities in order to deliver a ROV that we are confident will deliver the requirements of the mission brief.

RGU SRS has been engaged in what we consider to be important outreach work to promote and increase awareness of ourselves, MATE, ROVs and engineering as a fun and intellectually invigorating career path. Our outreach work has to date involved hosting a visit of fifty ten and eleven year old children from Kittybrewster Primary School for the day showing them our facilities, conducting exciting and interesting experiments and giving them the opportunity to pilot the Haggis MKI. Furthermore at the time of writing we are looking forward to sixty Mile End Primary School pupils visiting at the end of May with the itinerary remaining almost the same. See Figure 31.

In addition to this RGU SRS participated as centre attraction at a Takeover event hosting an exhibit at Satrosphere Science Centre, Aberdeen. This is an event designed to engage adult members of the public in science in a friendly and welcoming environment. The Haggis MKI was on display, alongside miniature ROVs for the public to take control and experience what being an ROV pilot is like. See Figure 30. Furthermore in collaboration with pupils and staff from Mintlaw Academy, Peterhead we manned a stall at Subsea Expo 2014 held at Aberdeen Exhibition and Conference Centre engaging members of industry and raising awareness of MATE and local participation in the competition..

Through the duration of the project RGU SRS has had the opportunity to interact with industry specialists through site visits to industrial premises. We were invited to visit Oceaneering's premises in Dyce, Aberdeen for a tour of their facilities and it was really fascinating to see their work class ROVs, their ROV simulator and their workshop area. It was excellent getting the opportunity to converse with members of staff and to gain valuable insight into their experiences and knowledge of working with ROVs. RGU SRS also made a visit to Subsea 7 i-Tech 7 in order to test our ROV in their 9 m deep tank. It was an excellent day and thoroughly rewarding to again meet members of staff, learn their views on ROV engineering, and to be treated to a lovely day with our photos being taken with their Hercules work class ROV.

Overall participating in the MATE competition has been an excellent experience and has allowed us to learn a lot about ROV's and the subsea industry. It has been a fun and rewarding team bonding exercise that has given us exposure to those in industry whom we aim to emulate upon graduating. It has been thoroughly enjoyable interacting with school children and the general public spreading the word about who we are and what we do. Whilst being a difficult challenge at times pushing us to our ultimate limits of stress and endurance it has been totally absolutely worth it.

Figure 31 Pupils from Kittybrewster Primary School

Figure 30 Group photo taken at the conclusion of the Satrosphere Takeover event

9. References

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10. Acknowledgements

MATE for putting on such a great competition.

Robert Gordon University

RGU staff

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Help with machining motor guards and mounts

David Smith – also gave solid advice on waterproofing, Martin Johnstone

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Alan McLean

Marketing

Jenny Rush, Racheal Hayward

Support

Andy Ross, Les McLaren, Gavin Murison, David Howie, Rosslyn Shanks, Margaret Jenkinson, Slim Kerrouchi

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Fergus Russell, Laura Steedman, Ryan Stewart, Stewart Pitt

Other Organisations

i-Tech 7, Oceaneering, Kongsberg Maritime

Satrosphere Science Centre – Particular mention to Chris Mark for all his help.

Our sponsors: