RGU
marine ops

Robert Gordon University
Aberdeen, Scotland

Technical Report

Team

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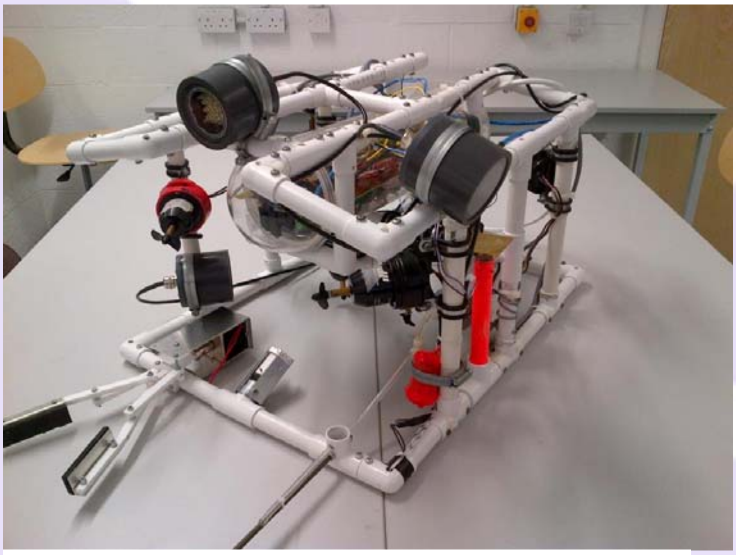
1. Abstract

RGU Marine Ops is a new company pushing the boundaries of ROV exploration, specialising in WWII wrecks.

Our custom designed and constructed Remotely Operated Vehicle (ROV) has been specifically produced to survey, explore, and evaluate sunken World War II ships. Ship wrecks from this period of time commonly still contain harmful substances such as crude oil, engine oil, diesel and explosives. The leakage or mishandling of such substances can desolate surrounding wildlife, devastate coastal communities and leave behind harmful hydrocarbons, the basis of any fuel.

We offer a safe and efficient service of operating, surveying and exploring hazardous environments which may not be safely accessible to human divers. The ROV has a uniquely designed tools specific for the MATE mission. The removable robotic claw is the focal point of the ROV with respect to tooling due to its ability to carry out multiple tasks



The Finished ROV

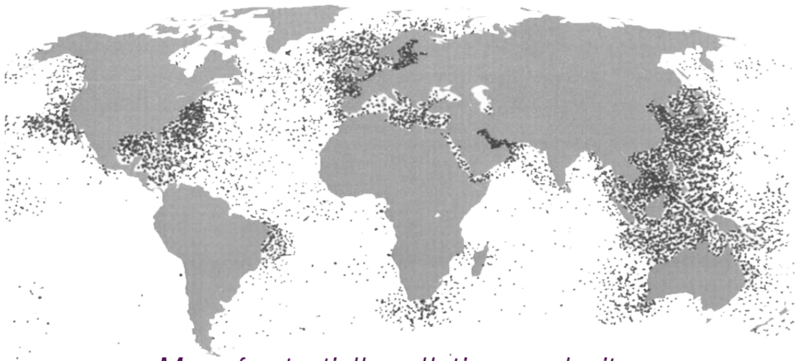
2. Contents

3. Background

There are over 8,500 environmentally dangerous ship wrecks, of which more than 6,300 are from the World War II era, lying at the bottom of the oceans and great lakes of the world. World War II was a period in which ships transporting oil and other managing substances were targeted by enemy artillery. Over the years these sunken vessels have eroded to the stage that they have begun to create an environmental hazard which has to be dealt with.

Oil Bubbles seen coming from a ship wreck in Chuuk Lagoon.

David Conlin, chief of the National Park Service's Submerged Resources Center, headquartered in Lakewood, Colo has stated, "A lot of these wrecks are reaching a point in their decay curve where they may experience some structural changes and they may leak some pollution." .



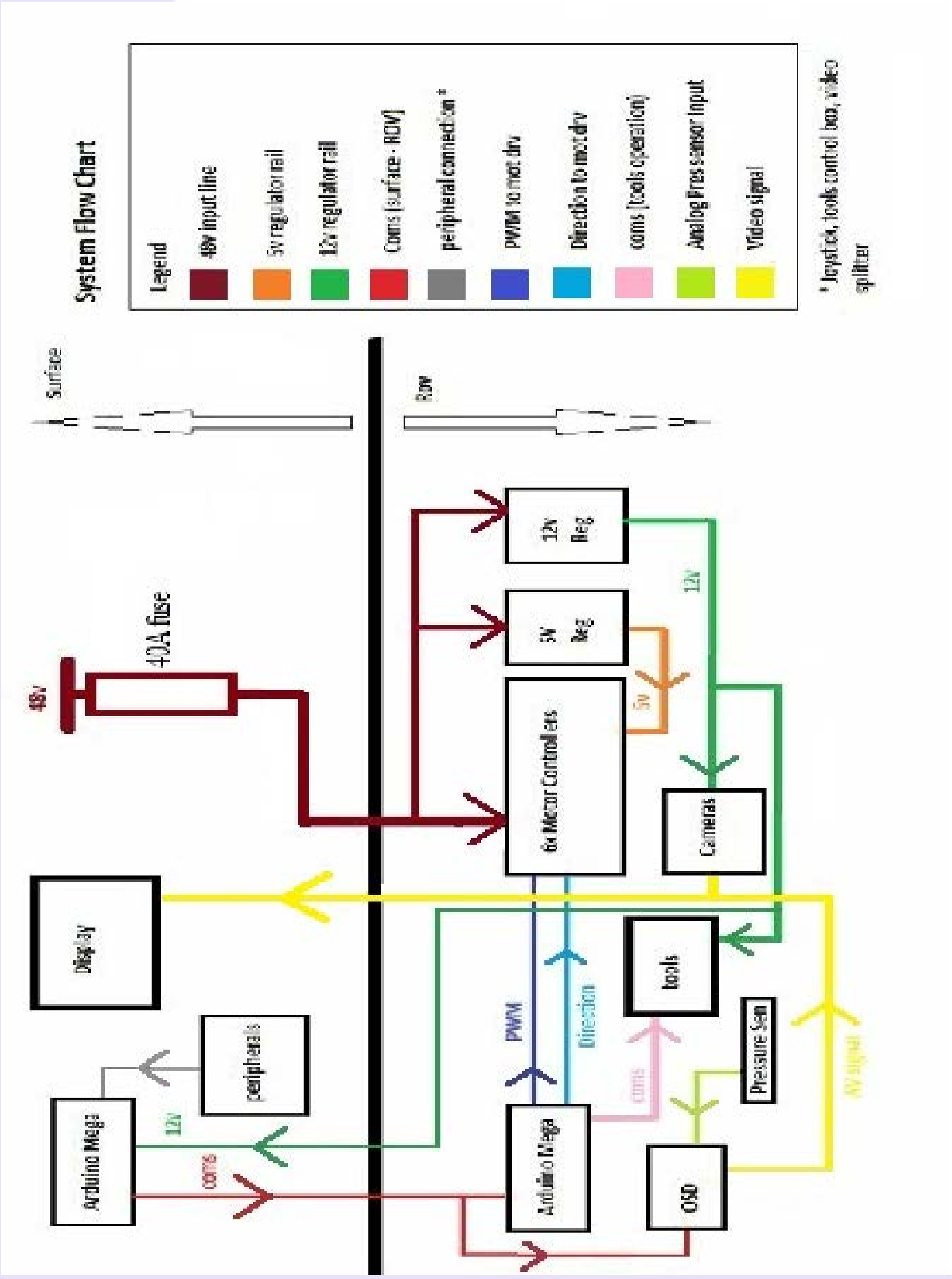
Map of potentially polluting wreck sites.

4. Expense Sheet

Item	Donations	Expenditures
Bilge Pumps 24V (x8)		£242.72
3 axis joystick		£72.97
Cameras (x3)		£125.12
Arduino Mega (x2)		£70.98
Propellers (x10)		£20.60
Cable glands (x15)		£23.92
DPDT relays (x7)		£17.22
MOSFETs (x9)		£13.50
Voltage Regulators (x4)		£18.00
Inductors (x6)		£9.66
Main Control box		£18.19
Tools Control box	£3.15	-
Slide potentiometer		£1.15
Rotary potentiometer (x3)	£1.20	
Rotary switch (x3)	£1.23	
Stackable pin headers (x11)		£6.12
SpeakON socket 2 pole	£2.02	
SpeakON plug 2 pole	£2.50	
3 wire 18m tether	£10.00	
Frame components		
Hemispherical Dome		£7.91
Pressure vessel cylinder	£20.00	-
PVC Pipe 3m (x2)		£4.98
L-joints pack (x5)		£11.91
T-joints pack (x5)		£11.91
P clips (x20)		£20.00
Tools	-	-
LEDs (x10)		£3.75
Electromagnet 25mm		£38.72
Pull action solenoid 24V 12W		£18.05
Triple Axis Magnetometer		£10.29
Arduino Pro Mini 328 - 5V/16MHz (x2)		£22.70
Video sync chips (x2)		£4.52
Cable glands (x5)		£8.73
O-rings 2mm (x15)		£5.94
Syringes (x6)		£7.16
Geared motor (x2)	£20.00	-
Pressure sensor		£8.74

Accelerometer		£2.20
Gyroscope		£17.70
3 way connector plug IP68		£12.58
3 way connector coupler socket IP68		£10.95
8 way connector socket IP68		£3.17
8 way connector coupler plug IP68		£3.06
5A solder pin contact, 22-26 AWG		£4.28
5A solder socket contact, 22-26 AWG		£6.76
Bulgin 900 buccaneer gland pack		£1.32
Total	£60.10	£887.48

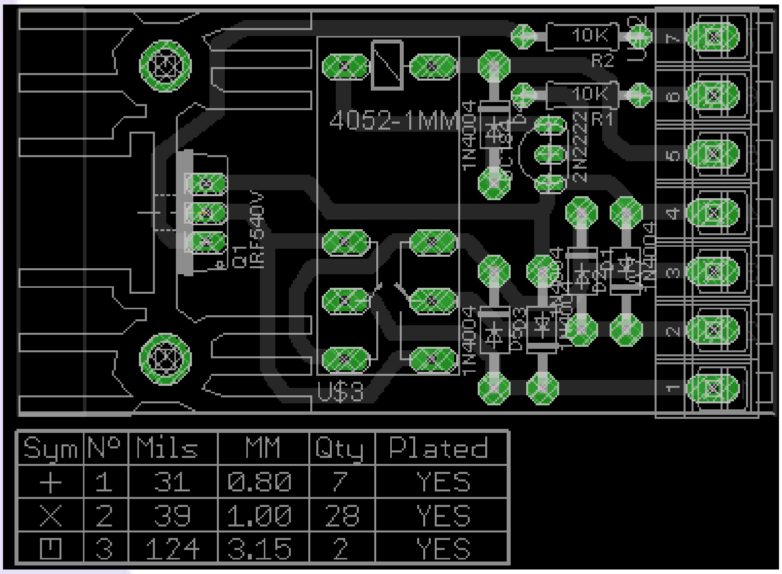
5. System Flow Chart



6. Electrical Schematics

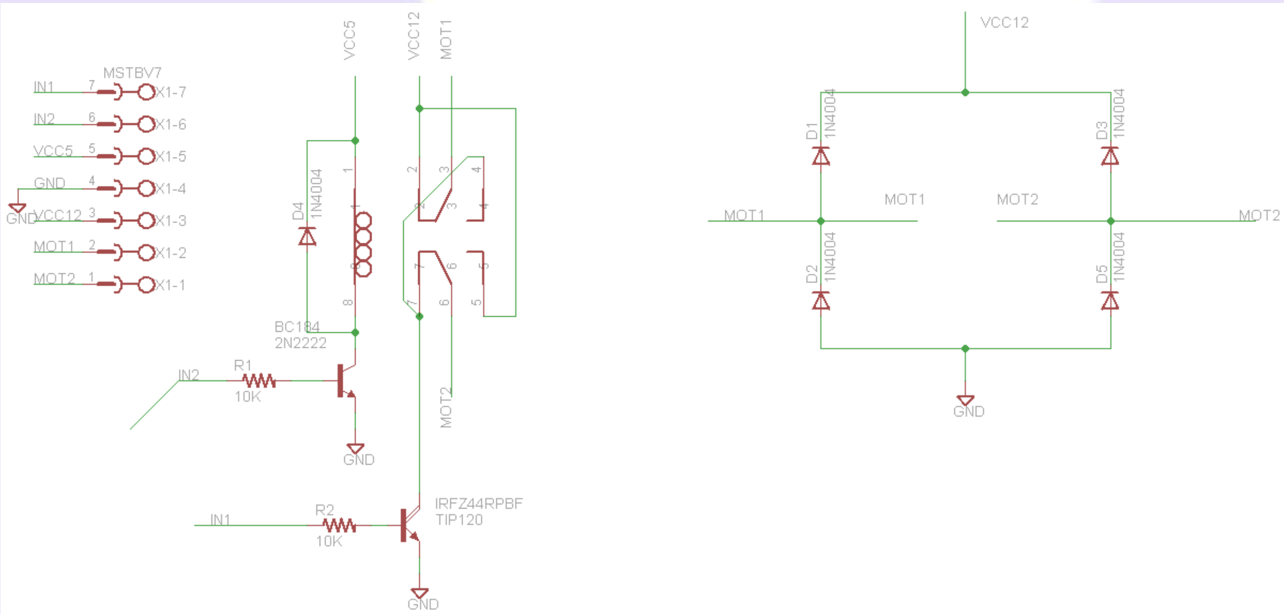
Below is a selection of the electrical schematics. The remainder of schematics can be found in the Apendix.

6.1. Motor controller



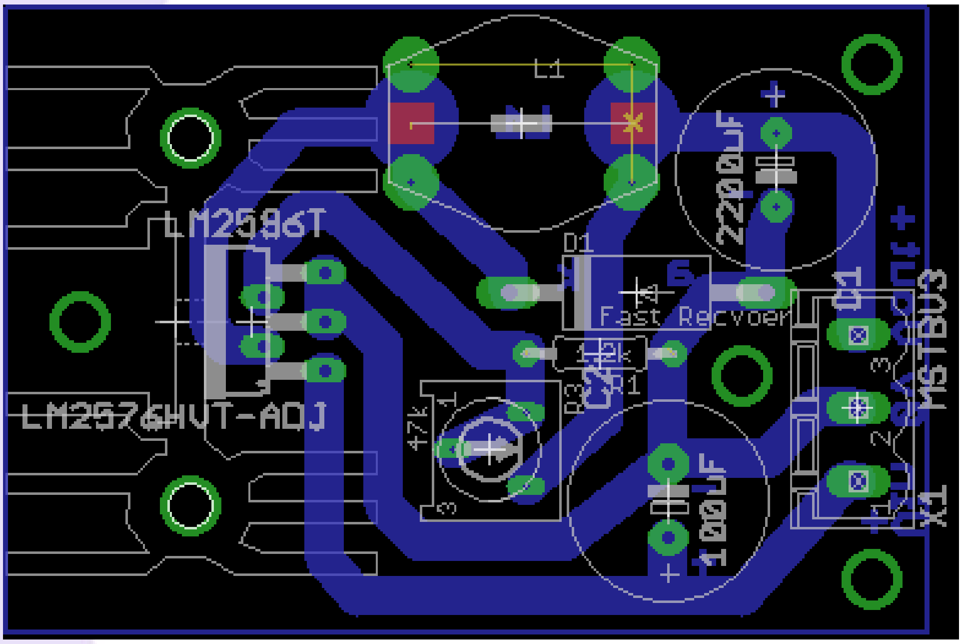
Sym	Nº	Mils	MM	Qty	Plated
+	1	31	0.80	7	YES
X	2	39	1.00	28	YES
◫	3	124	3.15	2	YES

PCB Layout

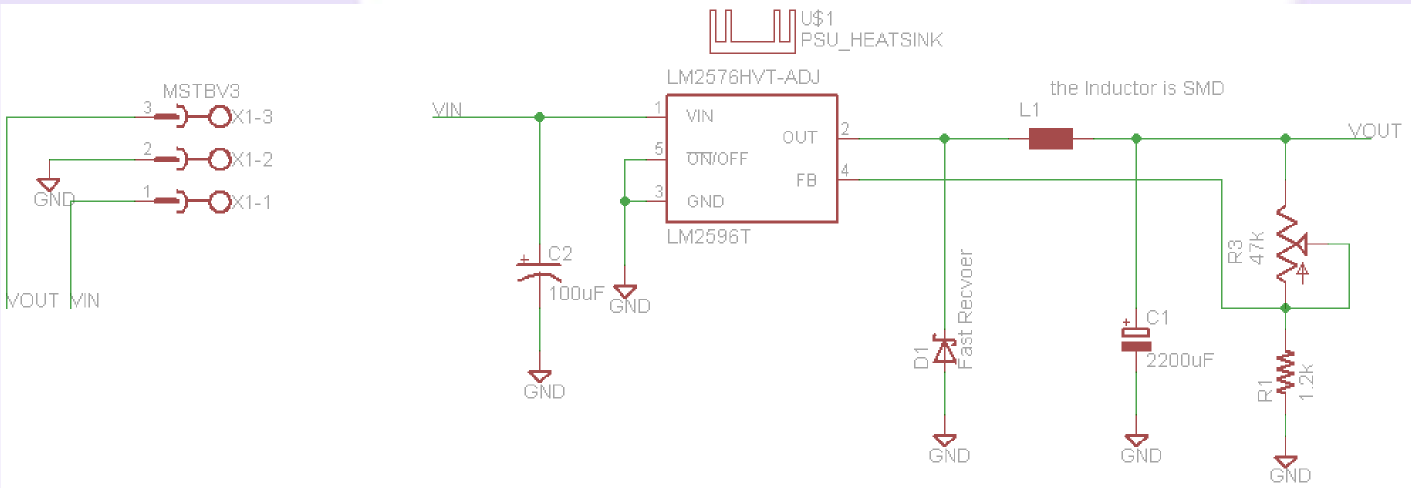


PCB Layout

6.2. Adjustable Voltage Regulator



PCB Layout

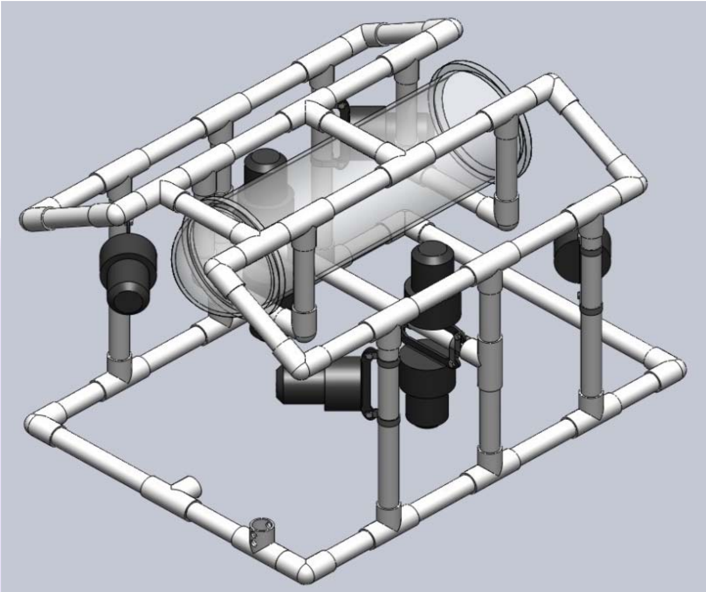


Schematic

7. Design Rationale

7.1. Frame

The ROV frame encloses the pressure vessel and provides mounts and attachments for the tools, cameras, lights and thrusters.



The employed design was selected for the stable support of the pressure vessel and ample space in the lower section for tooling and in the upper section for buoyancy aids. By utilising the maximum dimensions available (550x400x350mm due to transportation arrangements) it was ensured that obstacles arising from bulky modifications to tooling were reduced. It also allowed room for eight thrusters, each enclosed in the frame for safety and to prevent damage or repositioning. By positioning the pressure vessel centrally and at the top of the ROV, greater stability is achieved (see Buoyancy, below).

PVC pipes, elbows and tees were used for construction. These were chosen over aluminium and other alternatives since PVC is cheap, light and very easy to cut, assemble and modify. The latter in particular was important, since it was inevitable that alterations would be made as challenges were overcome. The frame was simply slotted together and once the team was satisfied it could be securely fixed with self-tapping screws.

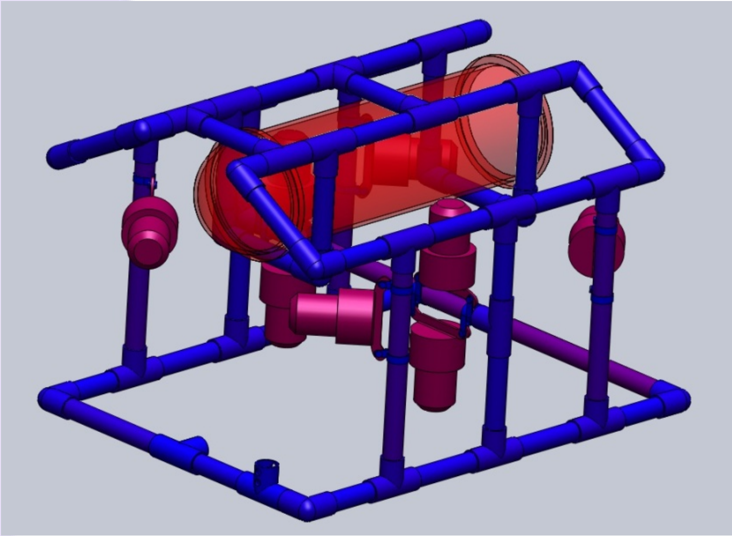
The hollow piping used allows cabling from components to the pressure vessel to be safely and neatly housed. By drilling a number of holes the frame is flooded when in operation.

7.2. Buoyancy

Stability of the ROV is crucial to its operation and this was kept in mind when positioning components. Foam blocks are used as buoyancy aids since they have low density and are easily cut to size. Considerations to ensure that the centre of gravity (CoG) and centre of buoyancy (CoB) of the ROV are aligned in the z-direction, with the CoB above, include;

- Tooling located in the bottom section. The samplers and claw in particular lower the CoG due to their weight.
- Pressure vessel elevated as high as possible. Since it is light with a large volume, the vessel contributes a large buoyant force.
- Flooding of the frame. Greatly reduces buoyant force, removing the need for weights to be added. Also eliminates the challenging task of sealing the PVC connections.
- Buoyancy aids located in the upper corners. Positioning the aids in the upper section lifts the CoB, and by spacing them far apart this reduces the tendency of the ROV to pitch and roll.

The individual contribution of each singular component of the basic ROV is shown below. It can be seen that the pressure vessel has a large volume and hence a large buoyant force.



Volume Analysis of the frame, thrusters and pressure vessel. Warmer colours indicate a greater volume.

Another goal in the design of the ROV was to have it neutrally buoyant, improving control and the ability to perform precise missions. To achieve this, the completed ROV was weighed in air and water and hence the additional volume required for weight and buoyant force to be equal was calculated. Due to slight inaccuracies in values for density of water and buoyant foam, this method was not entirely precise and small alterations had to be made to the volume and position of the foam.

7.3. Thrusters

Our ROV owes its manoeuvrability to eight thrusters, made from modified Johnstone 24V bilge pumps. The pump casings were removed and propellers fitted, secured using grub screws. It was decided that pumps would be used as thrusters since they provide a watertight motor with suitable torque for the task.

A bilge pump similar to that selected is pictured. This particular model was selected as testing proved that it provided satisfactory thrust, while being compact and within our budget. The wings on the casing make the pumps straightforward to attach, achieved by drilling two holes and securing them to the ROV frame with P-clips.

The horizontal thrusters are orientated at 45°, providing similar thrust in all horizontal directions as well as superior rotational mobility. Vertical thrusters are placed centrally, keeping them close to the ROV's CoG and preventing unwanted pitching when diving or surfacing.

7.4. Pressure Vessel

All electrical components are housed in the pressure vessel. Perspex was used in construction, as it is light, strong, can be readily glued and can have threaded holes machined. The main features are as follows;

- Cylindrical body giving optimum strength when externally loaded.
- Perspex dome at the head of the cylinder, allowing the main camera approximately 140° of clear and unobstructed view.
- Removable back panel, tightly screwed to a flange on the cylinder during operation. The panel is fitted with ten waterproof glands for cabling to enter the vessel.

The pressure vessel is held in place by the ROV frame, and can be removed by unscrewing the supports.

7.5. Grabber Claw

A drastic alteration was made to previously seen claw designs. The team desired a claw which is easily removable for transportation, doesn't rely on motors which would need to be waterproofed and is fast-acting so that the ROV does not need to hover in place while the claw is in operation.

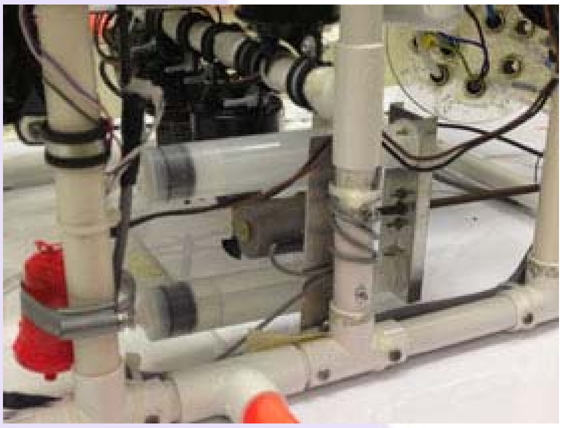
The solution is an entirely unique design, employing a spring-loaded, heavy-duty solenoid to open and close the grabber in an on/off fashion. The skeleton of the claw was drafted entirely from scratched, designed to maximise the swing of the grabber with the minimal

switch of the solenoid. Since the bolt is not physically attached to the solenoid, it is easy to detach the grabber by removing two screws from the frame. Rubber contacts are attached to the grabber plates to provide extra grip.

The grabber claw is to be used in the completion of the following missions:

- Transporting and attaching the lift bag.
- Transplanting the endangered coral.
- Resealing drill holes.

7.6. Fluid Containers



The ROV is fitted with two sampling devices, each consisting of two parallel 60ml syringes which are opened and closed by a geared motor driving a threaded bar. Using this set up one sampler can extract fuel oil while the other simultaneously injects seawater into the fuel tank of the wreck. The extraction and injection tubes are each guided by a steel rod to ensure they stay straight during operation.

7.7. Metal Detector

Our metal detector follows the KISS principle, a simple design which gets the job done. An electromagnet in a machined housing and fitted to a spring slides forward when activated next to ferrous metal. The detector is in view of the main camera so that the pilot can confirm its response. It is positioned facing inwards so that the outward facing tools (claw and sampler) do not get in the way.

8. Cameras

The ROVs camera system is made up of one navigation camera internally housed within the Perspex pressure vessel and two external cameras mounted on the ROV to ensure the tools can be operated effectively.

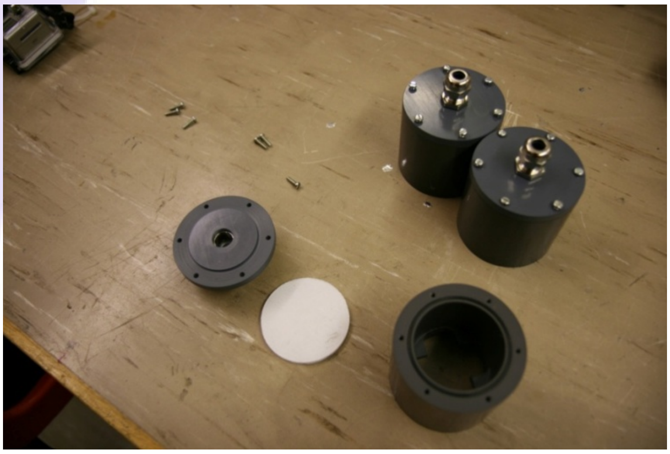
Inside the vessel the camera mount is hinged on a small servo motor. This gives one axis of rotation (tilt) for the pilot to adjust the viewing angle during navigation.

8.1. Module

The choice of camera for the 2012 competition was based on the need to upgrade in picture quality from the previous year. The decision was made to use a 'SONY Super HAD' as it boasts an integrated regulator and menu system but also runs on 12v – minimising the need for any additional regulators to be implemented. The main improvements are detachable 'On Screen Display' button modules which optimise the camera settings for the underwater lighting conditions.

8.2. Housing

The housing is a complete redesign from the option used in the previous 3 years of competition. Several problems have been engineered out with the new design. The material used is ABS plastic machined from a solid bar. The camera is mounted inside the housing simply by screwing the module to the four tabs. A 5mm thickness Perspex lens is secured with silicon. The casing lens indent is deeper than the lens thickness which gives a slight overlap of plastic housing. This is intentional to give the lens protection during both operation and transport of the ROV. An O-ring is located on the main body of the housing to ensure the back plate seals against the main body fully. The back plate itself is screwed into the walls of the main body. A cable gland is used to connect the camera to the pressure vessel.



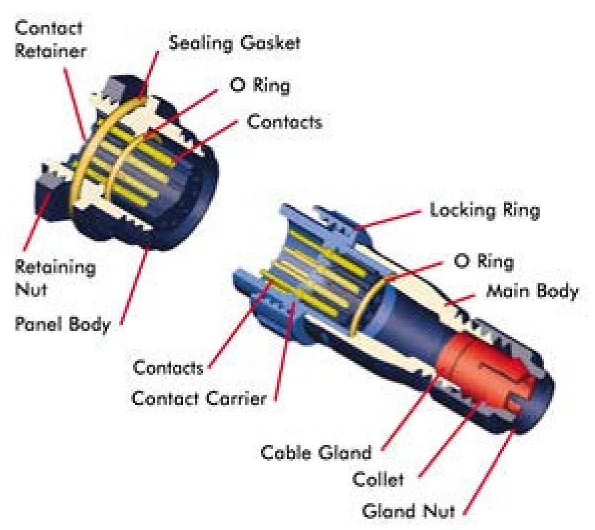
Finished Camera Housings

The camera housings are mounted to the frame with ‘Jubilee clips’.

9. Tether

The tether consists of a Catagory 5e data communication cable and a 3 core domestic mains cable. The data cable consists of 8 conductors in the form of 4 ‘twisted pairs’. The power cable has 3 conductors each rated at 12A. Both of these options are a convenient and cost effective method of supplying the ROV with power and data due to the University having them in stock.

Improvements over previous years’ tether include reducing the number of cables considerably to just two. Also the tether is fully detachable from the ROV in a matter of seconds with use of submersible cable connectors. A diagram from the suppliers data sheet is shown. The power connector is very similar but much larger.



Submersible Data Connector

10. Hardware and Circuitry

The hardware design posed a few challenges: Stepping down the supplied 48v to the different components, rating components appropriately, isolating noisy circuitry from the cameras and more.

In order to optimize performance and minimize any potential failures, the hardware was designed to be as simple as possible. The whole system is built to be redundant meaning in case of substantial hardware failure, the ROV controls and cameras will still operate.

10.1. Voltage Step-down Overview

The ROV uses 3 voltage rails, as listed below:

24v – motors (48v down to 24v with use of PWM)

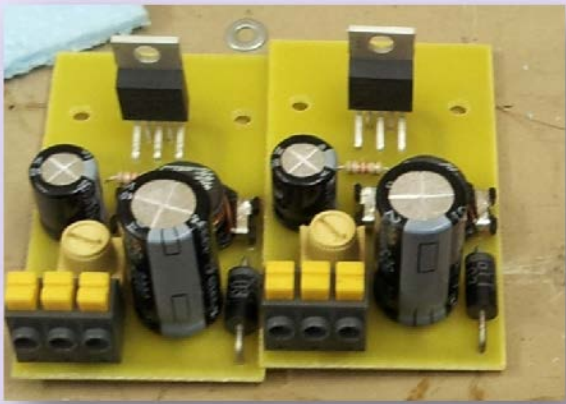
12v – cameras and tools (switching voltage regulator)

5v – microcontrollers and speed controllers (switching voltage regulator)

10.2. Voltage Regulators

The ROV uses two 12v regulators (cameras, tools, Arduino and other peripherals) and one 5v regulator (pressure sensor, speed controllers)

In order to keep the costs down, instead of using specialized regulators for every voltage rail, adjustable voltage regulators have been designed. This also simplifies replacing a faulty regulator if needed.



The regulators are based on the **LM2576HVT-ADJ** step down switching buck regulator chip. The HVT version used allows a maximum input voltage of

60v which is appropriate for the ROV (max supplied ROV input approx 50v). The use of only a few discrete components alongside the regulator IC makes this adjustable voltage regulator very reliable.

10.3. Motor controllers

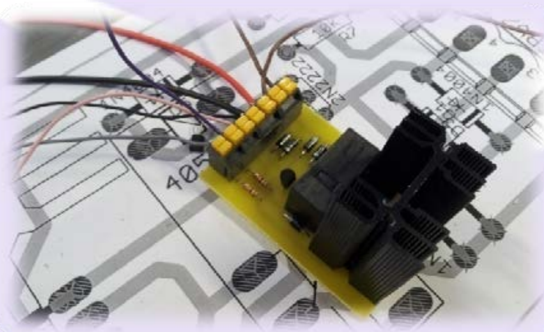
The motor controllers are the most used part of the hardware. The ROV uses six controllers to drive its 8 motors (4 horizontal and 2 pairs for vertical). Also, the ROV uses vectored thrust propulsion which gives advanced manoeuvrability (3D motion), but a failure in either motor controller will make the ROV almost impossible to steer. This is why the controllers have been designed to be reliable.

10.4. Motor Controller Main Features

- Ultra high rating of the speed controller (50A continuous drain current)
- Simple direction changing H-Bridge design using a high rated DPDT Relay
- No overheating problems
- Modular and compact design
- Allows occasional motor Boosts for very fast manoeuvres.

As stated above, the motor controller has been designed to be as simple as possible to improve reliability.

An N channel MOSFET (**IRFZ44RPBF**) is used to regulate the voltage going to the motor by stepping the available 48v directly down from 24v (max rated motor voltage) to 0v via **PWM**. The direction of the motor is controlled by a DPDT relay (**8A 5Vdc**) acting as an H-Bridge. The 5v regulator is used to drive the numerous DPDT relays because the microcontroller cannot supply enough current to trigger them (relay needs 200mA to trigger vs the maximum 40mA available from the microcontroller). This is why an additional low current NPN transistor is used to trigger the 5V rail to the relay.



Both the MOSFET and DPDT relay are directly controlled by the onboard Arduino Mega microcontroller.

10.5. On Screen Display (OSD)

An on screen display is a very useful addition to the ROV as it overlays important information about the status of the system onto the pilot's main screen.

OSD telemetry displayed

- Individual motor speeds
- Approximate depth
- Tools status (operating / offline)
- Navigation crosshair
- Digital compass heading

10.1.1 OSD Hardware

The OSD is based on an Arduino Pro Mini (16Mhz, 5v) and video sync separator chip (LM1881).

The On Screen Display is connected in parallel to the camera's video out signal. This way, the camera signal will not be affected if the OSD stops working.

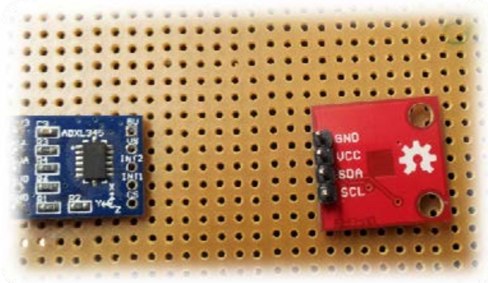
10.1.2 OSD Software

The software is based on Dennis Frie's DIY open source OSD project. The original code was substantially modified as it was initially written for UAV and FPV (first person view) RC plane use.

10.1.3 Quick OSD code overview

- The Arduino uses the SPI interface to generate pixels that will overlay on the transmitted video signal, line by line.
- The LM1881 video sync separator chip is then used to detect the start of a new line.
- Each character is generated using an 8x8 bit map
- Telemetry data is piggybacked from the tether TX line.
- OSD also supplies and reads the analog value from the pressure sensor.

10.6. Digital compass



In order to provide heading and direction information, the ROV uses a tilt compensated digital compass module. The system consists of a three axis HMC5883L magnetometer and a three axis ADXL345 accelerometer. The accelerometer is used to tilt compensate the magnetometer module because a slight change in the position of the HMC5883L will affect the reading.

11. Control System

11.1. Surface

The surface control system is where the pilot and co–pilot will control the ROV and its tools. The majority of tools are controlled via a number of switches and potentiometers, and are mounted on a dedicated tools control box. The main control box is dedicated to ROV movement, which is controlled using a 3 axis Hall Effect joystick for horizontal movement, and a linear potentiometer to control the depth. A pressure sensor is used to implement an auto depth system for additional stability.

The PWM limit is user adjustable via a rotary potentiometer, to either increase the maximum voltage to the motors, up to 48V for a thrust boost, or decrease the maximum voltage to allow more delicate manoeuvrability. These analogue control signals are fed into an Arduino Mega 2560 microcontroller via the onboard ADC converter and a custom designed shield.

An on screen display overlay displays telemetry to the displays. On the tools control box are two rotary switches connected to two of the displays. This allows switching of camera feeds to different screens. The third screen is fed from the movement control box through another rotary switch. The PCBs are connected via 10 way right-angled connectors. This allows fast, easy and tidy connections between PCBs. The two control boxes are connected via a 9 pin VGA connector cable.

The 48V supply connects to the main control box, in series with a fuse, then to the power cable. Both connections are done through speakON connectors from Neutrik. These were chosen due to their small size and power rating (see figure to the left).

The camera feeds come from a separate cable and are connected to phono/RCA plugs mounted on the main control box. The screens are connected to the same box via similar plugs.

Outgoing data and incoming telemetry is fed through another data cable and is connected to the main control box through a 9 pin VGA connector.

12v is supplied from the ROV back up to the main control box to power the Arduino. The power is connected via banana plugs.

11.2. Subsurface

The pressure vessel is housed within the frame of the ROV, where the main power supply, video and control signal tether connects to. A second Arduino Mega 2560 microcontroller with another bespoke shield interprets the control signals and outputs 6 PWM (pulse width modulation) and 6 direction (logic) signals. These signals feed to 6 custom built H – bridges, each connected to the motors. This allows precise speed and direction adjustments of the ROV. For additional stability, an accelerometer and a gyrostabiliser are mounted within the vessel and are used to stop any unwanted movement due to momentum or any other factors. The pressure sensor outputs a signal that feeds into an analogue to digital converter (ADC) pin on the Arduino. The Arduino then converts the signal from pressure to depth, and the value is used in the auto depth system.

The motors are 24v 3A bilge pumps. As the power supply was 48v, the PWM signals is initially capped at 50% duty cycle, so only up to half the supply voltage will be supplied to the motors. But if a boost is needed the duty cycle cap can be increased to 100%, or if fine movements are required the cap can be reduced further.

11.3. Control Program

The control program interprets the inputs and converts them into various PWM cycles. As the horizontal motors are vectored, the ROV can move in any combination of surge, sway and yaw movements. They are controlled by a single joystick so the program will determine how much power each motor receives and which direction they spin. It also sends full power (24v at 50% cycle if no boost or reduction is required) to all horizontal motors if the ROV needs to move in only one direction.

Vertical control is much simpler where the placement of the slide on the potentiometer on the surface determines the speed and direction of the vertical motors. The duty cycle cap for these motors are the same as those of the horizontal motors, so the same adjustments can be applied. When the slide is in the middle, the auto depth will intervene and keep the ROV at a steady depth, eliminating any movement due to momentum.

There is a tools breakout board that the Arduino is connected to and logic signals are sent to it to switch the tools on or off, or reverse the direction of certain tools.

Communication between Arduino’s is dealt serially, and is done through an open source library called “EasyTransfer”, created by Bill Porter, an electrical engineer. The library allows the variables to be easily defined, transferred and decrypted. It also allows easy two way communications between the microcontrollers.

11.4. Troubleshooting

One of the main challenges in the project was creating a pressure vessel to our required specification. Even with a design based on the previous year's vessel many problems were encountered with the plastic glue used on the Perspex. In order to fault find and redesign some parts we worked closely with technicians from the workshop. Their knowledge input was crucial to the success of the pressure vessel.

11.5. Software

A major challenge that was encountered was when attempting to put movement control and tools control into a single pair of communication programs. It seemed that once the tools components were introduced, interference was caused and full control of the motors and tools were intermittent at best. We overcame this problem by reverting to early versions of the programs and created modular sections and functions where any bugs were easily found and fixed.

11.6. Noise/Interference

In the first tests of camera to monitor feeds, we found that there was a large amount of interference coming through. After a series of tests, trial and error and fault finding we separated the camera 12v supply from the rest of the electronics, i.e. made a separate 12 source. We will also use a dedicated camera tether to reduce any noise.

12. Conclusion

In conclusion the project was a huge task to undertake for each of the team members. Taking part in the MATE ROV competition is a unique experience that has so many benefits. The practical experience gained from participating in the MATE competition is something that helps us prepare for working as professionals. It gives the experience needed in team work, problem solving and organisational skills to work as professionals after graduation. With several setbacks and lessons learned, the project has been a success.

13. Reflections on the experience

"The MATE ROV project was an excellent opportunity for me to test the knowledge and experience gained in the last three years of doing electrical and electronics engineering with The Robert Gordon University. Improving my team working and professional skills was a huge bonus as well. I also proved to myself that I am capable of delivering the given tasks within the given specification keeping a high level of quality."

- Mihai Andrian

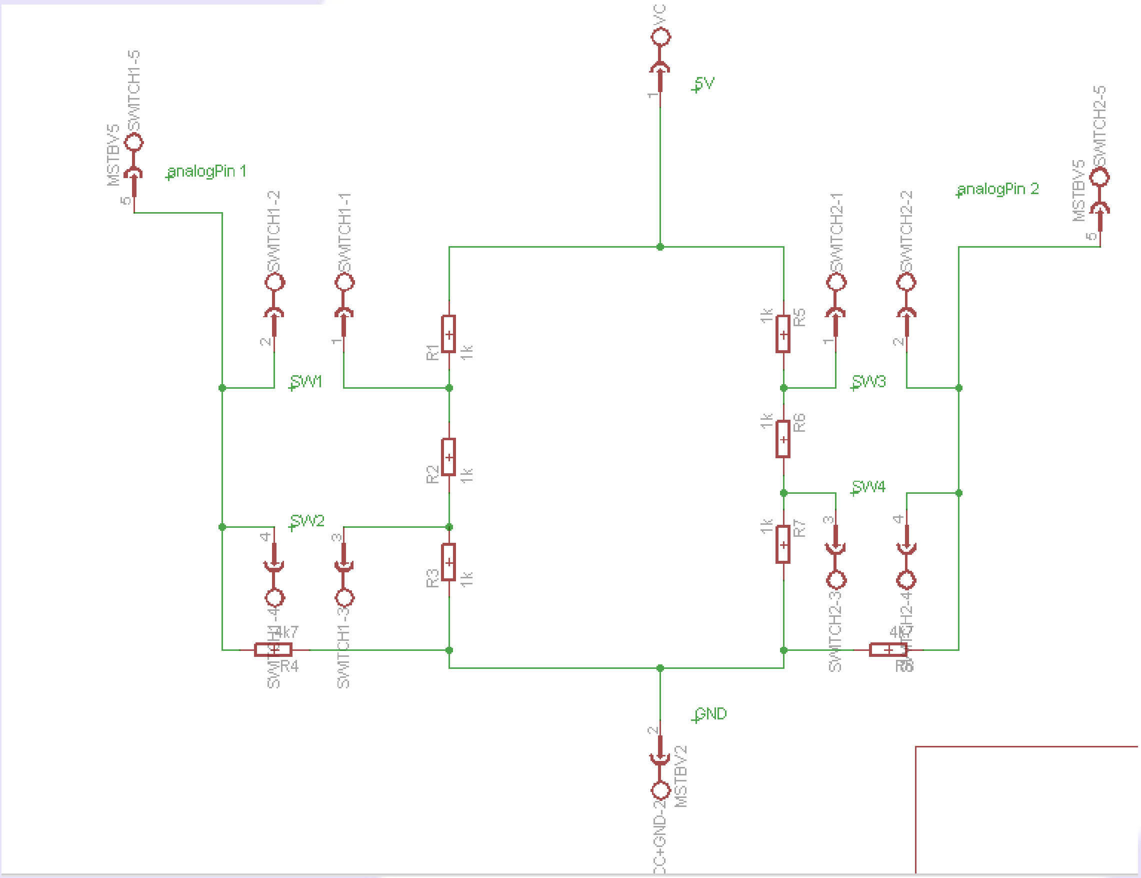
"*The experience of being part of a team in the MATE competition has been a real insight into many different areas, it's been a great delight in understanding the creation of an ROV and getting a glimpse into how the industry operates. It's been a real challenge at times for everyone and due to this struggle it has helped me improve my skills in greater depth. I've learnt new skills along the way, as I can imagine is the same for everyone taking part.*

Having a background in graphics and visual work, I feel that a strong visual design can bring a sense of coherency and a level of professionalism to a project; a company's image can be as important as their products, a good design can create a strong first impression. I tried to bring my specialities to the team and hope it benefited for it. I feel privileged to be part of the competition as the whole experience has opened my eyes to so many new possibilities and objectives to pursue." -
Jon Nicolson

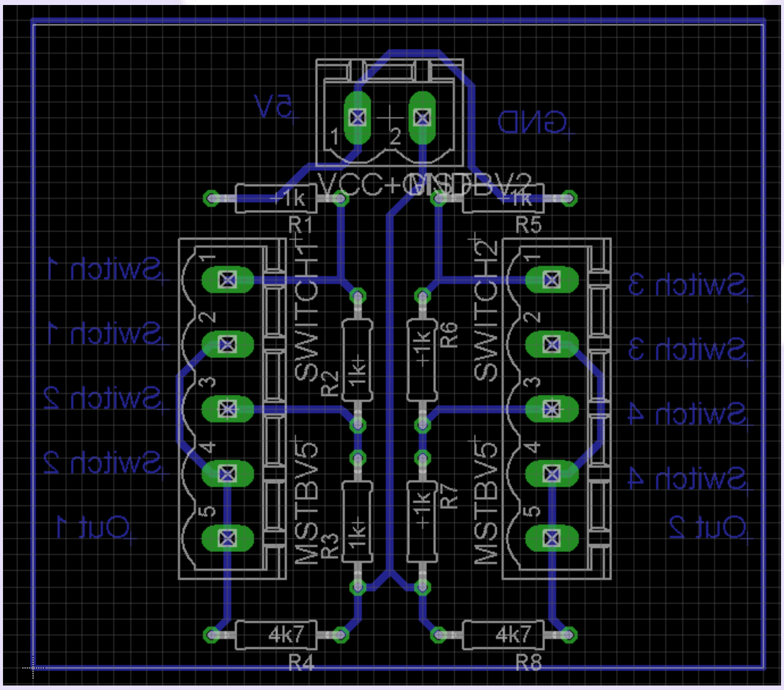
"*Experience with working in a team is highly sought-after in engineering careers. The MATE project has helped me to develop essential core skills which will be useful throughout my working life. The project has also given me a much deeper understanding of the operation and construction of ROVs, piquing my interest in pursuing an ROV-related job after graduation.*"

- Stuart Lamb

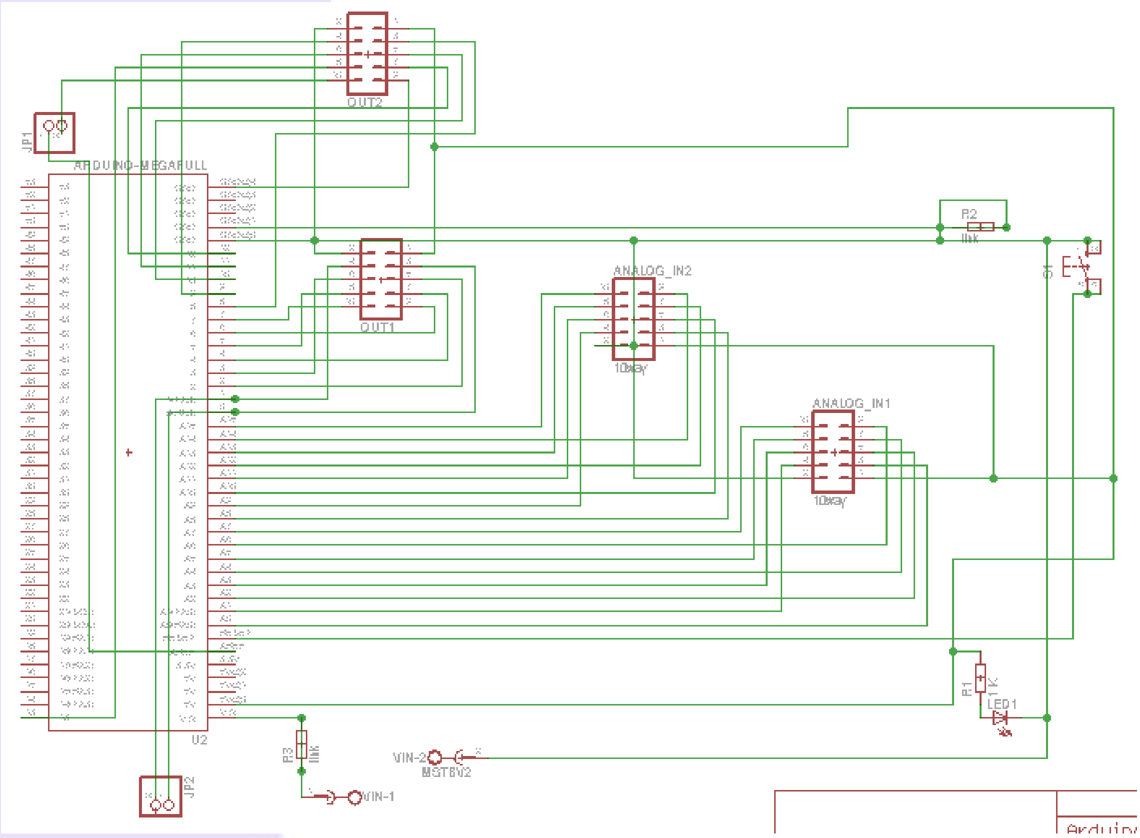
14. Appendix



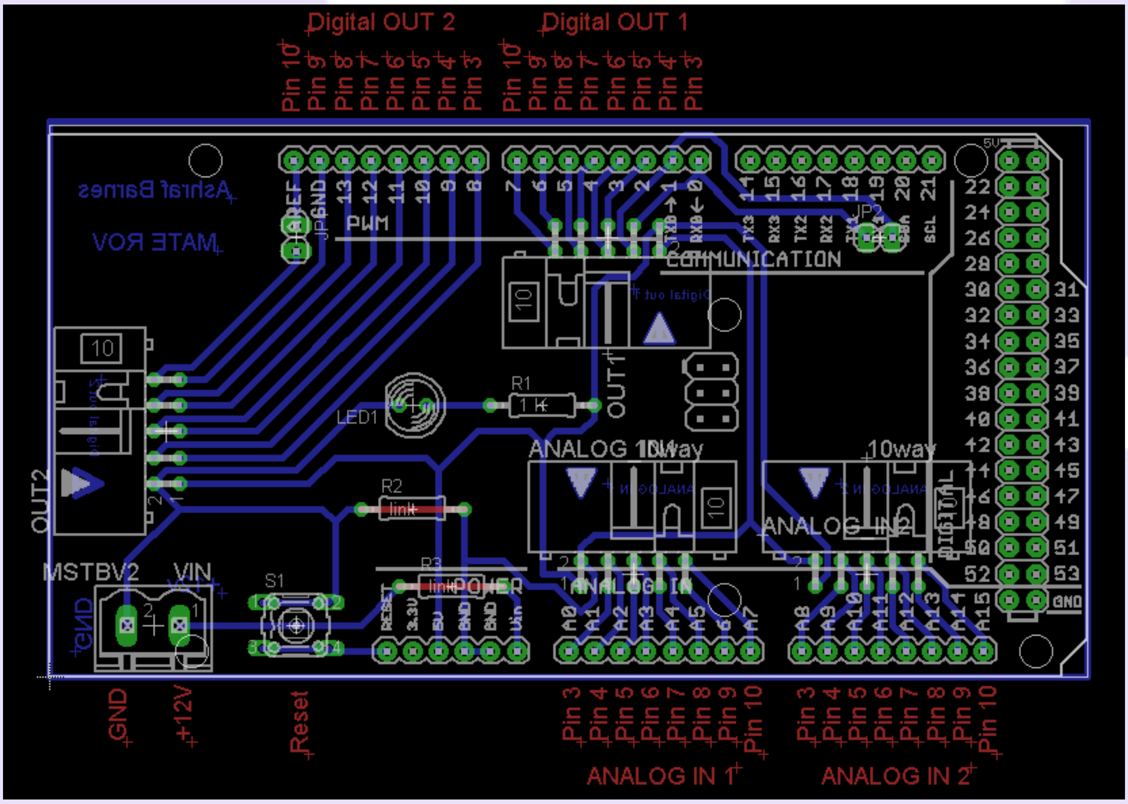
Above: Switch board schematic for tools controls board



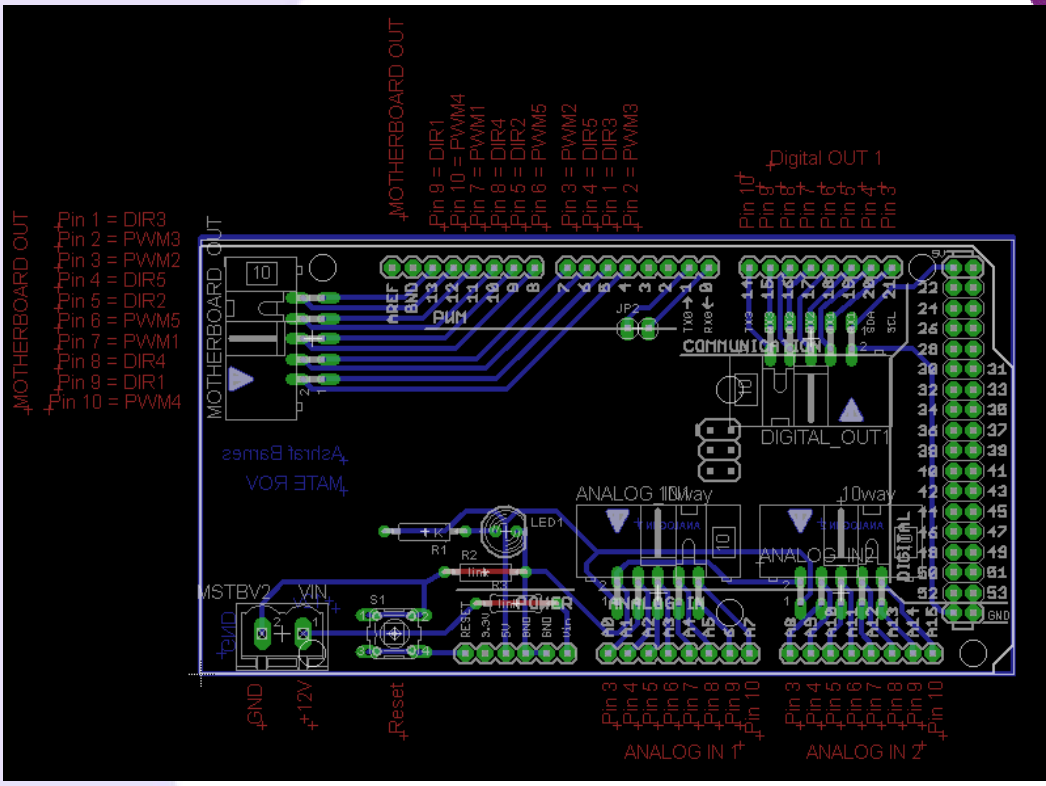
Above: Switch board layout for tools controls board



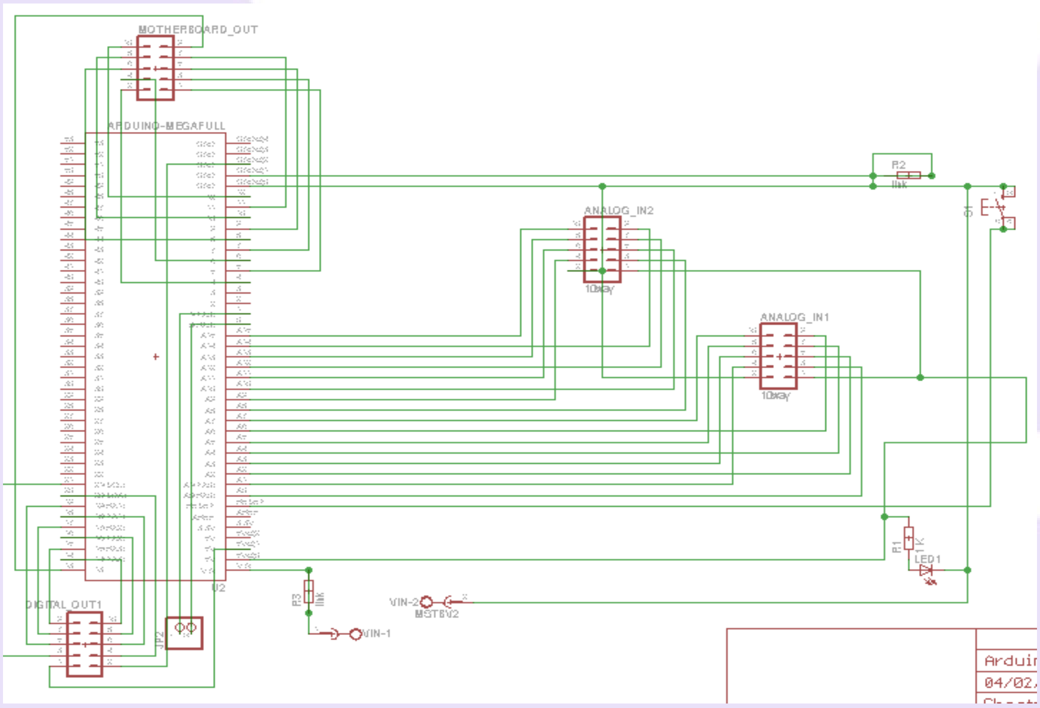
Above: Arduino mega 2560 surface shield schematic for main control box



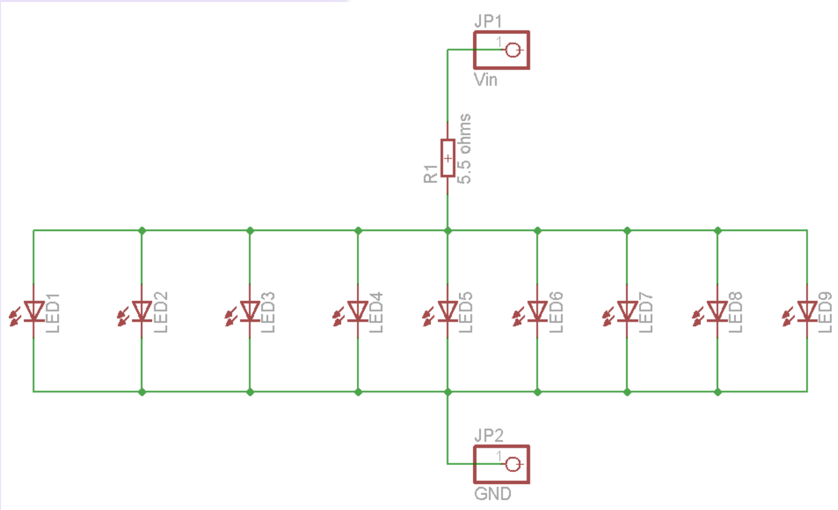
Above: Arduino mega 2560 surface board layout for main controls board



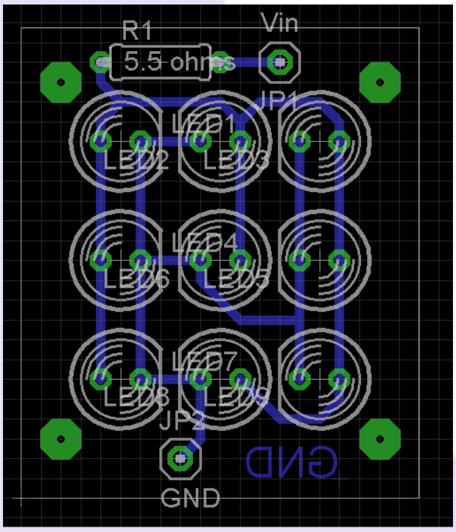
Above: Arduino mega 2560 onboard board layout for pressure vessel



Above: Arduino mega 2560 onboard schematic for pressure vessel



Above: LED board schematic diagram



Above: LED board layout