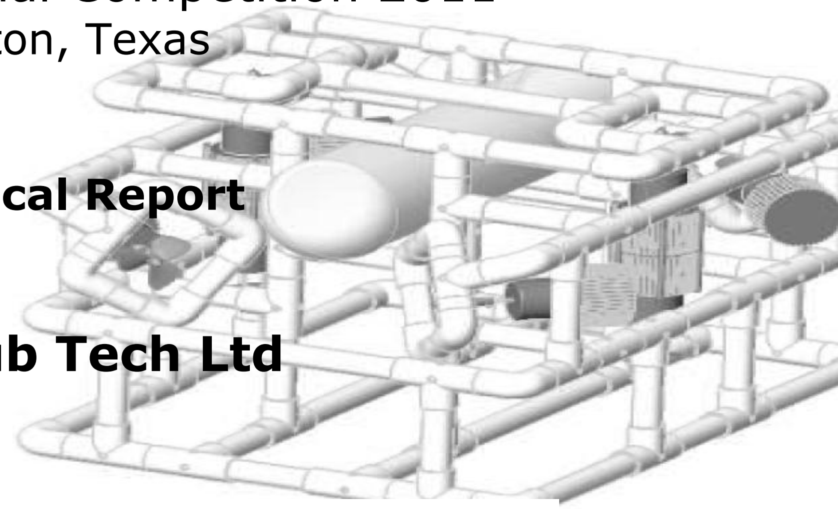
MATE International Competition 2011

Houston, Texas



Technical Report

RGU Sub Tech Ltd

Explorer Class

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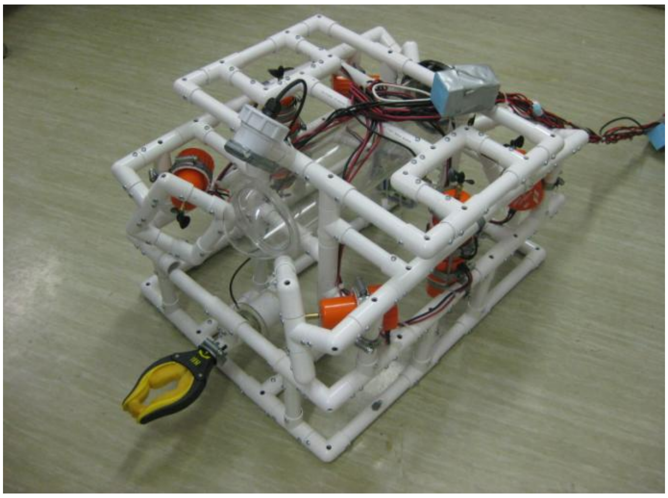
ABSTRACT

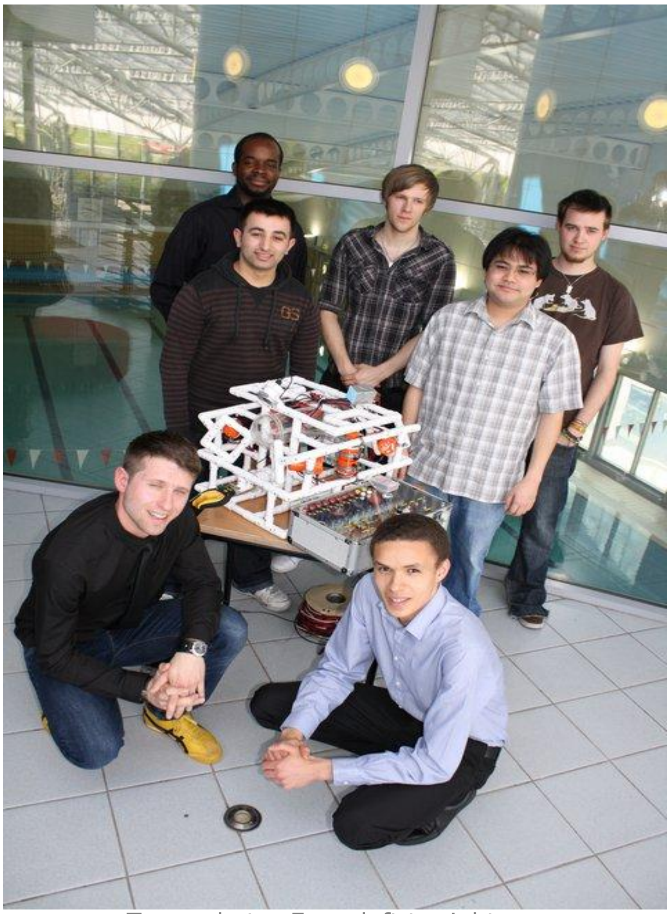
The following report details the design and manufacture of the Robert Gordon University's ROV for MATE International ROV 2011 competition held in Houston, Texas. The theme is based on the Gulf of Mexico disaster which was the largest oil spill in the history of the petroleum/ Marine industry. The ROV was designed to handle similar tasks to the real world accident.

The ROV was designed to be low cost, easy to transport and easy to repair. It was also designed to be simple, reducing the chance of failure and also increasing the rate of manufacture. The frame is made out of PVC pipe which provide easy and quick manufacture of the ROV as well as making it strong, buoyant and capable. The ROV has a total of ten motors; eight of which are individually connected 24V motors set up in a vectored thrust configuration and two twelve volt geared motors for the tooling.

The ROV has three main tools; the modified grabbing at the front will be used to complete most of the tasks, an oil capping tool to simulate capping the flow of oil. A custom harpoon tool will be used to remove the damaged riser pipe. The water sampler and pressure sensor will then take a required water sample and measure the depth at specific point respectively.

The ROV has three cameras which are used for the pilot manoeuvring as well as to carry out tooling operations. An in-depth description of the ROV control system is also contained within the report.





Team photo- From left to right
Back: Folarin Tubi, Douglas Mackay, Jack Christie.
Middle: Bilal Goheer, Ashraf Barnes
Front: Kamil Sobolewski, Slimane Kerrouchi

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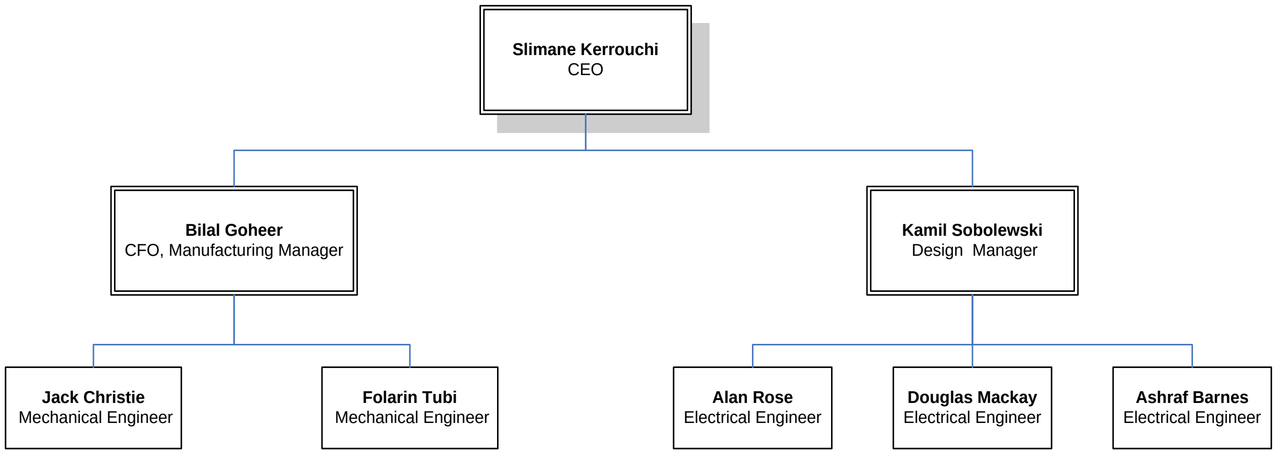
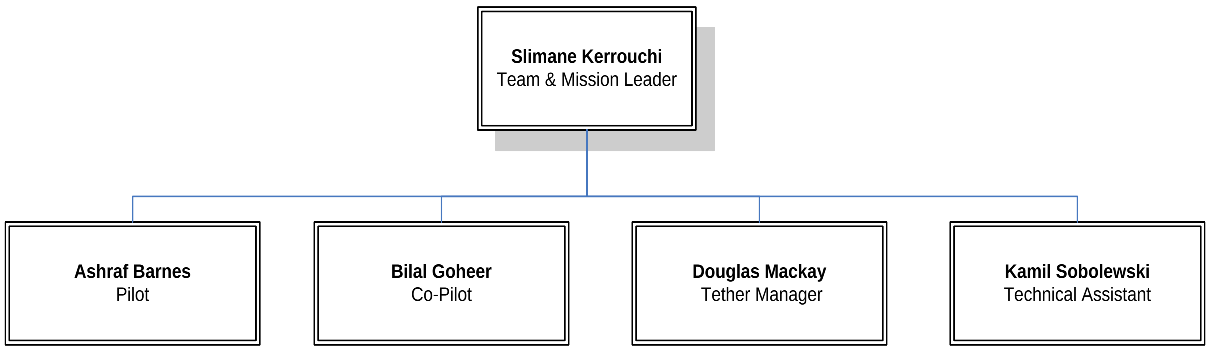
1. Company Structure:

1.1 Organisation Chart:



1.2 Team Members Role:



2. Budget/Expense Sheet:

Item	Donations	Expenditures
Bilge Pumps (x10)		£222.50
Pressure Sensor		£67.36
Cameras (x3)		£153.82
Arduino Mega		£48.00
Propellers (x10)		£23.54
LMD Motor Controllers (x10)		£85.62
Solenoid		£7.64
Hemispherical Dome		£4.79
Shaft Coupler (x8)	£28.40	
PVC elbow piece (x)	£0.38	
PVC T piece (x)	£0.38	
Plastic Pipe ø21mm	£3.98	
Grabber jaw	£9.99	
12Vdc Geared Motors (x2)	£44.48	
Self-tapping Screws		£2.50
Jubilee Clip 45-60 mm (x12)		£8.28
Jubilee Clip 17-25 mm (x8)		£4.56
100m Black Tri Rated Cable	£5.00	
100m Red Tri Rated Cable	£5.00	
TOTAL	£97.61	£628.61

TOTAL COST	**£726.22**

3. Design Rational:

RGU Sub Tech limited is specialised on developing underwater technologies to face deepwater challenges such as the oil spill in the Gulf of Mexico. In order to minimise the consequences of such disasters, the team of RGU Sub Tech Ltd has designed a Remotely Operated Vehicle (ROV) equipped with tools that can carry the mission tasks in a simplest and effective way. And the method followed by the team was by identifying all the possible approaches to perform the tasks, and then the optimal ideas were discussed before finalising the ideal solution.

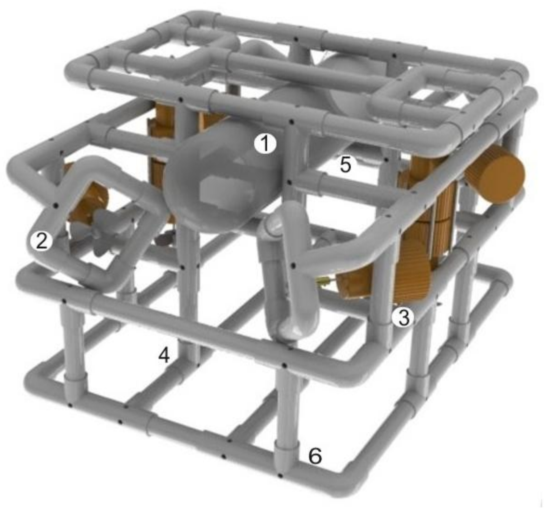
3.1 Frame:

The main framework of the ROV is made from PVC components such as pipes, elbows and Tees. The main advantages of using PVC material are:

- Light and buoyant construction
- Cheap and readily available components
- Easley assemble and disassemble construction

The frame was designed and constructed by taking the following into consideration:

1. Pressure vessel to be placed and fixed in a central position.
2. Thrusters to be hidden within the frame and properly secured – special square covers designed.
3. Motors properly fixed to the frame to prevent any movements – minimum two fixing points
4. Extra crossbars for future tools
5. Free top area for the buoyancy block if needed
6. Bottom extension to hide additional tools and protect bottom side of the ROV



The frame was designed and build by the company members using hand tools. Due to the symetrical construction of the vehicle, the frame was divided on modules and each of them was built separately. Once all were built, the frame was assembled together. Then, holes were drilled on the frame to flood the frame once it is in water. Also all the joints were secured with tap screws.

3.2 Thrusters:

The thrusters used in this ROV are the modified OceanSecure Bilge Pumps of 1100GPH which operates at 24 volts DC. And in order to match a propeller to these motors, the performance characteristics of the submersible motors were determined first, and these correspond to the relationship between the rotational speed, draw current, output power, and efficiency of the motor in respect to the output torque. The resulting performance curves are presented in the following figure:

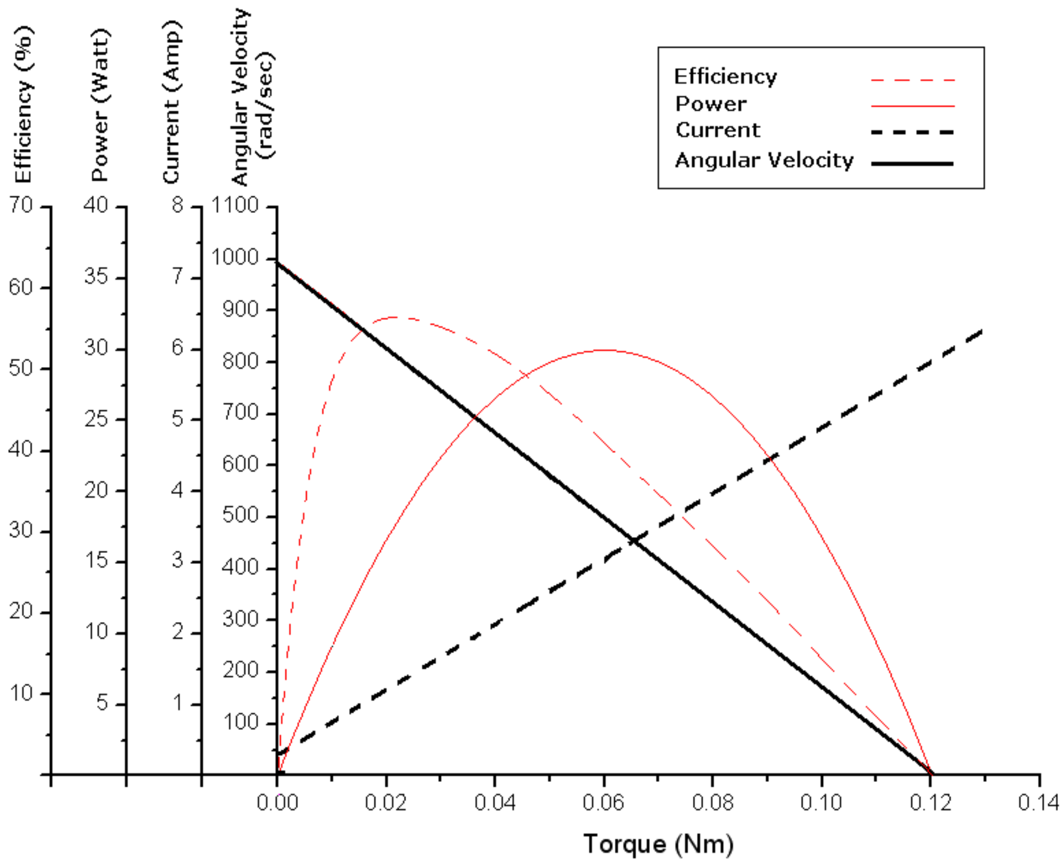


Figure: Submersible motor performance curves

From the figure above, the optimal characteristics of the 24Vdc OceanSecure Bilge Pump are taken at the maximum efficiency which is about 56%, and these characteristics are concluded in the following table:

Table 1: Optimal characterstics

Maximum Efficiency η_{max} (%)	Optimal Angular Velocity ω (rad/sec)	Optimal Torque T (Nm)	Optimal Draw Current I (Amp)	Optimal Power P (Watt)
56.21	826.42	0.0205	1.254	16.94

Hence, if the propeller was to be designed to meet the motor characteristics, these would be the most efficient operating conditions. However, due to the time constraints, different commercially available propellers (2, 3, and 4 bladed) were tested with the motor, and the most efficient propeller was a Graupner two bladed 34mm in diameter which delivers a forward thrust of 7.16N at 2.3amps and reverse thrust of 4.08N at 2.05amps.

Figure: Thruster

3.3 Cameras:

The ROV requires three cameras to operate efficiently and effectively. Navigation will be carried out via a forward facing camera which is mounted internally within the pressure vessel. A further two external cameras serve the purpose of providing vision while carrying out tooling operations. The voltage is dropped first from 48Vdc to 12Vdc via a voltage regulator circuit (See Figure) and shared out accordingly between the cameras. It is then dropped on each individual camera board to 5Vdc (See Figure). The two external cameras are individually housed and waterproofed. The three video signals are fed back from the pressure vessel to shore via a single cable with three cores.

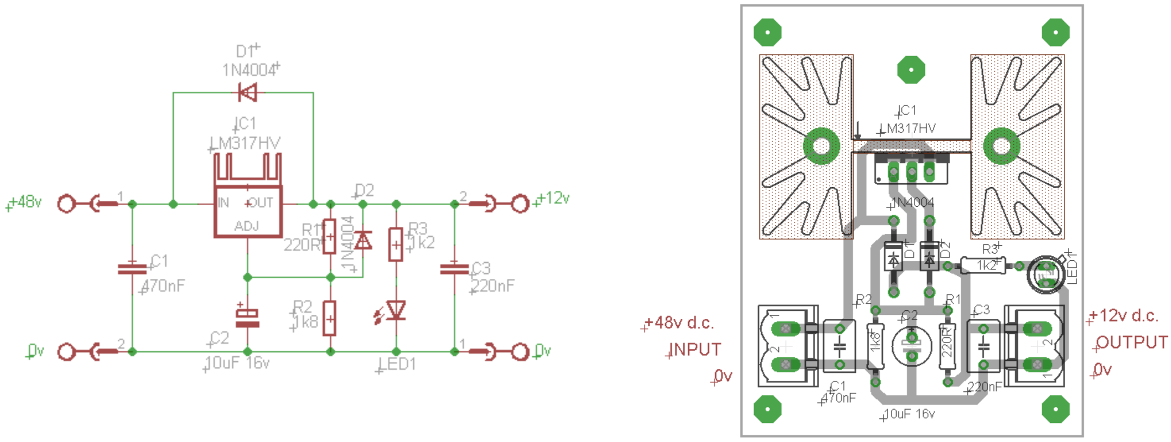


Figure: Voltage Regulator (48Vdc to 12Vdc)

The camera circuit and external housing are presented in the following figure:

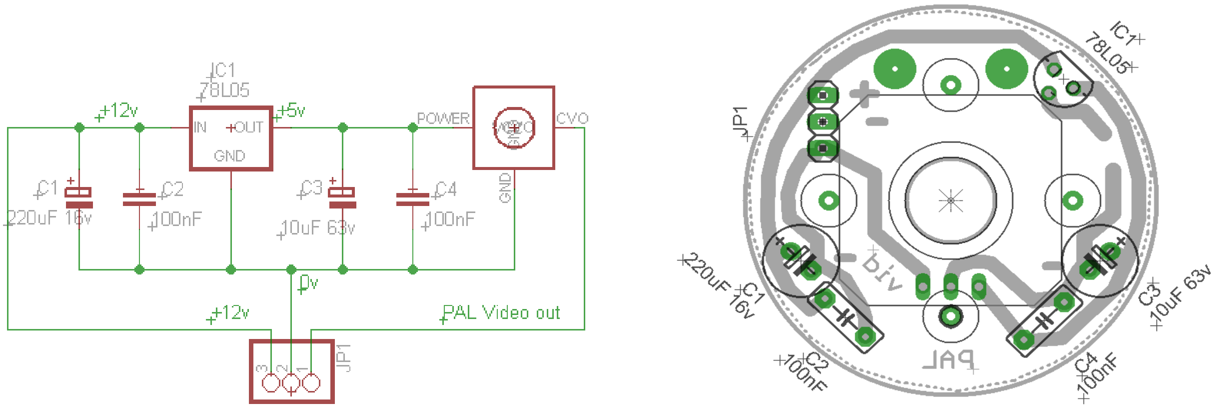


Figure: Camera circuit

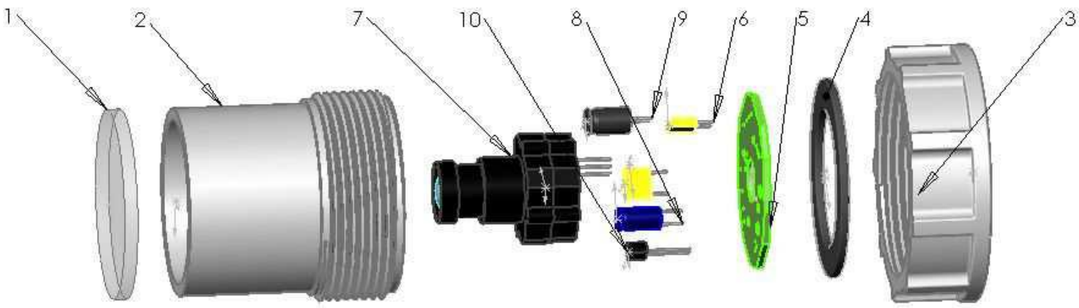


Figure: Camera external housing

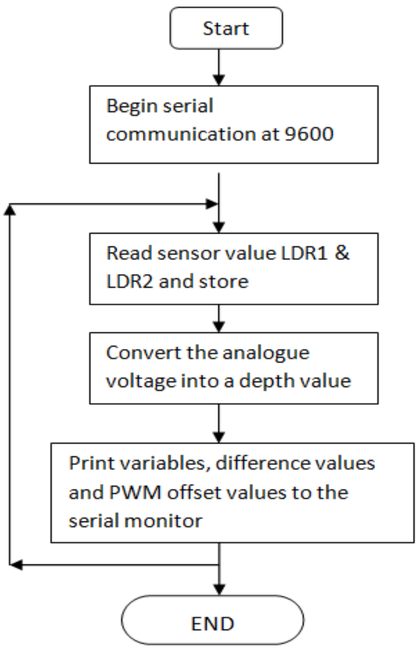
3.3.1 Camera Module:

The camera system is centered around three C-Cam8 modules (shown on right). The modules themselves are an updated version of a previous C-Cam module the team has used. The performance of the module is substantially greater than the previous model. The modules boast 1/3" CMOS imager sensors and a very low operating current of 10mA (no load). The module is very small and can neatly be installed within small housing.

Figure: Camera Module

3.4 Depth Sensor

SDX30A4 pressure sensor final circuit is based on a SDX Signal Conditioning Circuit Technical Note from Honeywell. The circuit has 2 amplifiers; the first amplifier is used to give an offset to the second amplifier. The offset is negative so a ICL7660CPA is used to convert +5 Volts to -5 Volts. The circuit still did not work as required so -5 volts was set to pin 4 of each amplifier.



The potentiometer is used to set the input on the first amplifier, and therefore, the output which is 2 volts for the circuit. Further adjustment is done by using the software on the Arduino microprocessor as the air pressure is variable and therefore the output from the sensor at sea level.
The second amplifier reads the output from the sensor and amplifies to the required level which is set by the value of R1, which is 1kΩ, minus the offset from the first amplifier to give an output voltage between 0V and 5V.
The sensor is an absolute type where "absolute pressure is zero referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric

pressure". The sensor has a power supply of 9V and has an input and output resistance of 4kΩ where the resistance is calculated from having 4 resistors in a bridge arrangement.

3.5 Pressure Vessel (Electronics housing):

The electronics housing is made of 360mm length Perspex pipe of 90mm internal diameter and 100mm external diameter. At the front end, a hemispherical dome is fixed to the pipe using a flange to reinforce the connection surface in order to withstand the pressure at 12m deep. At the other end, a 3mm flat aluminium plate is screwed to the flange fixed to the Perspex pipe, and a rubber gasket is also placed between them to seal the pressure vessel and not allowing water through. All the cable glands are placed at the flat end to pass the cables through and allow communication between the surface and the ROV. The calculations of pressure vessel dimension in order to withstand the water pressure at 12m with a safety factor of 2 are presented in appendix 1.

The developments of payloads to perform each mission tasks are illustrated as following:

3.6 Task 1: Remove the damaged riser pipe

The first tasks at hand for the ROV is to cut and remove the portion of the damaged riser pipe. For cutting the riser, this is simulated by removing a Velcro strip which is achievable by using a simple grabber mounted at the front side of the ROV, and the opening and closing of the grabber is controlled by the motor depend on its switching direction. Also before cutting the riser, a line has to be attached first to the U-bolt on the damaged riser pipe, and this is performed by transporting the harpoon with a line attached to it from the surface down to the riser with a grabber. And once the line is attached to the U-bolt and the Velcro strip is removed, the damaged riser pipe portion is lifted and removed from the work area.

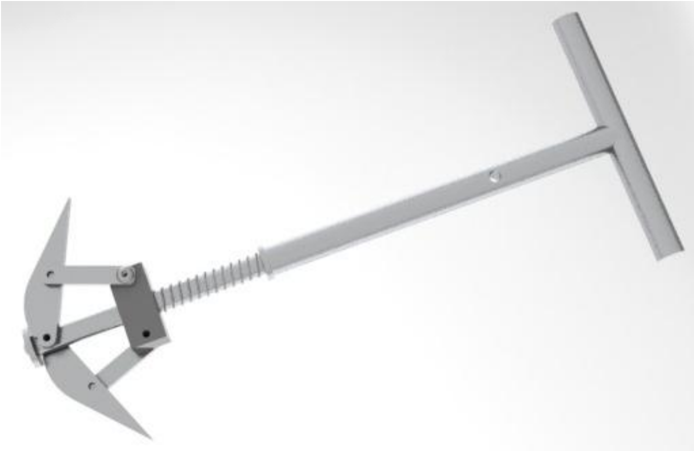


Figure: Harpoon tool

3.7 Task 2: Cap the oil well:

In this task, the company has designed a cap to cover the wellhead and stop the flow of oil, and this is achieved by transporting the cap to the oil well and places it on the wellhead to stop the oil flow. The well cap is designed in such a way that it is attached first externally to the wellhead by allowing oil to flow, and once the cap is secured then the cap is activated to stop the flow. The procedures on how the cap mechanism works is described below:

1) To put the cap on the position, and then
2) realese the main piston by remowing the pin. Due to the spring-hook-shaped bottom part of the cap, the tool will be attached to the small growe/flange on the well pipe and will stay on the position all the time.

Once the cap is on place, the pin will be remowed by grabber. Due to the downwards spring force the main piston will be holding the cap closed. The two (open and closed) configurations of the cap are shown below:

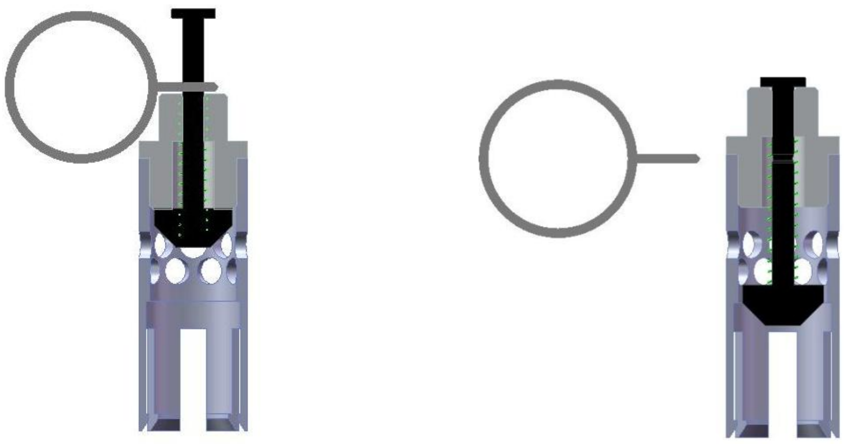


Figure: Cross-section view of the open and close configuration of the cap

3.8 Task 3: Collect water samples and measure depth:

In this task, the graph is interpreted to determine the correct depth at which to sample, and once this is completed, the ROV is manoeuvred to the sampling site and measure the depth using the depth sensor (described above). After that, a 100ml water sample is then taken and returned to the surface. For this task, the company design team developed a mechanism which employs two 60ml syringes working in parallel (open and close at the same time). And this is controlled by a geared 12Vdc motor, connected to the motor is a threaded rode which passes through a flat plate where the two syringes end are fixed onto. And by turning on the motor, the flat plate will move and open the syringes which in turn will suck water into the housing.

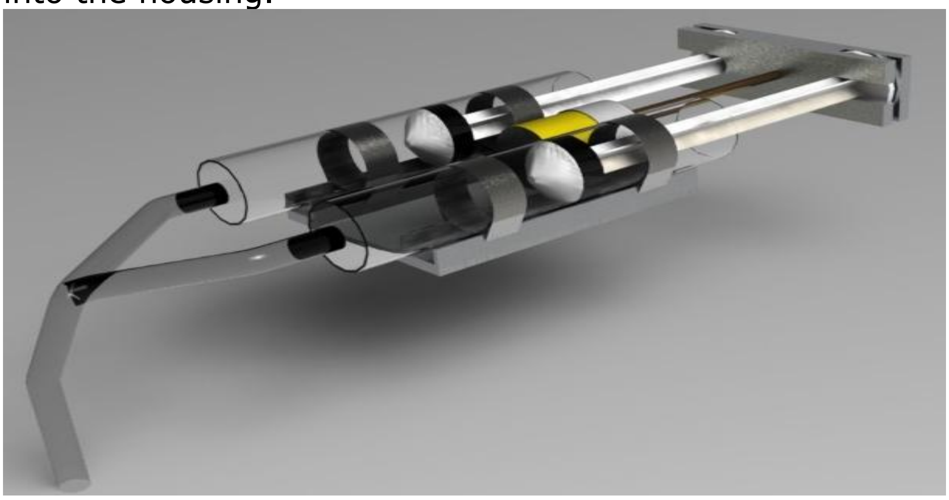


Figure: Final water sampling tool

3.9 *Task 4: Collect Biological samples:*

The final challenge is to collect one sample of each of the sea cucumber, glass sponge, and Chaceon crab. And this is achieved using the grabber which can pick up to two samples. However, because of the 12m operating depth, travelling up to the surface and back to the bottom will take a lot of time, and developing a tool which can pick all the three samples at the same time is necessary, and this is achieved by modifying the grabber as shown in the following figure:

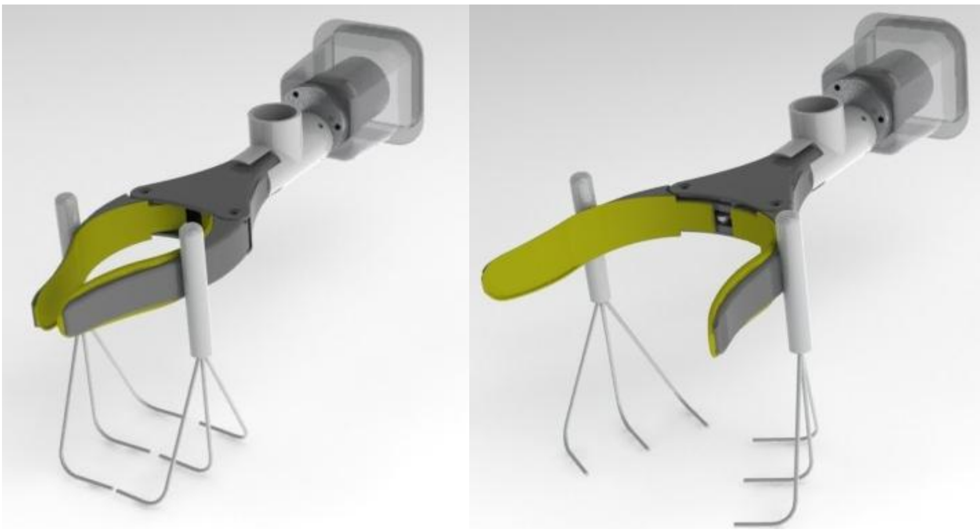
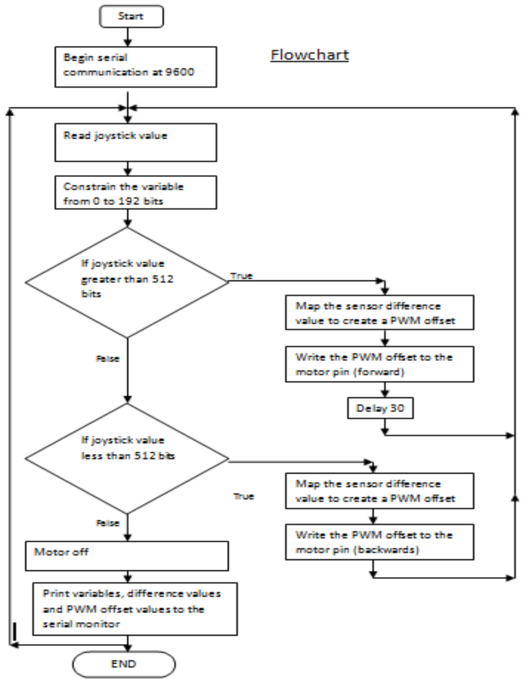


Figure: Open and close configuration of the grabber with claws attached to it

4. Control System:



At the time this report was created the company design and manufacturing team have not finalised the control system of the ROV. There are two control systems that are currently under test, and the third system has been tried and tested. However this system does not allow for speed control, and it is therefore used as a backup system, just in case the other two fail. Regardless of which system is used, they all consist of two main parts. This part of the report will explain the system that uses H – bridges alongside PWM (pulse width modulation) to control the speed and direction of the thrusters.

4.1 Surface control box:

The surface control box is where the pilot will control the ROV and its tools via a number of switches, a rotary potentiometer for depth control, and a three axis joystick of horizontal movement. These controls will feed into an Arduino Duemilanove microcontroller, amplifies them via a custom made PCB module, and sends these signals to the ROV via a 25m tether. The main power supply will be connected in series with a 40amp fuse to a similar tether. An LCD screen will display the depth of the ROV. The PCBs will be connected via 10 way right-angled connectors. This allows fast, easy and tidy connections between PCBs.

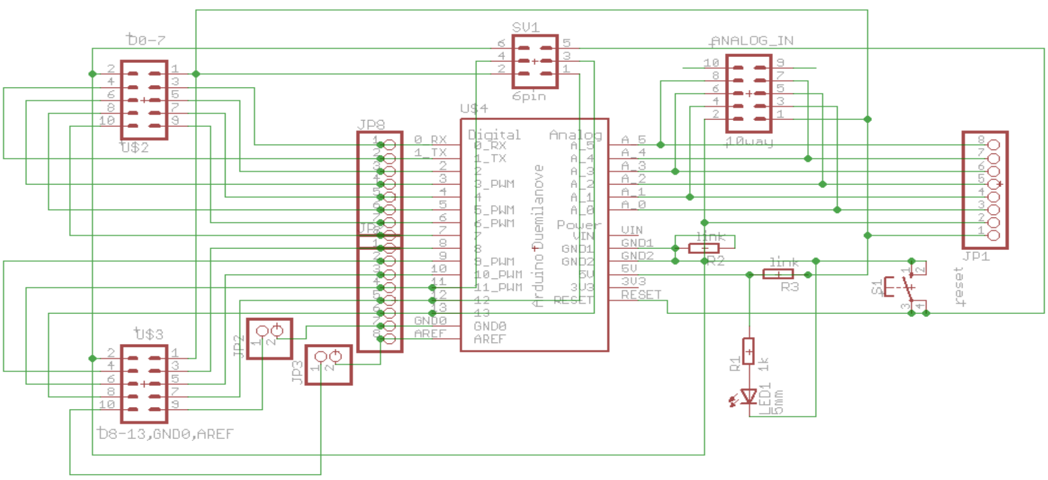


Figure: Duemilanove 10 way connectors shield schematic diagram (prototype 1)

4.2 *Pressure vessel electronics:*

The pressure vessel is housed within the frame of the ROV, where the main power supply and control signal tether connects to. An Arduino Mega microcontroller will interpret the control signals and will output 6 PWM (pulse width modulation) and 6 direction (logic) signals. These signals feed to 6 LMD18200 H – bridges, each connected to the motors. This allows precise speed and direction adjustments of the ROV. The pressure sensor amplifier circuit is also housed in the pressure vessel. It 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, amplifies them using a custom made PCB module similar to the one on the surface, and sends the signal back up the tether to the surface control box to be displayed on the LCD.
The motors are 24Vdc 3amp bilge pumps. As the power supply was 48v, the PWM signals will be capped at 50% duty cycle, so only up to half the supply voltage will be supplied to the motors.

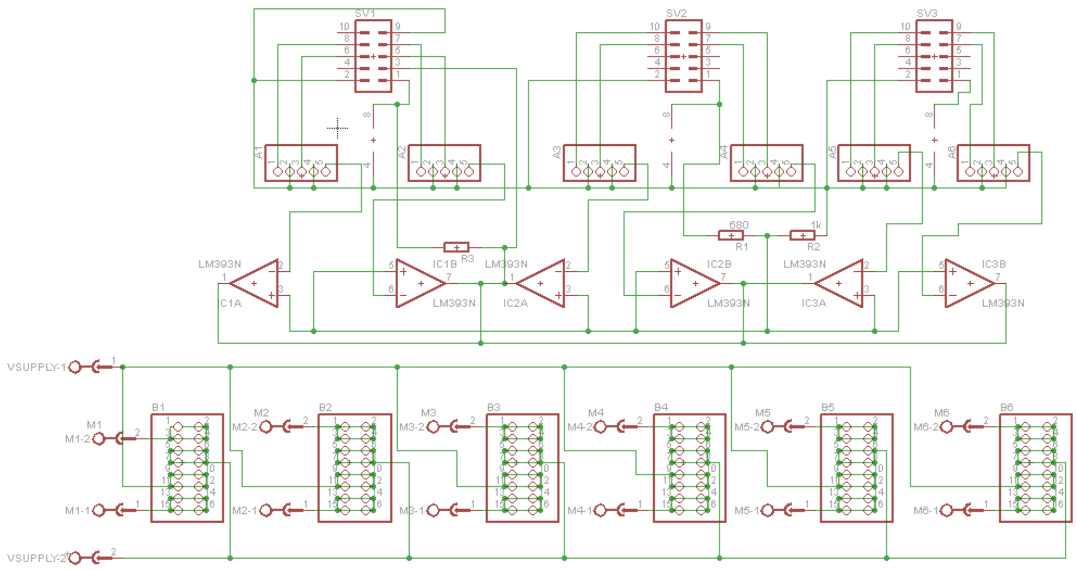


Figure: Motherboard schematic diagram (prototype 2)

The motor control circuit consists of 6 identical daughterboards that fit onto 6 identical slots on a motherboard. As the daughterboards are identical, if one H – bridge fails, a second board can be quickly assembled, as oppose to removing the damaged H – bridge, which is time consuming. Each daughterboard houses a H – bridge, 2 bootstrap capacitors to allow faster switching speeds, and a resistor for a current sense voltage output. The motherboard houses 3 dual voltage comparators to compare the current sense voltages. If a voltage level from any of the H - bridges exceeds the equivalent of 3A, the combined comparators output to the Arduino switch from logic high to logic low to indicate a fault. The motherboard also houses four 10 way right-angled connectors. This allows fast, easy and tidy connections between PCBs within the pressure vessel.

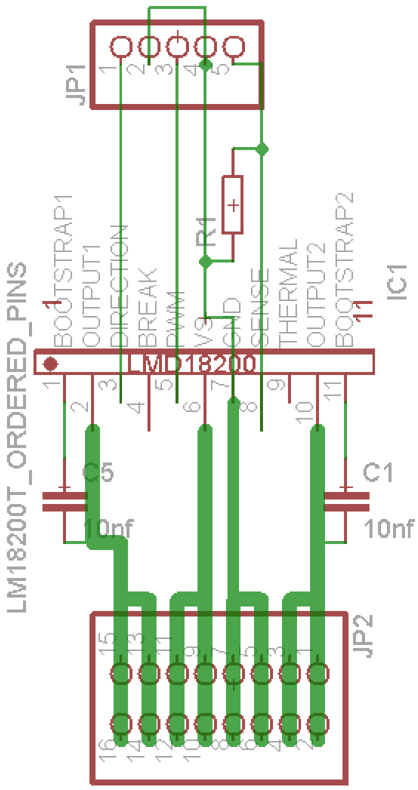


Figure 1: Daughterboard schematic diagram (prototype 2)

4.3 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) to all horizontal motors if the ROV needs to move in only one direction.

5. Challenges:

The main issue about the controls was to find a suitable and reliable method of waterproofing the circuitry on-board the ROV that could handle the pressure at a depth of fifteen metres and then reliably transmitting and receiving from it by a communication tether. Due to a depth of fifteen metre, the signal losses increased every 1.5m as the thin strand, multi-fibre cable used was being disrupted by noise and interference. This issue was then resolved by further research into different cables and amplification techniques and a suitable solution was found.

6. Troubleshooting:

A major challenge that was encountered when using the LMD18200 H – bridge was that the motors are rated to 3A and the H – bridges have a max continuous current output of 3A. If a motor stalls for any reason, it will draw higher current than the H – bridge can handle and overload. The amount of power that the H – bridges has to handle also presents an overheating problem.

These problems were encountered on the first prototype control PCB, where all the H – bridges were mounted on a single board, with a shared heatsink, and no copper planes tied to any of the voltage supply pins.

The second prototype resolved the possibility of current overload by utilising the current sense pins alongside voltage comparators in the circuit design, along with changes in the control program, so if current exceeds 3A, the Arduino mega will automatically switches off the PWM signals until the controls on the surface are set to neutral.

It was decided to separate the H – bridges, so a main motherboard was designed, and separate daughterboards were designed to aid cooling by mounting each H – bridge onto dual layered PCBs where the top layer is 2 square inches of copper plane tied to the voltage supply pin. The addition of a large heat sink to each H – bridge will also help with cooling.

7. Future Improvements:

To further improve on the ROV, a moving camera will be an advantage as it will allow for the reduction of cost and also give the pilot the exact view required to manoeuvre. Another improvement was to design and build a custom gear box for the ROV thrusters. This would then give a greater thrust for the same amount of power but however was very time consuming and expensive to implement which led to the idea being abandoned. A multiple channel video card is also a considerable advantage due to this reducing the amount of cables in the tether as only one video cable will only be required to give the user as many feeds as the video card can offer.

8. Lesson Learned or Skills Gained:

This year as always due to new missions added in the competition, the team had to acquire further knowledge into different aspects of engineering to come together with a working solution to the task at hand. This included on the control team to find a method to communicate effectively between two Arduino boards at a distance greater than 15 meters

9. Reflections:

The most rewarding part of this experience was to participate in a group project which had precise parts relating to work some of us had never done before. This proved challenging yet exciting and allowed us to contribute and work together as an effective team. So much of what we do as student engineers is theoretical. Having a working ROV to show for all our hard work is great. To improve on this experience for next time, we would spend further times thoroughly testing the ROV to ensure it is suitable and reliable to work under all conditions.

Bilal Goheer

During my time as a member of the RGU ROV Team I have learnt a vast amount about ROVs and the ROV industry as a whole. My personal experience with the project has benefited me in many ways, and has given me a taste of what to expect in industry. The learning curve is not only challenging but very rewarding. As the project has progressed, the benefits I have received from the journey have increased significantly. I felt the project was a large commitment alongside my studies in engineering, but when an element of the project shows progression it brings new excitement and enthusiasm towards the competition. The ROV Team has significantly influenced the path I wish to pursue in my career as a professional engineer.

There were several elements of the project that I found both challenging and interesting. But I feel the close bond within the team has helped me overcome difficulties regarding engineering problems that I would have struggled to address solely by myself. I whole heartedly recommend joining the ROV Team to all student engineers in the university.

Douglas Mackay

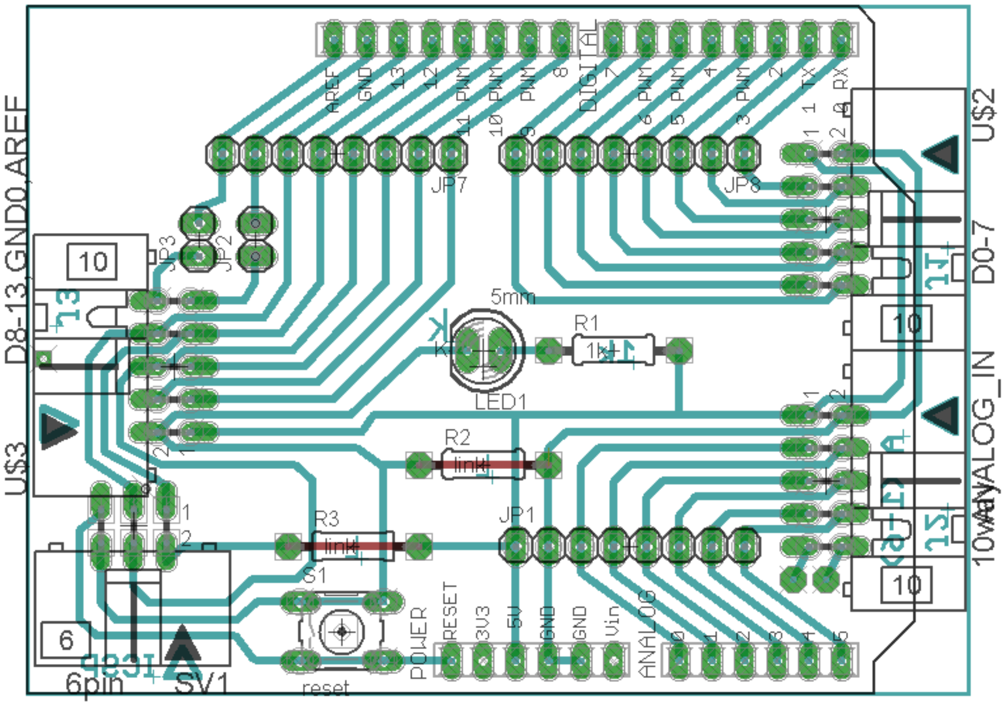
10. Acknowledgments:

We would like to thank the following sponsors for supporting the RGU Sub Tech Ltd:

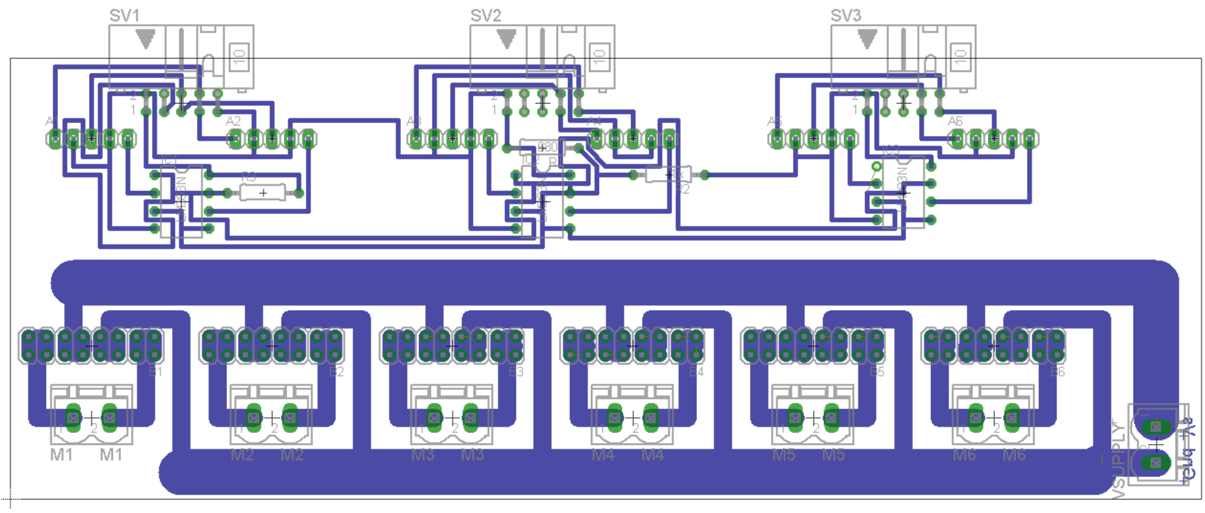
- **Robert Gordon University**, Aberdeen, United Kingdom
- **BP (British Petroleum)**, Sponsor
- **Subsea 7 UK**, Sponsor
- **MATE (Marine Advanced Technology Education Centre)**

We would also like to thank our mentors: Graeme Dunbar, John Still and Steve Allardyce for all their help, knowledge and wisdom. And finally, we would like to thank Margaret Jenkinson for organising events and the trip to America.

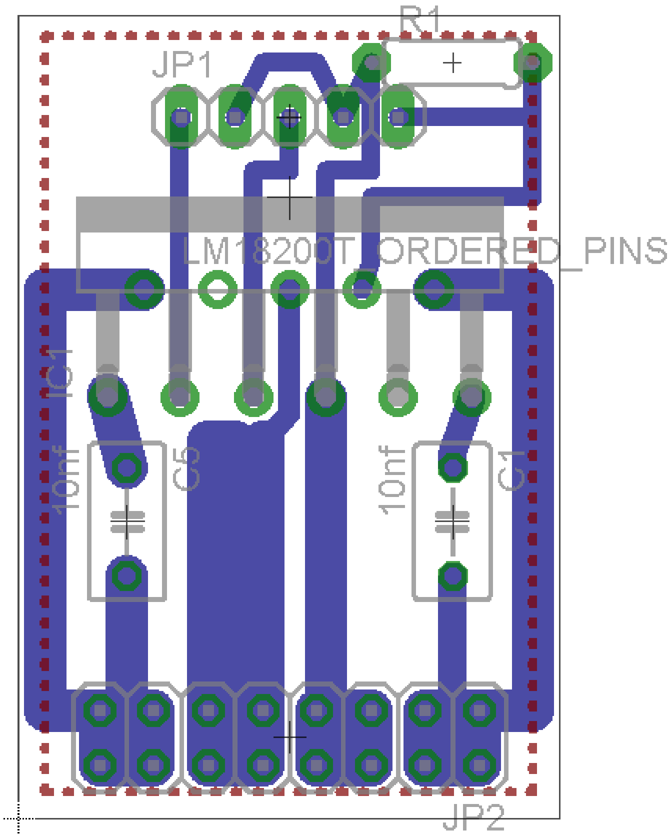
11. Appendices:



Arduino Duemilanove 10 way connectors shield board layout (prototype 1)



Motherboard board design (prototype 2)



Daughterboard board design (prototype 2)

Back-up control system

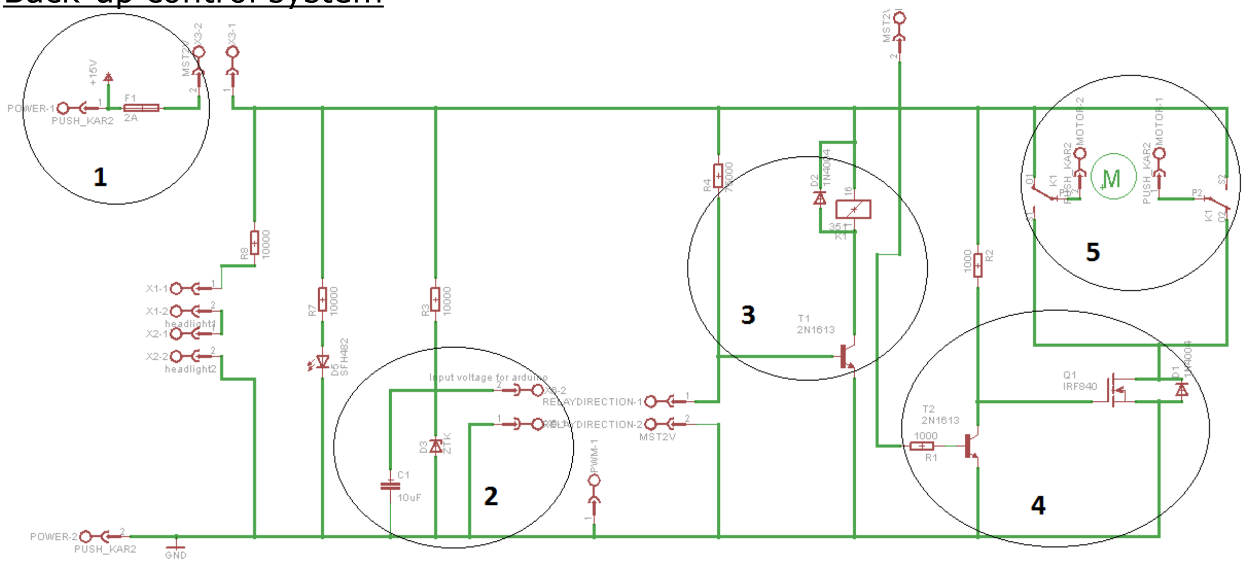


Figure 6: Motor driver circuit 2

1)

A motor driver circuit was constructed using a relay to power and change the direction of the car motor (see figure 6). The circuit incorporates a 3amp fuse (see Part 1) as a safety feature to safely disconnect the circuit from the supply to avoid catastrophic failure if for an example an unintentional short circuit occurs. Due to the Arduino requiring a minimum of 9volts to power, a zener diode approach was taken to reliably drop the supply voltage from 15volts to approx 9 volts.

3)

Part 3 of figure 6 is a transistor controlled relay to allow the user to change the direction of the motor. This was not actually required in the circuit as the race car only had to travel in one direction but was only added in as an extra feature. The circuit is controlled by a switch indicated by the push connectors. At the current state of the switch, the relay contacts stay in the normal positions but when the switch is actuated the transistor is brought down to base allowing current to flow into the transistor hence allowing it to start conducting and changing over the relay contacts which in turn changes the direction of the motor (part 5).

4)

Part 4 of figure 6 is a small transistor circuit which is activated by the PWM pin from the Arduino. The Arduino pin allows a limited current into the NPN transistor which is then amplified before feeding into the MOSFET that turns on and of corresponding to the rising and falling edges of the PWM input from the Arduino.

Zener diode voltage regulator:

Supply voltage = 15Volts   Required Voltage = 9Volts
Maximum load current = 1Amp
Power through Zener diode: P = VI
P = 5.1 x 1 = 5.1 Watts
15Volts – 5.1 volts = 9.9 Volts.   R = V/I
R = 9.9/1 = 9.9Ω (closest standard value = 10Ω)

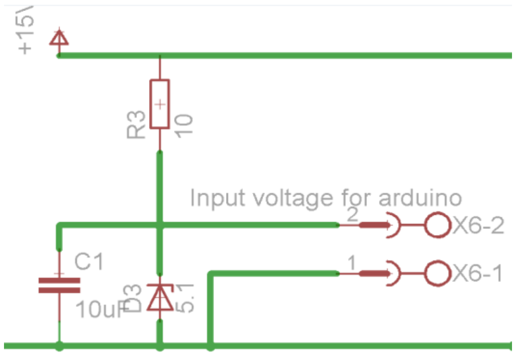
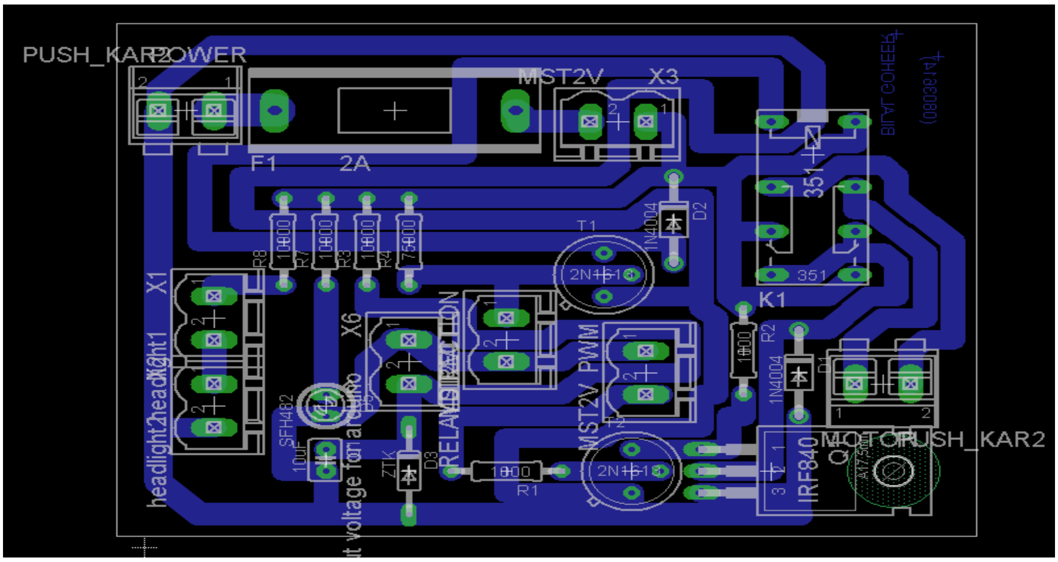


Figure 7: Zener diode 9 volt regulator (part2 of figure 6).



Regional Control System

Circuit diagram:

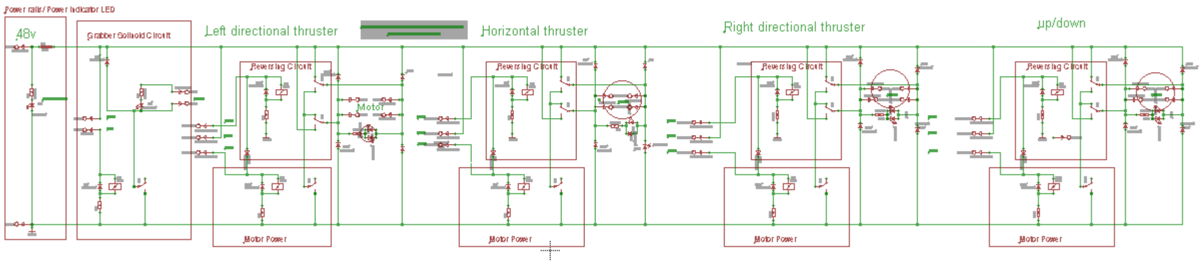


Figure 1

Figure 1 of the circuit contains the 48volt and zero volt power lines with the addition of an L.E.D connected in series with a base resistor to be used as a power indicator. The purpose of the base resistor would be to limit the amount of current entering the L.E.D. A 40amp fuse is also inserted to correspond with the safety requirements by the MATES organisation.

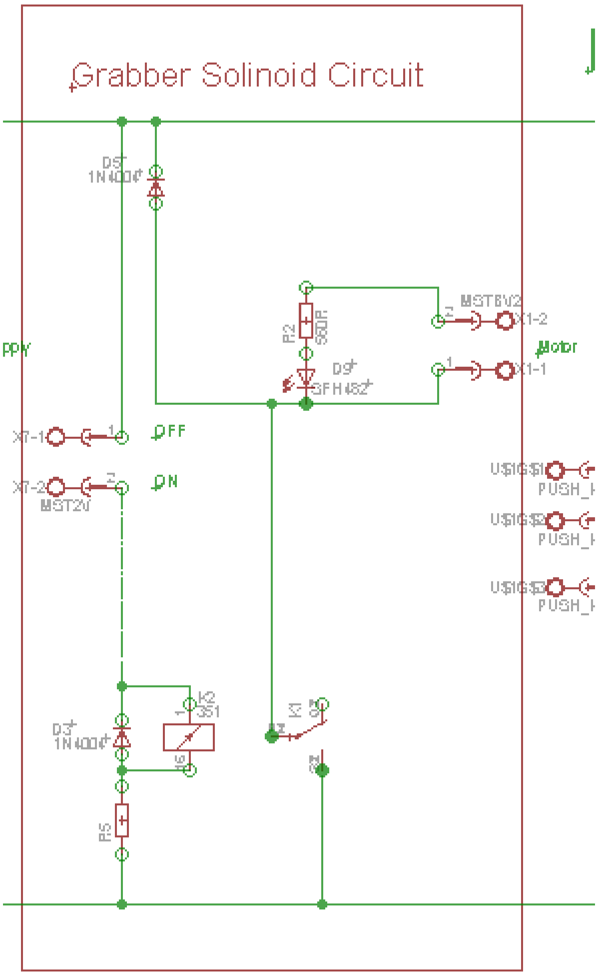


Figure 2 is the control circuit for the grabber. The circuit consists if a simple relay switching configuration. When the switch is set at the off

position, Relay 1 switch stays in the same position as there is no current passing through the relay coil to energise it hence allowing no power to travel to the motor output terminals. When the switch is toggled to the ON position, current is allowed to pass through the relay coil hence energising and switching the position of it to allow power to be supplied to the motor output terminals. A unidirectional L.E.D is used for indication of power and is again connected in series with a base resistor to limit the current.
Section will consist of one relay reversing/motor power circuit designed and to be used in series four times to provide control for the following thrusters:

- Left directional thrusters.
- Right directional thrusters.
- Horizontal thrusters.
- Up/down thrusters.

The circuit works as follows:

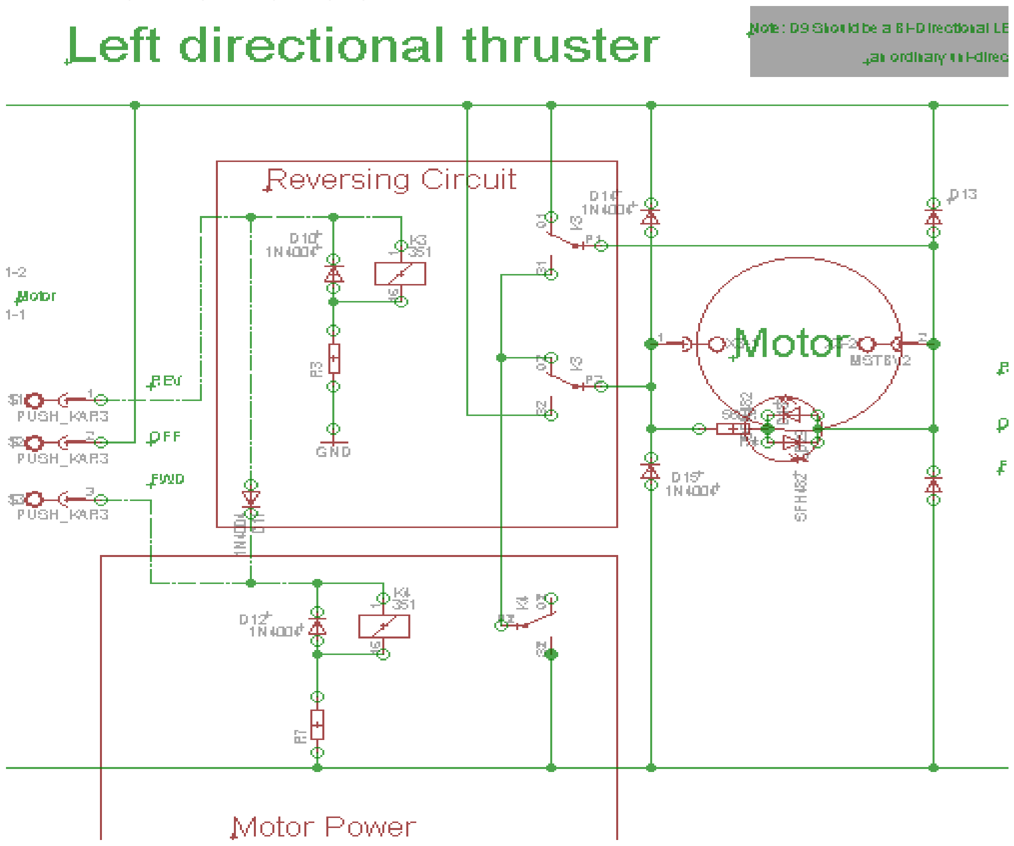


Figure 3

The circuit consists of a 3-push button connector to provide for simple creation of a printed circuit board. The push button connector will then be connected to a 3-way switch for controlling the motor direction. When the switch is in the OFF position, neither relay receives any current and would therefore provide no switching to occur hence providing no power to the motor output terminals. When the switch is toggled to the FORWARD position, the coil of Relay1 does not receive any current and is therefore left in its original position with switch switch1 and switch2 occurring in no change of position. However current passes through Relay coil 2 and allows to switch 3 changing position and allowing power to the motor

negative terminal and through to the positive hence allowing the motor to rotate in a clockwise direction with the full voltage of 48volts being applied.
When the switch is toggled to the REVERSE position, Relay coil 1 is energised providing switch 1 and switch 2 to change position, however current is also allowed to travel through diode D2 hence also energising Relay coil 1 allowing switch 3 to change position and allow power to the motor out terminals hence reversing the direction of the motors. Diode D9 is a bi-directional L.E.D which will change colour to match the direction of the motor. The motor outputs are connected to a h-bridge of diodes to avoid any BACK EMF which could possibly cause a short circuit.

Harpoon Tool

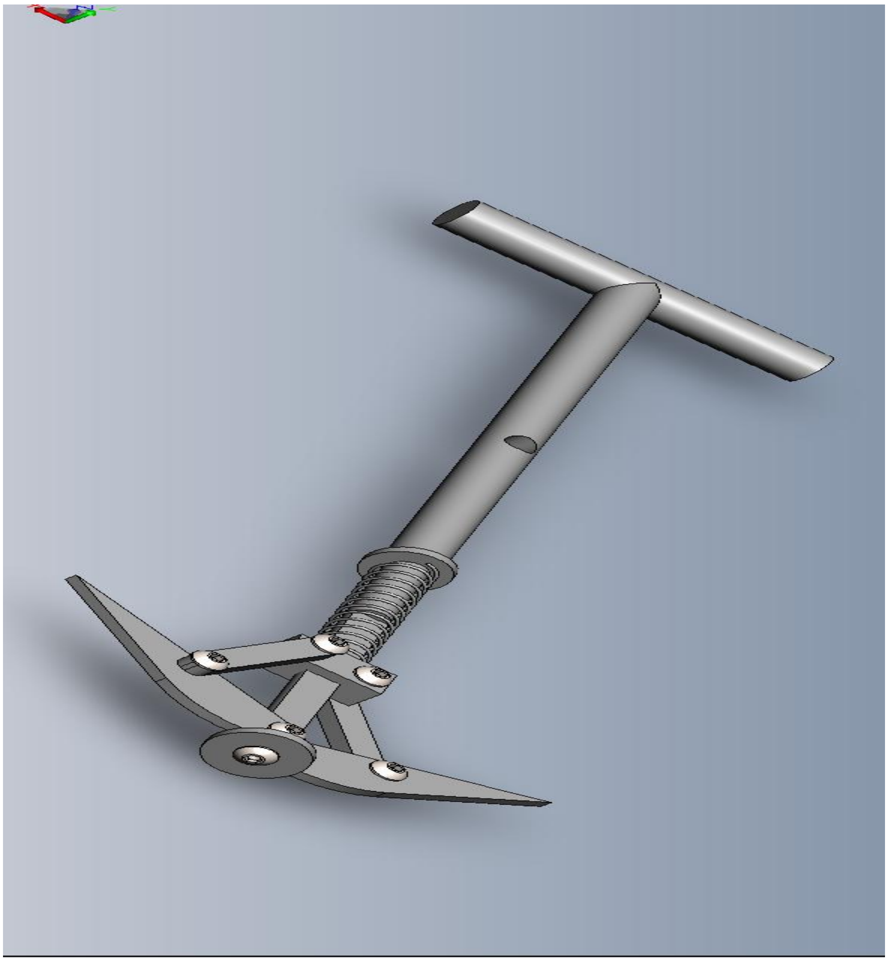


Figure: Final harpoon tool design