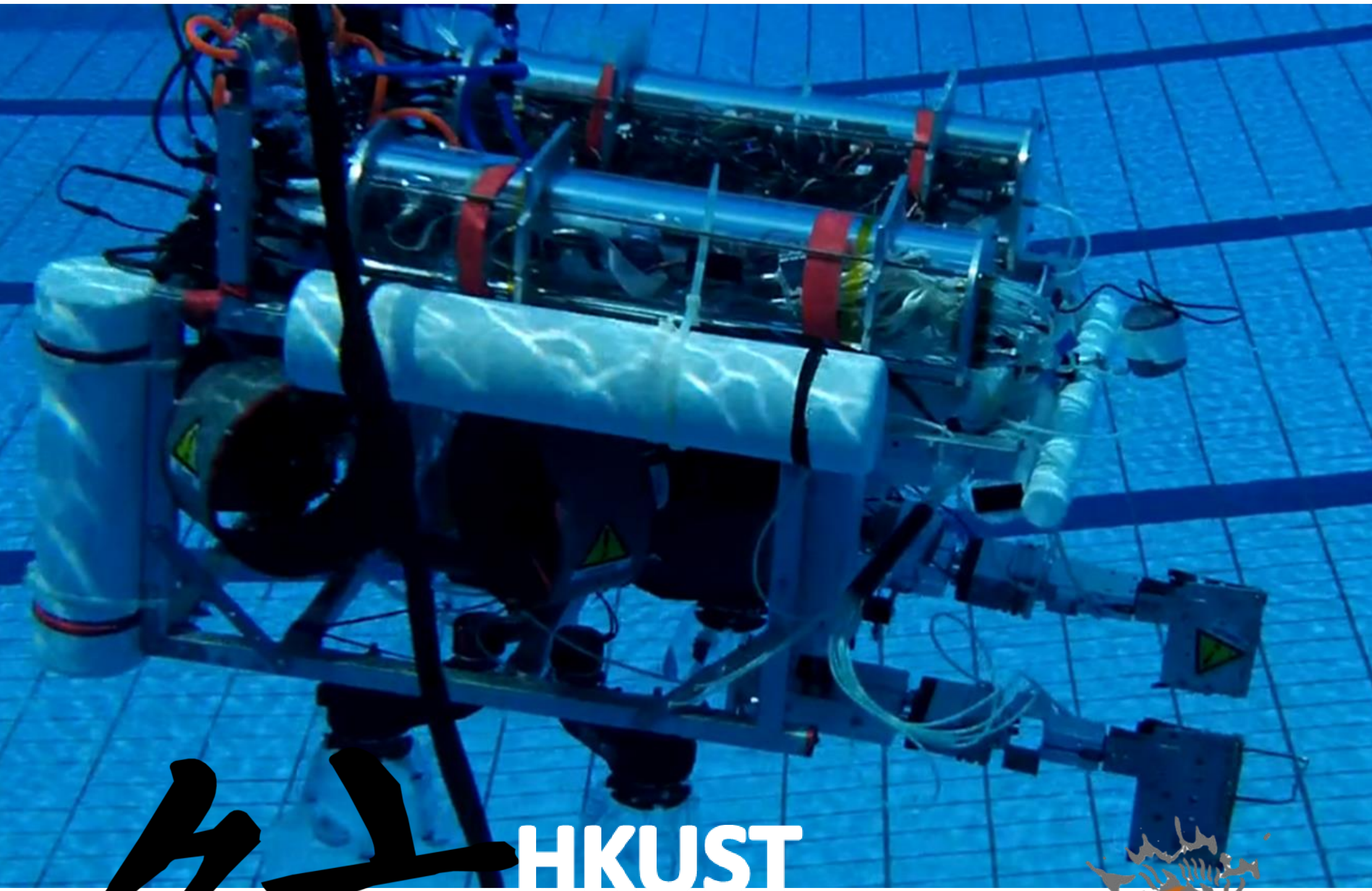
香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

SENG 工學院 SCHOOL OF ENGINEERING

GCE Global & Community Engagement

HKUST Robotics Team

HONG KONG



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HKUST WHALE

JOKER
ENJOY THE GAME!

TECHNICAL REPORT 2013

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1. ABSTRACT

This report illustrates the technical aspects of the Whale, an Underwater Remotely Operated Vehicle built and developed by Joker Incorporated. The Whale is a response to the call of proposal made by the Marine Advanced Technology Education Centre for a ROV for the installation, operation and the maintenance of offshore regional cabled ocean observing systems. The Whale is an unique machine which employs a pneumatic system, a Cortex M4F microprocessor and a 9 degree of freedom (9DOF) orientation sensor.

There are 2 transparent acrylic tubes containing the control systems for the Whale. The vision system of the Whale consists of 5 wide angle cameras which give a complete view of the environment and the pneumatic manipulators to the pilot on the shore. All the electronics are custom built for the Whale enabling high efficiency and easy debugging. As for the propulsion unit, we have used 6 underwater thrusters with vector control. The control program is designed based on the C# programming language and the communication between the ROV and the onshore control station is managed by two TP-Link routers connected via a network switch. 9DOF sensor provides feedback control giving the pilot easy manoeuvrability control.

One of the major improvements compared to last year is the pneumatic system. The Whale was designed and built by the Joker Inc.'s 12 creative engineers. Employing an out of the box thinking, we have managed to come up with an underwater ROV that is capable of meeting the requirements set forth by MATE Centre.

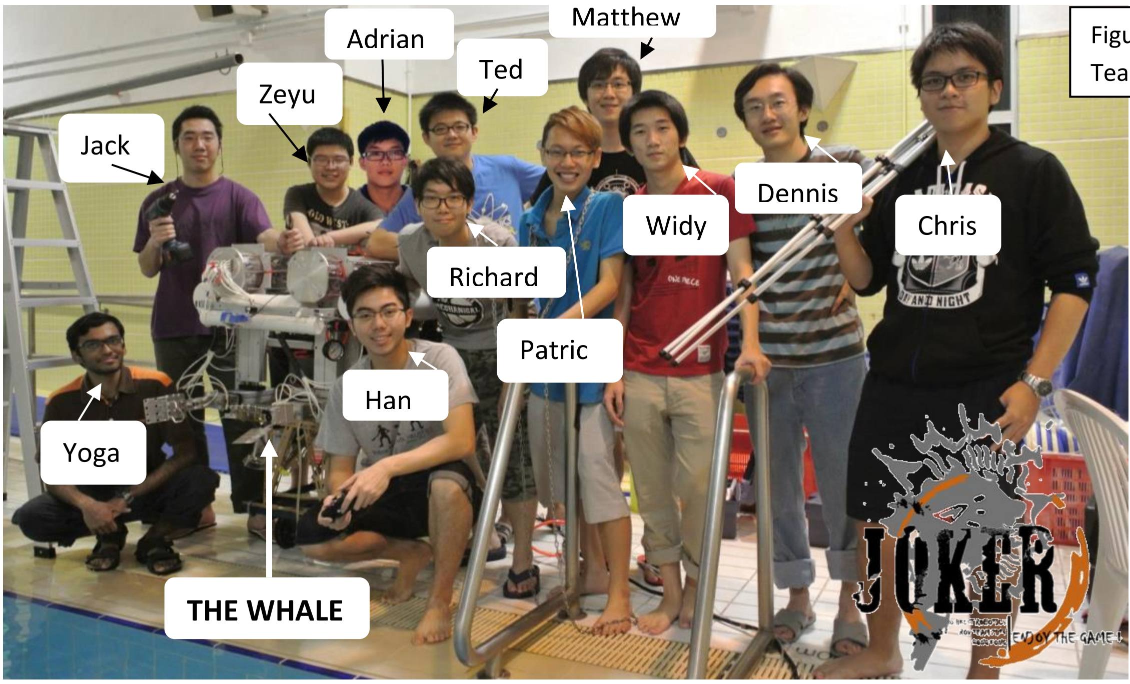

Figure01: Team Photo

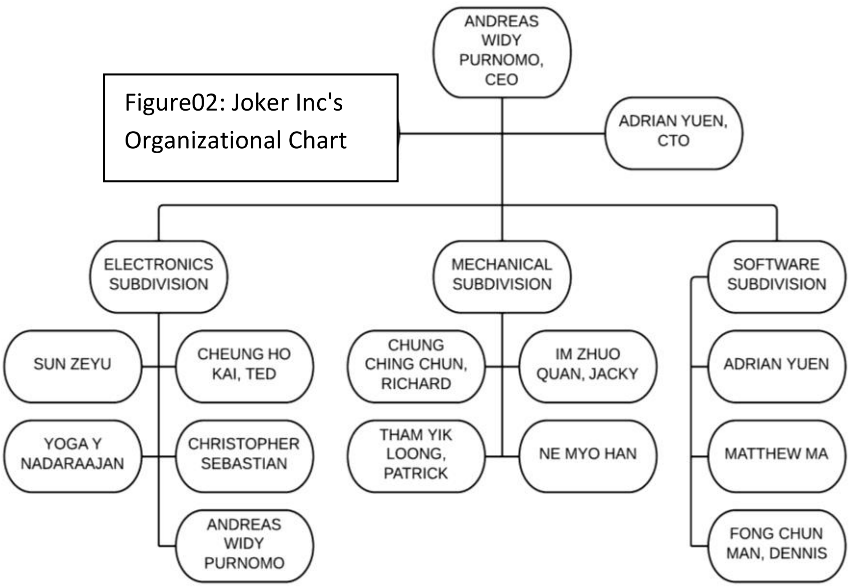

Figure02: Joker Inc's Organizational Chart

Figure03: Sponsors and supporters of Joker Inc.

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2. BUDGET REPORT

This is the budget sheet for the year of 2012-2013. It includes all the expenses and income of Joker Inc.

No.	Item	Income (USD)	Expenditure (USD)
1	School of Engineering, HKUST	USD 3,000.00	
2	DHL for transporting ROV between Hong Kong and USA	In-kind sponsorship	
3	RS Components for electrical equipment	In-kind sponsorship	
4	HKUST sponsorship of supporting students' travel	In-kind sponsorship	
5	HK Government Reaching Out Award Scheme for supporting students' travel	In-kind sponsorship	
6	Year Expenditure (Details are shown in the table below)		USD 2,831.26
		Total Balance :	USD 168.74

2012-2013 Year Expenditure:

No	Item	Quantity	Unit Price	Price (RMB)	Price (HKD)
1	Soldering Equipment	NA		CNY 175.00	
2	Digital Multimeter	1	CNY 110.00	CNY 110.00	
3	Fuse Sockets	3	CNY 43.00	CNY 129.00	
4	Velcro	5 m	HKD 1.80		HKD 9.00
5	USB Hubs	1	HKD 50.00		HKD 50.00
6	Electric Plug with main switch	2	HKD 37.50		HKD 75.00
7	Bearing for motors	18	CNY 6.69	CNY 120.50	
8	Pneumatic Cylinder Rotary	2	CNY 209.00	CNY 418.00	
9	Pneumatic Cylinder Gripper	3	CNY 187.50	CNY 562.50	
10	Pnumatic Cylinder Vertical and Horizontal	4	CNY 100.00	CNY 400.00	
11	Air tubing for pneumatics	20 m	CNY 10.00	CNY 200.00	
12	PVC Pipes for Bouyancy	NA			HKD 300.00
13	LAN Cables	2	HKD 10.00		HKD 20.00
14	Hooks	3	HKD 50.00		HKD 150.00
15	Gearbox for legs	4	CNY 45.00	CNY 180.00	
16	Clamps, tools, cutter	NA			HKD 100.00
17	Motor Driver & Other PCB Boards	20	CNY 11.35	CNY 227.00	
18	Power bus bar	2	HKD 23.00		HKD 46.00
20	Safety Items for sharp edges	20	HKD 5.00		HKD 100.00
21	Bilge Water Pump	4	HKD 71.20		HKD 284.80
22	Webcams	5	HKD 109.00		HKD 545.00
23	Epoxy Quick Dry	4	HKD 35.00		HKD 140.00
24	TP-Link Routers	2	HKD 106.00		HKD 212.00
25	Aluminium Parts	NA			HKD 6,000.00
26	Propeller Shield	12	CNY 35.00	CNY 420.00	
27	Thrusters	6	CNY 600.00	CNY 3,600.00	
28	Propeller Blades	6	CNY 30.00	CNY 180.00	
29	Camera Joints	5	CNY 25.00	CNY 125.00	
30	Chain Hoist	1	CNY 310.00	CNY 310.00	
31	Regulators	1	CNY 39.00	CNY 39.00	
32	WD 40 Lubricant	1	HKD 50.00		HKD 50.00
33	Cable Zip Tie	10 Packets	HKD 15.00		HKD 150.00
34	Acryllic Tubes	4	HKD 200.00		HKD 800.00
35	Camera Lens	5	CNY 38.33	CNY 191.67	
36	Water proof cables 2,3,4,9 Pins	40	CNY 12.40	CNY 496.00	
37	Air compressor	1	CNY 750.00	CNY 750.00	
38	Air Tank Parts	NA		CNY 248.00	
39	STM 32 F4 Discovery Board	2	CNY 250.00	CNY 500.00	
40	Valves, pipe fitting and air pressure controls	NA		CNY 150.00	
41	Network Switch	1	HKD 150.00		HKD 150.00
42	Ladder	1	CNY 150.00	CNY 150.00	
43	Pneumatic Vertical Actuator for Base Clamp	1	CNY 100.00	CNY 100.00	
44	Temperature Sensor	6	HKD 5.00		HKD 30.00
45	Current Sensor	6	CNY 20.00	CNY 120.00	
46	Arduino Nano	3	CNY 45.00	CNY 135.00	
47	9DOF Sensor	1	CNY 60.00	CNY 60.00	
48	Solenoid Valves	10	CNY 30.00	CNY 300.00	
49	X-Box 360 Controller(From Last Year)	1	HKD 312.00		HKD 312.00
	TOTAL COST OF WHALE			CNY 10,396.67	HKD 9,211.80
	TOTAL COST OF WHALE In USD Based on 1 USD = 6.30 RMB = 7.80 HKD				USD 2,831.26

3. DESIGN RATIONALE

This year, we Joker Inc. adopted a different approach. We wanted to make the Whale a versatile yet robust underwater platform to carry out deep-water missions. Having said so, after some research and our own experiments, we found that the most important function of the ROV required for the tasks mentioned by MATE Center is the object location manipulation function. A lot of the tasks specified involved the movement of an object from one location to another by the ROV. This meant that the Whale had to have a manipulator system that is agile and easy to manoeuvre.

Furthermore, we also required powerful thrusters in order to be able to lift heavy objects underwater and also be able to overcome the water resistance. Given all the above requirements, we decided to use a pneumatic based manipulator system, 6 heavy-duty underwater thrusters assisted by adjustable buoyancy system. For the manipulator we had the choice of using servos but we found out that if we are using servos, we would require more time to maintain and ensure the waterproofing on the servos. As for the propulsion, we decided to employ adjustable buoyancy system as it could help us reduce the load on the thrusters (they no longer need to waste power to stay at a certain depth). Not only that, we could also control the depth of the Whale precisely which allowing us better handling and control. As for the on board electronics, we have used a modular design whereby each subsystem can be easily swapped without affecting the other systems.

We also take a great amount of pride in the Whale. In order to save costs and also to make an efficient ROV, we have designed the Whale from scratch and custom built it using our own mechanical, electronic and control subsystems.

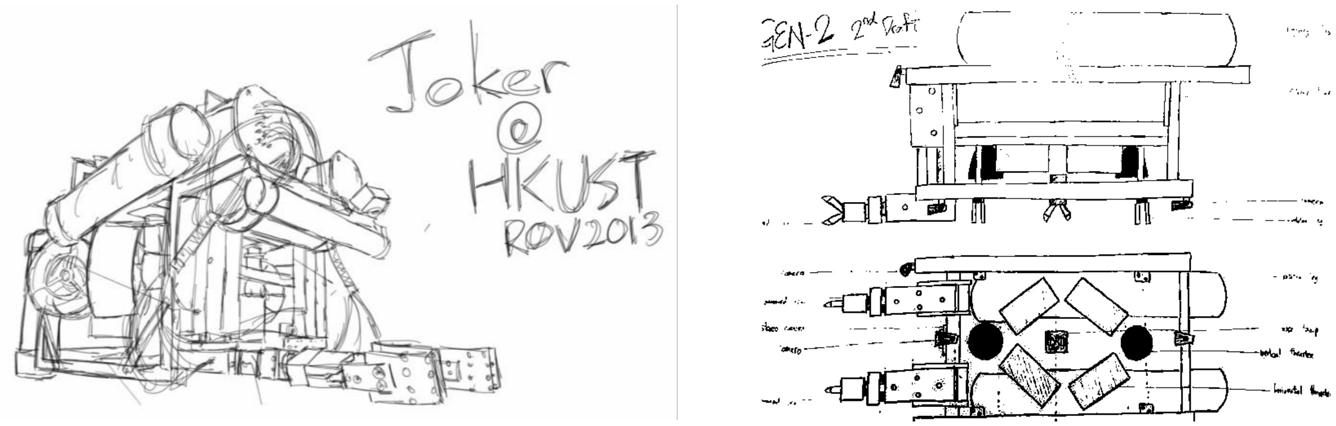


Figure04: The concept design drawings of the Whale based on the design rationale

4. SAFETY MEASURES

At Joker Inc., we give utmost importance to safety. Safety has become part of our routine from the design process up to the implementation of the final ROV. In order to achieve better coordination and to make sure that all the safety concerns are addressed completely, we had classified the safety protocols into 3 different categories as shown below:

4.1 Mechanical Safety

All rotating parts have been labelled and the propellers are guarded by motor shell which prevents direct contact with the propeller and the propeller is covered using a bright red guard to prevent people from putting their fingers through it. The sharp edges have been sawed off or protective silicon covering has been put in place to prevent cuts and accidents during transportation.

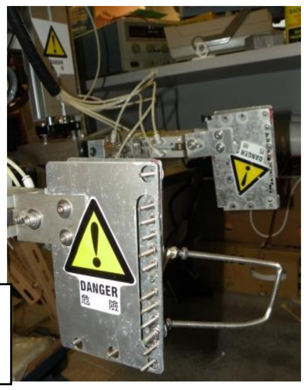


Figure05: Danger signs scattered throughout moving parts

4.2 Electrical Safety

This perhaps is the most important part of safety as most of the equipment run on high current and is not easily seen. All our circuit boards are equipped with fuses to prevent current overload and to safeguard our circuits. Diodes are added to prevent back currents from damaging other equipment and capacitors are place to stabilize the voltages and to prevent sudden spikes in the supply. The electronics tube is made of acrylic, a non-conducting material. Emergency switch is also included to allow quick and easy cut off of power in the case of an emergency. The power supply itself has a failsafe mechanism in which it cuts off itself in the case of a short circuit. Indicator LEDs are added to the circuits to see which one are on power and which one are off.

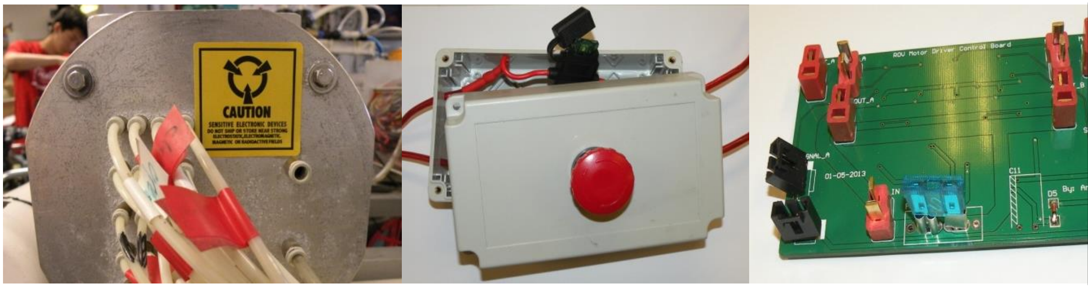


Figure06: From left to right: Electronic device hazard sign, emergency stop button and fuse, fuse installed on motor driving circuit.

4.3 Water Test Safety

Every time before a water test, an elaborate power test is done to see if all the voltages are correct. Then a safety checklist (included in the appendix) is run through to ensure that all the safety protocols have been completed. Once the power goes on the Control Station Master shouts "Power is on. Hands off." to alert the people around the launch area of the "Live" condition of the Whale.

5. DESCRIPTION OF SUBSYSTEMS

5.1 Mechanical Subsystem

In this section we will describe our mechanical subsystem. It consists of 5 main parts namely propulsion, node leveller, the claw, the manipulator system and the adjustable buoyancy tube.

5.1.1 Propulsion

Like any other ROV system, the Whale also requires a propulsion system to allow it to move and carry out tasks underwater. The Whale is powered by 6 HDQ-200 Rowing Motors. These motors are rated at 200W when powered using a 12V power supply. At this rating they can deliver up to about 80N of thrust each. 4 of these thrusters are arranged at an angle of 45 degrees to the x-axis. The diagonal arrangement of thrusters allows us to use vector control (which will be explained below) enabling efficient shifting and rotational motions. These precise movements are required in aligning the Whale to the props in the mission to allow easy access. An example of this requirement would be in the task of reconnecting the CTA bulk head connector. 2 more thrusters are arranged vertically to provide emerge and submerge functions. The vector controls are as follows:

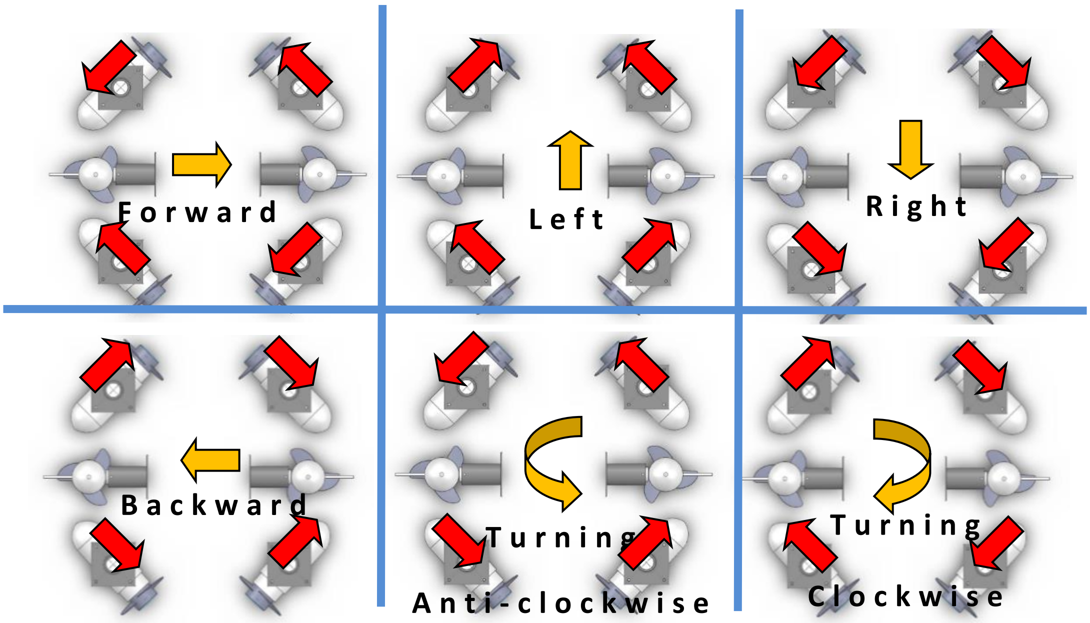
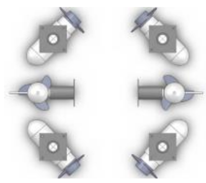


Figure07: The vector control system for the propulsion of the Whale.



Thruster arrangement

Thrust direction

Direction of motion

5.1.2 Node Leveler

This is a task oriented design. For task no 1.8 and 1.9, we are required to install the secondary node at a given position and adjust the secondary node so that it sits horizontally on the floor. After a lot of brainstorming and out of the box thinking, we came up with a simple yet efficient way of doing these two tasks. The node leveller is attached to the bottom of the Whale. The design of the node leveller is shown below:

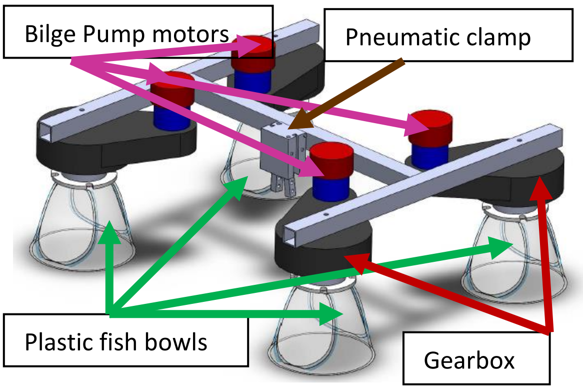


Figure08: The structure of the node leveller

The node leveller has a pneumatic clamp to hold the secondary node while transporting it. It also has 4 waterproof Bilge Pump motors, each one is capable of running at 12 V with a power rating of 20W. The motors are used to adjust the height of the node legs to make the platform levelled simultaneously saving time and effort. The motors are connected to a gearbox to give some extra power to be able to screw and unscrew the node legs. To help the driver manoeuvring the Whale to align with the node, we have a camera attached to the back of the Whale. The Johnson Bubble level is constantly monitored via a camera to ensure that the node is levelled. The legs are made from plastic fish bowl with a curved plastic padding to fit the shape of the node legs. This allows us guide the Whale easily to fit the fish bowls on top of the node legs.

5.1.3 The Claw

This year's mission tasks largely involve the manoeuvring of the apparatus underwater. Due to the extensive requirement in moving the apparatus, we needed a claw that is strong yet versatile in being able to hold objects of different size and shapes. The claw on the Whale is made of stainless steel plates with screws attached to it. The plates give a large enough surface area so as to enable the easy handling of the ADCP, SIA, bulkhead connector, bio-fouling etc. It has a loop to allow us to open and close the BIA easily. The screw density is small enough to allow us to carry the ADCP in a vertical position. For plugging and unplugging the CTA, the claw enables Whale to hang the CTA on it. When the plates are vertical, the CTA hangs and it is ready to plug/unplug by moving Whale forward and back. The loop on top of the plate help Whale to open the door by sliding it into the handle. It is more convenient since it does not involve any motion control such as clampping.

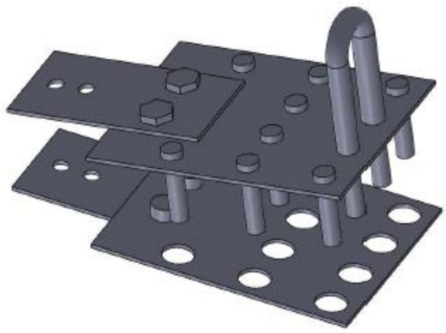
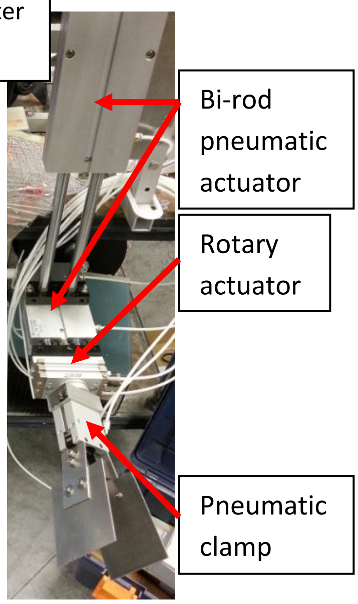


Figure09: The design of the claw

5.1.4 Manipulator System

Figure10: The manipulator right after the installation on the machine



The manipulator system is a continuously evolving system. Last year we had decided to use waterproof servo motors. Although the servo motors could give us a high degree of freedom and allow us to mimic precise and accurate motions, waterproofing the servo motors was a nightmare. The high amount of friction produced due to the servo motions wore out the O-ring rotary shaft seal casing a breach in the waterproofing. The servos also could not provide us with enough torque at a depth of 3-4m.

This year, based on last years' experience we decided to use a pneumatic system. The pneumatic system is powered by air and does not contain any electronics in it. The pneumatic parts are constantly pressurised by supplying it air from the shore. This helps to keep the water out of the pneumatic actuator. The solenoid valves controlling the motion of the pneumatic actuators are positioned in the electronics tube away from any sources of water. All the actuators are powered by a FIAC 2.0HP Air Compressor. The specifications of the pneumatic actuators are as below:

Actuator / Criteria	SMC MHC2-25D pneumatic clamp	MSQB-10R rotary actuator	TN32 * 100 bi-rod pneumatic actuator
Working Pressure Range	0.1MPa-1.0MPa	0.1MPa-0.6MPa	0.1MPa-0.9MPa
Angle/Extension range	10^{o}-30^{o}	0^{o}-90^{o}	100mm
Piston Diameter	ø25	ø15	ø32

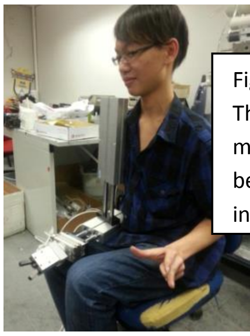


Figure11: The manipulator before installation

We have two manipulators installed on the Whale so that we could multi-task. For example, one manipulator can be used to hold the new ADCP while the other manipulator can remove the old one from its place and replace it with the new one. This saves us a lot of time and allows us to complete more mission tasks. Doing this task also requires each hand to have different height and length reaches. The first manipulator should be able to reach into the mooring platform while the other maintains its height and length until the ADCP is out of its location.

RIGHT HAND TASKS:
1. Open the BIA door
2. Remove the old ADCP
3. Lock and unlock the hatch
4. Open and closing the hatch
5. Transporting and installing the transmissiometer

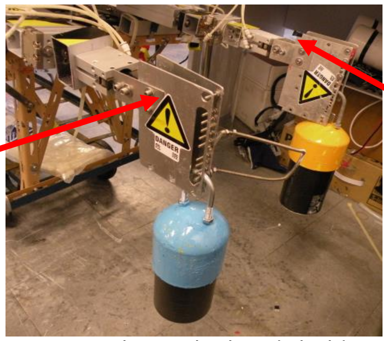


Figure12: Shows the hands holding two ADCPs

LEFT HAND TASKS:
1. Hold and place the new ADCP
2. Retrieve and connect the CTA bulk head connector
3. Retrieve and connect the SIA connector
4. Pull the pin from elevator

5.1.5 Adjustable Buoyancy Tube

When we initially started testing the Whale, most of the major components were not installed yet. The weight of the Whale was not fixed and was changing from time to time as we added more and more components to it. Thus, during every test, we had to add or remove bouyancy tubes according to the need. This turned out to be very time consuming and it did not give us a lot of freedom in achieving the exact amount of floatation that we wanted. We wanted the Whale to adapt to waters of different densities. Our mechanical engineers went to the drawing board and came up with an innovative idea of an adjustable bouyancy tube.

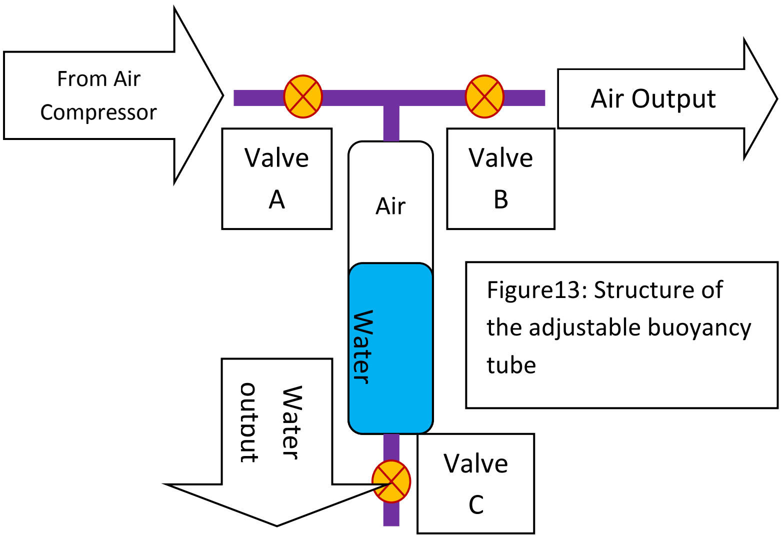


Figure13: Structure of the adjustable buoyancy tube

The adjustable bouyancy tube has a maximum volume of 6172 cm^3 and it is made from an acryllic tube with metals plates on both ends to ensure waterproofing. The bouyancy tube has 3 valves, one to control the air going into it, one to control the air going out and one to release water from the tube. The working principle and the design is shown beside:

Initially, the buoyancy tube will be filled with water as it is submerged. Valve A is opened and some of the water is then forced out through Valve C creating an air pocket in the tube. This created an upward thrust providing buoyancy. In the case that more air than the desired amount has been allowed into the tube, Valve B will be opened to release some of the air. This way, we can tune the buoyancy quickly, accurately and easily. Finally, after the tuning has been done, all the valves are closed to maintain the buoyancy level. This allows us to maintain our depth without powering the thrusters at all. This enables us to carry out water column mooring platform tasks (Task 3) efficiently.

5.2 Electronics Subsystem

The electronic subsystem is completely enclosed in two waterproof acrylic tubes. The tubes are named as Tube A and Tube B. Tube A contains all the essential control electronics such as the microcontroller board, router, network switch, USB hubs, solenoid valves, pneumatic control system and the 9DOF sensor. Tube B contains all the necessary electronics to drive the thrusters such as the motor drivers, multiplexer and the node leveller control system. We have also made debugging easier by adding indicator LEDs for each output and input. This would allow us to identify the problem by just looking at the LED statuses on each circuit board. Furthermore, we also adapted the modular design concept this year. All our circuit boards are easily replaceable and is hot swappable.

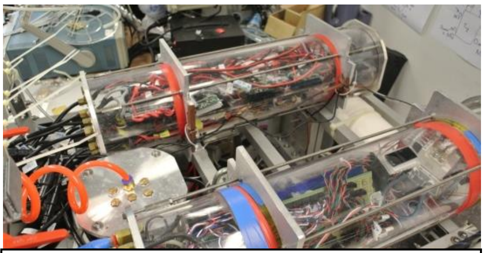


Figure14: The two electronics tubes

5.2.1 STM32F4 Discovery Development Board

This is the microcontroller board used to store and run the program to control the Whale. The STM32 microcontroller features a 32 bit ARM Cortex M4F core which is capable of running at a speed of 168MHz. The reason for using this microcontroller is because, this controller is easy to program and it is robust. The large number of available General Purpose Input and Output (GPIO) ports enables us to add or remove components from the Whale without the worry of running out of ports. Hereafter, this development board will be called the mainboard. The mainboard is interfaced with an extension board which has all the necessary connection points. We wanted to make the dependency of each system on each other as minimal as possible. This motivated us to create a hot swappable mainboard. Instead of having all the connections and the microcontroller unit on the same circuit board, we decided to separate them. The circuit board containing the microcontroller unit can be easily plugged out and be swapped for a new one where the board containing all the connection points (extension board) need not be changed and the need to unplug and re-plug the connections was reduced. This improved our repair time significantly. The extension board has connections for 20 GPIO ports (for solenoid valve control), 7 PWM ports and directions port (for motor control) and 3 USART connections (for router-mainboard communication, 9DOF sensor communication and sensor board communication).

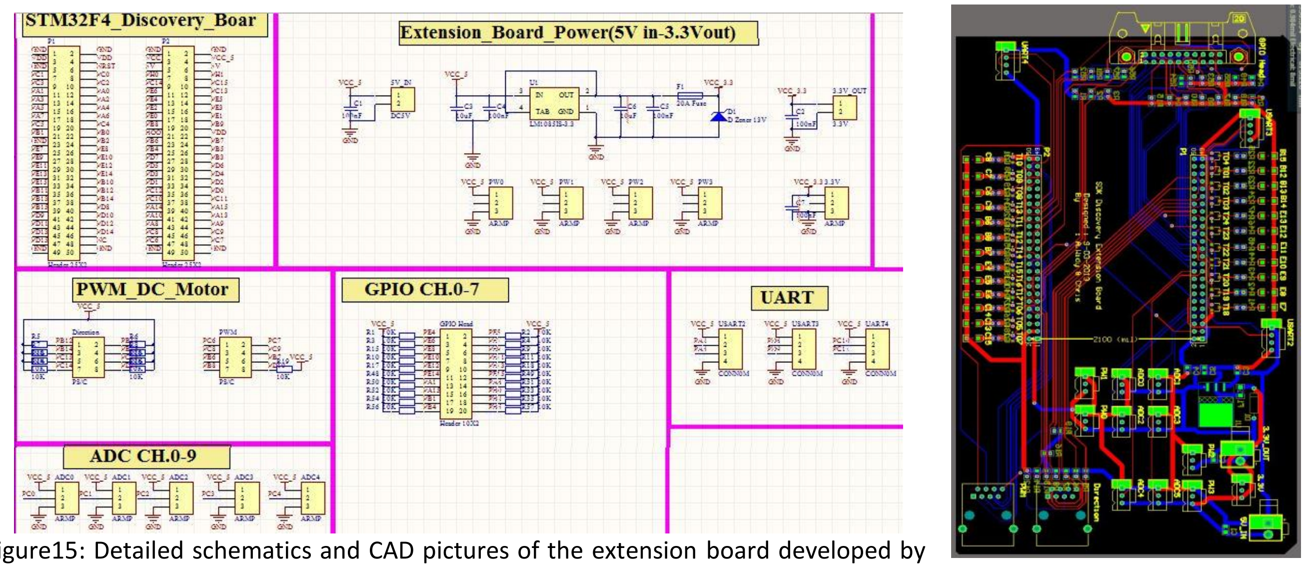


Figure15: Detailed schematics and CAD pictures of the extension board developed by Widy & Chris

5.2.2 Node Leveller Control

The node leveller as described in the previous subsection contains four motors. It is resource expensive to use 4 GPIO ports to produce the necessary PWM signals to run the motors. To solve this problem, we had created our own multiplexer which can assign the output from a motor driver circuit to one of the motors based on the motor selection bit. The control system uses a multiplexer which controls 4 relays. Using the motor selection bit, the multiplexer can produce a signal to switch on specific relays and thus specific motors. The schematic and the final product are shown below:

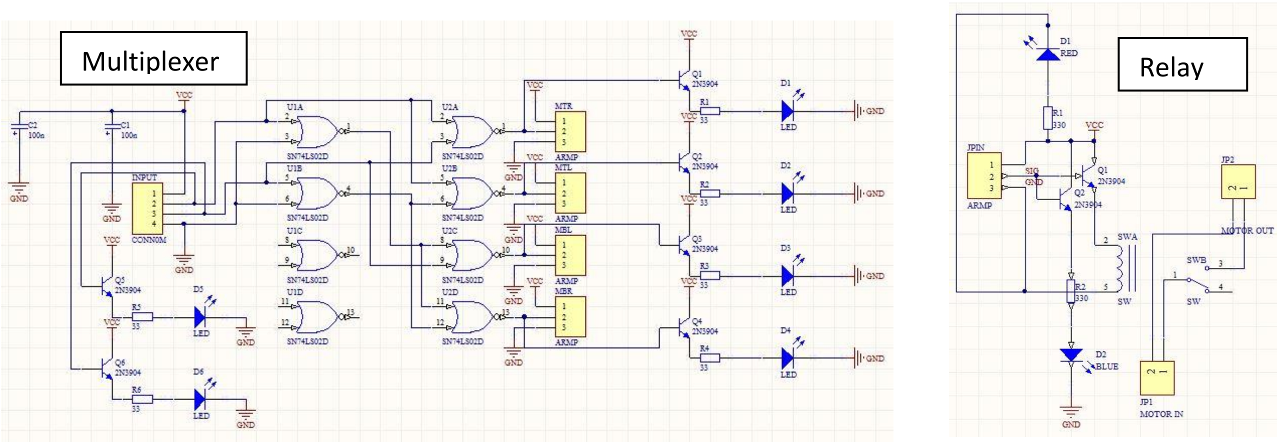


Figure16: Schematics of the multiplexing system to choose the node leveller motor and relay system developed by Yoga

5.2.3 Pneumatics Control System

There are 10 pneumatic actuators which needs a control signal to either open or closed the solenoid valves in order to control the pneumatic actuator. However the output from the STM32 F4 mainboard does not have enough driving capability to drive the solenoid. Amplification of the signal is required and is achieved through a Metal Oxide Semiconductor Field Effect Transistor (MOSFET). This requires 10 GPIO ports from the extension board (one for each actuator). By connecting the signal to each valve separately, it would be time consuming and inefficient to swap the parts if required. We would have to remove and plug in 10 different wires. To prevent this, we have used a 20-pin connector with a ribbon cable. The ribbon cable serves as an interface between the MOSFET amplifier board and the signal from the extension board. This way, we need to remove only one 20 pin cable to detach the extension board from the MOSFET amplifier board.

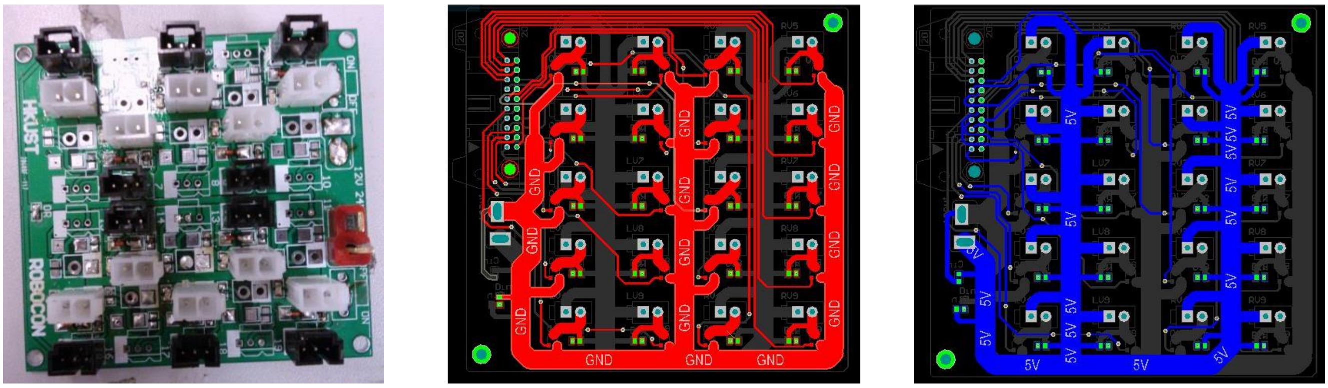
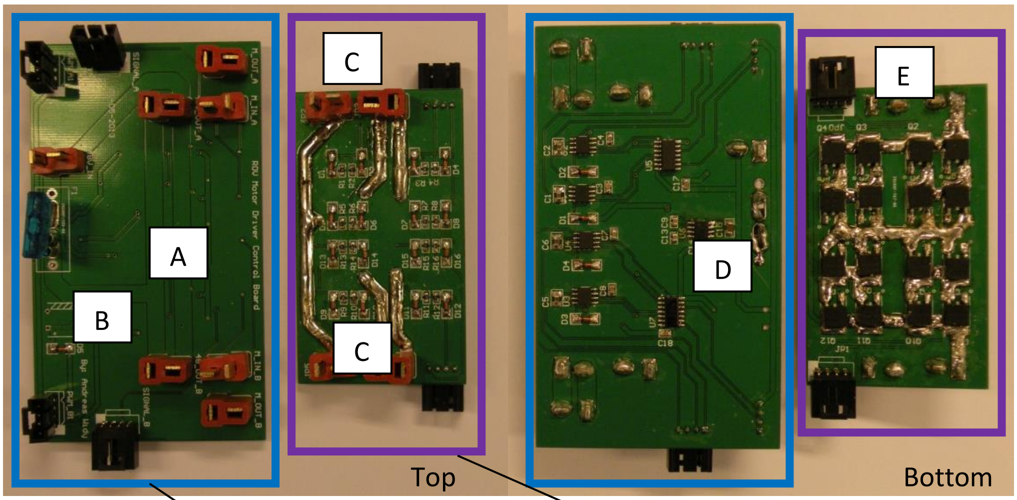


Figure17: The pneumatics control system board final product and CAD diagrams designed by Ted

5.2.4 Motor Drivers

This year we have decided to use a more powerful thrusters compared to last year. These thrusters are required since the Whale is a heavy machine and needs a lot of power to move freely in deep waters. We had used the motor driver boards from last year's ROV team. Although these drivers functioned well in shallow waters, they were inefficient in dissipating the heat and thus burnt out quickly due to the load exerted on them in deep waters by the thrusters. We then sat down and created a new motor driver that had a larger surface area and better transistors to dissipate the heat and to handle the load efficiently without burning out. The structure of the PCB boards have been converted so that the boards are heat sink friendly (heat sinks can be installed easily). The inputs for the motor drivers come from the mainboard. It takes in a Pulse Width Modulation (PWM) signal and a direction signal. These signals are then converted into a high and low level accordingly by a series of logic gates which then controls the H-Bridge MOSFETs. The MOSFETs then feed the thrusters 12V (varies according to PWM signal) power from a 48V input.



Legend:
A: Motor Power Input & MOSFET Board Connection

B: PWM and Direction Signal Input

C: Motor Power Output

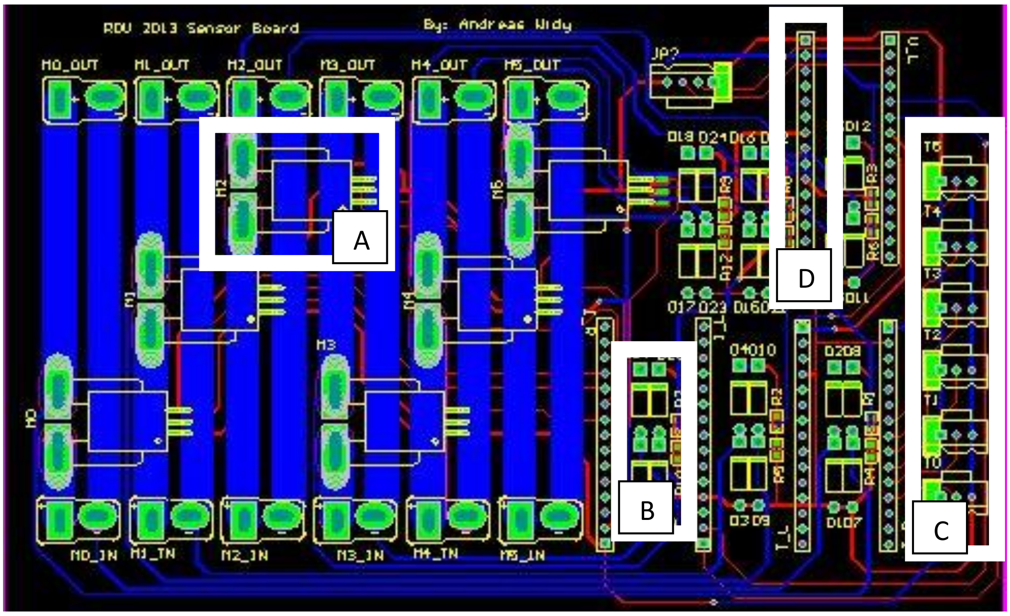
D: Control Logic Circuit

E: MOSFET board-large surface for heat dissipation and heat sink installation

Figure18: The control logic circuit by Widy and MOSFET board by Zeyu

5.2.5 Sensing System

As any living organism, the Whale also has its own homeostasis system. This system is helped by a variety of sensors to help it monitor its vital signs and allow the driver to make decisions based on it. The signs that we monitor are temperature of the motor drivers, current flow through the MOSFETs, voltage supplied to the thrusters and 9DOF sensor for orientation. This system has 6 temperature (LM035) sensors, 6 Hall Effect (ACS758) current sensor, 6 voltage dividers and 1 9DOF (ADXL345 accelerometer, the HMC5883L magnetometer, and the ITG-3200 gyro) sensor. Other than the 9DOF system all the other sensors are connected to an Arduino Nano controller board which collects all the data and sends it to the STM32F4 mainboard via the USART interface. The 9DOF system is directly hooked up to the USART of the STM32F4. These data is then displayed on the GUI for the pilot and chief engineer to monitor.



Legend:

A: Hall Effect (ACS758) current sensor

B: Voltage dividers

C: 6 temperature (LM035) sensors

D: 6 Arduino Nano Board Port

Figure19: Sensing system circuit designed by Widy

5.2.6 Waterproof Camera

This is the vision system for the Whale. This is how the driver can see the underwater world through the perspective of the Whale. There are 5 Microsoft HD-5000 cameras (2 in the front for the claws, 2 at the rear for the node leveller and to make measurements and 1 to watch the Johnson bubble). These cameras transmit a video with the resolution of about 800x448 pixels. The cameras are waterproofed by filling its body with epoxy resin. This fills out any open cavity and prevents any water from entering the camera.

Figure20: Self-made waterproof cameras designed by Jackie

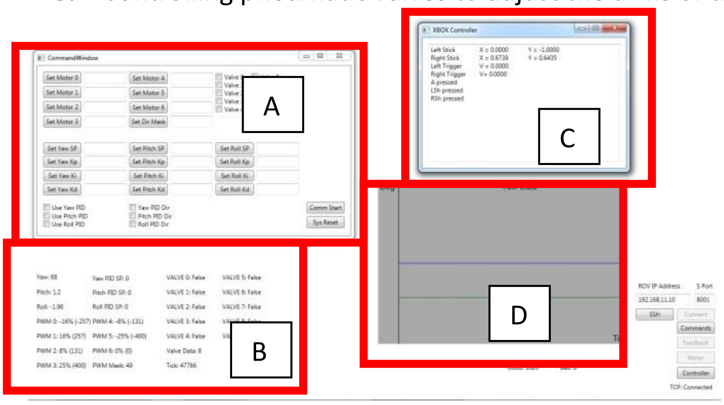
5.3 Software Subsystem

This section will detail the algorithms and the design of the controlling programs of the Whale. It includes the main control program, router and USB hub data transmission system, camera client system and the inertial measurement unit.

5.3.1 Main Control Program

The STM32F4 Discovery Board was programmed using the C language and the libraries provided by STMicroelectronics, with the integrated development environment uKeil, developed by ARM. The board may be seen as the main controller of the ROV, as it is responsible for all the actions that the ROV performs. It is responsible for:

1. Constantly transmitting the status of the ROV through the router to the on-shore computer
2. Receiving commands from the on-shore computer through the router
3. Sampling the sensors on the ROV
4. Controlling speed and turning direction of the motors of the ROV through providing PWM and GPIO signals to the motor drivers (as mentioned in Electronic Subsystem: Motor Drivers)
5. Controlling pneumatic valves to adjust the arms of the ROV



Legend:
A: Individual motor control

B: PWM, Direction and Orientation data

C: Temperature, Voltage and Current data

D: Status of the Whale in Graphs

Figure21: Main program designed by Adrian

5.3.2 Router and USB Hub Data Transmission System

Our cameras are capable of producing high definition videos which needs a high transmission rate to allow the camera feed to be displayed on the screen from the Whale. In order to get the required transmission rate we needed to run the cables directly from the computer to the camera. This increases the number of wires in the tether and makes the management of the tether a difficult job. In order to reduce the number of wires between the computer and the Whale, we first collect all the camera signals to a USB hub. The data is then sent to the router which compresses the data and sends it to the onshore computer. This way we need lesser number of wires in the tether and a high speed of transmission can be achieved.

The router is the gateway for the ROV to communicate to the on-shore computer station. It is a TP-Link TL-WR703N travel router, which has a custom OS, named OpenWRT, installed. It converts USART communication signals from the STM32F4 Discovery Board to TCP/IP packets, using a serial to network proxy daemon, and transmits them through the twisted-pair cable (LAN cable) in the tether to the on-shore station and vice versa. It also acts as a Motion JPEG (MJPEG) streaming server, allowing the on-shore computer to access the cameras on the ROV via the correct sockets.

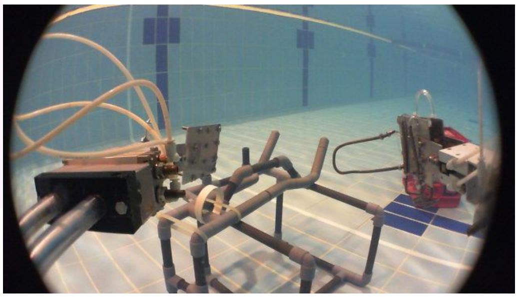


Figure22: (Clockwise) Router used, USB Hubs, Screen grab from on board camera via mjpeg streamer

5.3.3 Camera Client System

The Camera Client System is written in C# with Windows Presentation Foundations (WPF). It manipulates MJPEG (Motion JPEG) files, a stream of images to produce a video, onto the screen. Other than the display of the video feed from the on board cameras of the Whale, the Camera Client System also does other functions such as flipping of video, recording of video and calculation of distance in 2D pictures on single or multiple cameras. The distance can be measured to an optimal error of about 1-3%. The angle of image capture does not put much error into our program. We also found that the larger the image resolution, the smaller the error. Other than that, we also found that the higher the frame rate we use, the lower the lag in the video feed.

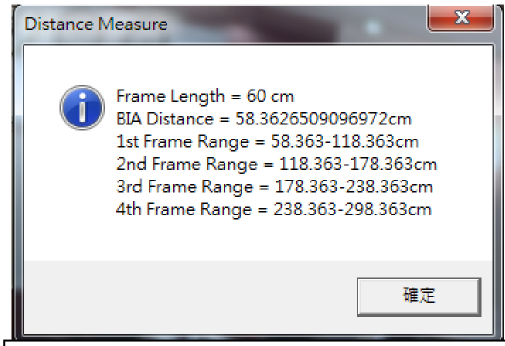


Figure23: The Camera Interface and distance measurement program designed by Dennis

5.3.4 Inertial Measurement Unit

An integral part of the ROV is the Razor 9DOF (Degree of Freedom) Attitude and Heading Reference System (AHRS) (SEN-10736), which is a subclass of the inertial measurement unit (IMU). It is a module with an on-board ATmega328, a triple-axis gyroscope (ITG-3200), a triple-axis accelerometer (ADXL345), and a triple-axis magnetometer (HMC5883L). The ATmega328 is responsible for using the Direct Cosine Matrix algorithm to calculate the Z-X'-Z" Euler angles, which can accurately determine the 3-dimension orientation of the ROV, and is also responsible for transmitting the Euler angles and sensor readings to the STM32F4 Discovery Board. Currently, this information is used to stabilize the ROV, maintaining it at a fixed 3D orientation with the Proportional Integral Derivative controller. The IMU is currently used to monitor ROV orientation.

6. TRANSMISSOMETER

One of the tasks this year is to come up with a design for a transmissometer. The main task of this transmisometer is to record the turbidity of the water. This piece of equipment needs to be deployed by the ROV and left on site to provide a long time data logging. This section of the report will detail the design of the transmissometer.

6.1 Structure

The frame of our transmissometer is constructed with PVC tubes. The front part of the frame is shaped like a funnel, and also functions as one. This part of the frame ensures easy placement of the transmissometer into the seafloor platform. A 20 cm transparent waterproof tube contains all hardware components, except the light source and receiver. The transmissometer is equipped with a 1W white light LED for the light source and some light dependent resistor (LDR) as a receiver. The light source and the receiver is placed 10 cm apart. The structure is tuned to be negative buoyancy to ensure that it would sit on the seafloor. The external structure is shaped like a hook to enable the transmissometer to cling onto the side of the hydrothermal vent ensuring that the transmissometer does not get dislodged due to current.

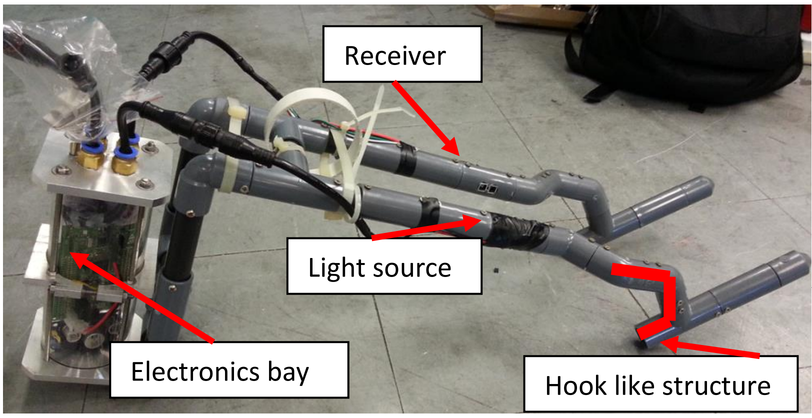
6.2 Choice of Light Source

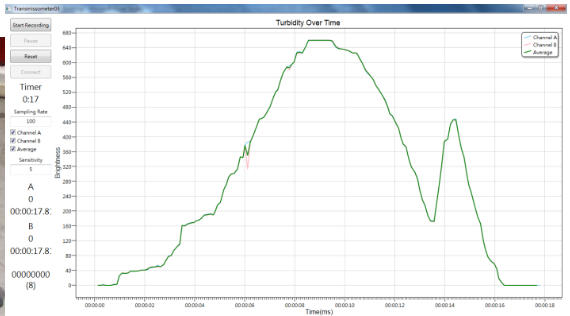
In the beginning we have listed out different kinds of light sources, namely laser and LED. The main characteristic of laser comparing to LED is that it gives a high intensity light focused at a single point. As the light intensity is high, a small change in the turbidity would result in a large change in intensity of the laser light picked up by the receiver, after the beam passes through the medium. The beam of light from the laser is too narrow and small bumps while transportation to the sea bed can cause the laser to misalign. Therefore, the finalized light source is the brightest LED that we could find as its light is not focused at one point and it has a higher tolerance to misalignment.

Confusion was on which colour to use. After some research we found out that red light is easily absorbed due to its long wavelength. We finally settled for the blue light source since it has a short wavelength and is not so easily absorbed. As for the receiver, we used a simple yet effective light dependent resistor.

6.3 Working Principle

The light source and the light dependent resistor (LDR) will be in a straight line with the medium passing through in between it. When the medium become less transparent, intensity of the light passing through the medium would decrease, and the resistance of the LDR would increase. The LDR is hooked up with the Analog to Digital Converter on the STM32F4 Discovery board which is able to calculate the resistance of the LDR and therefore the transmittance of the medium. The digitized data is then sent back to computer by a 2 pin cable for further analysis. With the digitized data, sensitivity can be simply done by dividing the data by a certain value. This way we can change the sensitivity of the transmissometer for different water conditions. For graph plotting, a library provided by Dynamic Data Display is being used on a WPF Application.





Figures24: The transmissometer structure designed by Han and the graphing GUI of the transmissometer designed by Matthew

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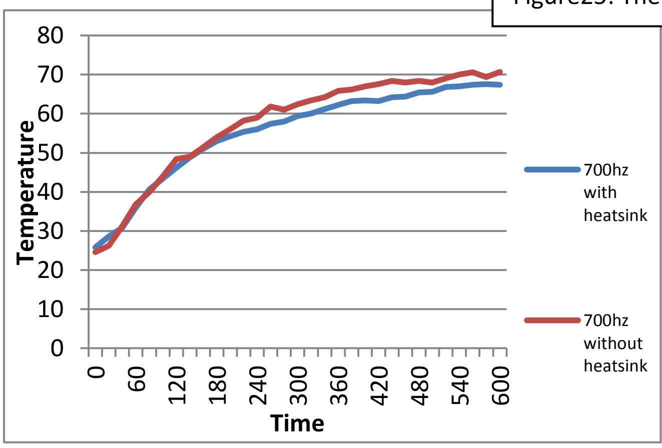
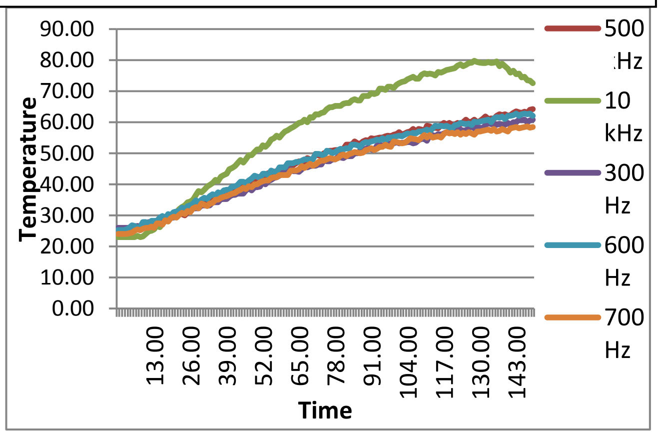
7. CHALLENGES AND TROUBLESHOOTING

7.1 Technical Challenges

Two major challenges that we had this year was with the motor drivers and the cameras. Firstly, this year, we had used high powered thrusters to power the Whale. The existing motor drivers were working when the Whale was tested under shallow waters. However as we moved to deeper waters, it started overheating due to the load exerted by the thrusters. The MOSFETs on the motor driver were not able to handle the heat and they started giving way. We started testing the motor drivers to find their failure points. Firstly, we tested them at a full wave PWM to get the highest temperature that the motor drives can reach. Then we started varying the frequencies and tried to get optimal frequency. These tests also showed us the peak temperatures that the MOSFETs can handle before they give way. Then we tested the motor drives with and without heat sinks. These are the data that we collected:

Figure25: The graph illustrating the findings of the test on the motor drivers





Based on these test results, we designed the new motor driver boards and added more protection such as diodes to prevent any back current from affecting the rest of the electronics. The motor drivers are now running at 700Hz with heat sinks. This way, we can prevent the catastrophe that happened a day before the regional competition.

The next challenge was the camera system. The plan was to give the driver a wide range of vision for the ease of piloting the Whale. We wanted the pilot to have almost a 360 degrees view of the environment around the Whale. In order to do this, we required around 5-6 cameras. However, after testing we found out that the routers were not able to handle the high demand for the bandwidth from the cameras. There were other problems such as frame rate affecting the delay in the video feed and the performance of the cameras in low light conditions. The software team had tested two cameras namely the Microsoft HD-5000 and the Logitech C210. The parameters that they tested were the frame rate, memory consumption, resolution and the percentage of CPU time occupied by the cameras. The results were as follows:

Parameters	Test Conclusion
Frame rate	Higher the frame rates lower the lag with an optimal rate of 30fps for Microsoft cameras while Logitech cameras maxed out at 24fps.
Memory Consumption	The Logitech cameras consumes 20-30% more memory than Microsoft cameras
Resolution	Optimum resolution for a balanced CPU time and memory consumption is about 800x448 pixels (Microsoft cameras), Logitech cameras maxed out at 600x480 pixels
CPU Time	No big difference between Microsoft cameras and Logitech cameras

Finally, we decide that we would use the Microsoft HD-5000 cameras and two routers with a network switch. One router is used to handle 2 cameras and the serial communication with the main board while the other router handles 3 cameras.

7.2 Non-Technical Challenges

The team behind the Whale is international, with members from China, Hong Kong, Indonesia and Malaysia. Language barriers and cultural differences had to be taken into account. With the Whale's Asia regional crowning, it is shown that our team overcame these difficulties. Our team is also multi-disciplinary (please refer to title page), hence the effective communication of ideas and academic theories between team members is necessary. Weekly pool-side team meetings, as well as bi-weekly lab meetings, were held to ensure important issues were addressed. Our team also encouraged members to communicate and collaborate online using platforms such as Dropbox, Facebook and Google Docs. Logbooks, draft sketch books were kept for review. Information frequently queried (for example: the pin assignment of the main board) is printed on paper and stuck upon the wall of the lab to increase efficiency. After two years competing in MATE International ROV Competition, senior members realized that a friendly relationship lubricates the cooperation between members. Many friendships blossomed within the team, thus language barriers and cultural differences had been overcome. The individuals behind the Whale have come together and formed an international and multi-disciplinary team.

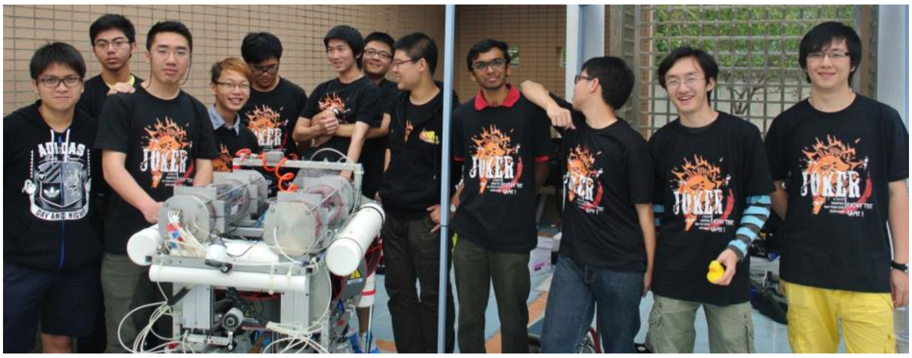


Figure26: The Joker Inc. - A vibrant, diverse, multicultural and multitalented team

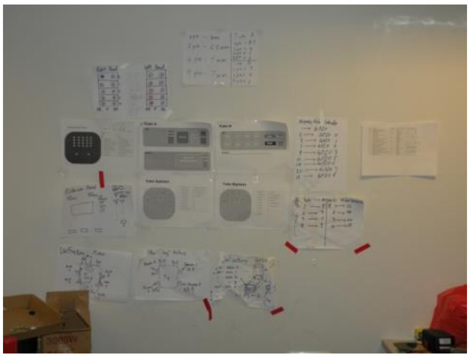


Figure27: Important Whale information posted on the wall

8. LESSONS LEARNT

There were many lessons learned through the design and construction of the ROV. We have successfully implemented pneumatic system into Whale. This is the first time we have adopted a different power source for the manipulator system. We have also successfully created a transmissometer that could measure the water turbidity over time. We learnt new things about LEDs, LDRs and lasers. We also learnt a thing or two about the dispersion of different coloured light in water and the optimum colour for a transmissometer.

In addition, we managed to improve the design of the electronic tube which is developed by last year's team. This year we have also managed to come up with a checking mechanism and a constant locking mechanism that ensures waterproofing every time the Whale goes for a dive. Since our ROV uses numerous cameras, sensors and motors we needed to pay particular attention to the power distribution within the ROV and in doing so our members learned and gained experience in designing voltage regulators. For levelling the secondary node, we thought outside the box, adopted a fishbowl design rather than using manipulators. Also, we learnt the signal control of pneumatic using solenoid valves.

Furthermore, we learned valuable soft skills through the process. We learned effective time management, working on the ROV, working towards deadlines, while managing our studies at the same time. We learned how to collaborate with team members from different disciplines, working together on integrating ideas and concepts to develop the complete ROV system. We used various online collaboration and communication tools, maintained a list of contacts and had regular meetings to familiarise our progress. This experience trained us to work together efficiently as a team to achieve, much greater than individual learning.

9. FUTURE IMPROVEMENTS

In the future we plan to include a larger variety of modules to help with the tasks. Currently, our main module is the manipulator module. This is because the tasks given to us this year mainly focuses on human like hand motions. However in the real world the condition might be different whereby the ROV might be required to carry out underwater observations, samples collections and other tasks. The inclusion of larger number of modules will give our ROV the needed adaptability.

We have also included a router that serves as an interface between the on shore computer and the microcontroller on the Whale. In the near future, we would like to enhance the system even more to enable the pilot to control the ROV from any corner of the world. The reason for separating the pilot from the ROV is to provide the pilot with a safer environment from which he can control the ROV. Seas can be a very rough place. The pilot need not be at sea to control the ROV. He/she can do it at the comfort of a land based control station. We did get some success in transmitting the images from the ROV to a phone/ tablet on shore wirelessly when the ROV was close to the surface. However, when the ROV dives, the signal strength dropped and we were not able to get any images back. We would like to change this condition so that we can use wireless technology to control the ROV.

Currently, our ROV is very large in size partly due to the large thrusters and the pneumatic system used. We would also like to shrink the size of our ROV without compromising the performance or the flexibility of the ROV. This is because under certain conditions, smaller size is required for an efficient completion of tasks. A smaller ROV can navigate easily through small spaces. The agility of the ROV can also be increased giving it a higher range of motions. The pneumatic system now is bulky and heavy. We are planning to change it to a smaller one with the same capability as the current pneumatic actuator.

10. REFLECTIONS

"After 4 months of hard work and the time spent in the Robotics Lab, we qualified for the MATE ROV International Competition. This is one of the most interesting parts in my life where I devote all my time and effort into an innovative product and I feel that it had been an irreplaceable experience. As this was my first time taking up charge, I might not have been a good leader. However, I am sure of one thing, I have the best team! All members are extremely passionate about Robotics, have a good working attitude, and are capable in handling

Figure29: Water testing on Widy's (center) birthday

the problems in the ROV even in our most dire state. We have much room to improve but this is huge step in our journey in the field of underwater robotics. Good job HKUST ROV team!!"

-Andreas Widy PURNOMO, Electronic Engineer, B.Eng in Electronic Engineering Year 1

Figure30: Matthew working on the transmissometer program

"It has been a fun and enjoyable thrill ride being the HKUST ROV team and a part of the Joker Inc. We have changed from being strangers with one unifying passion for ROV to a family of 12. This has brought us closer and had helped us to overcome the challenges. It has also been a very rewarding experience where I got to learn a lot of things about programming. One new concept for me was the router to serial conversion for communication protocol used in the Whale."

-Matthew MA, Software Engineer, B.Eng in Computer Engineering Year 1

"Being from the School of Science, I had never believed that Robotics could be so much fun. It was even more fun when it was underwater. Being the Mechanical team which gave the Whale its structure, I had learnt a lot about waterproofing and also machining techniques. Other than that, I also learnt teamwork and made a lot of new friends"

- Zhuo Quan IM, Jacky, Mechanical Engineer, B.Sc in Physics Year 1

Figure31: Jacky waterproofing the electronics tube

11. Corporate Social Responsibility

Joker Incorporated encourages a positive impact of ROV to general public through the outreaching activities. We co-organized two workshops for introducing ROV technologies to all the teams in Hong Kong regional contest. Mr, Thomas LAO, a mentor of Macao high-school team, commented "Workshop provides basic knowledge of waterproof technique and electronics especially for the beginner. The professionals from Joker Incorporated provide valuable suggestions and answer our inquiries clearly." Mr. German CHEUG, a mentor of Hong Kong high-school team, said "Workshop provides an excellent platform for participants enjoying learning with fun. We appreciate the contribution of the organizers, while giving the students new experiences outside the classroom and interests."

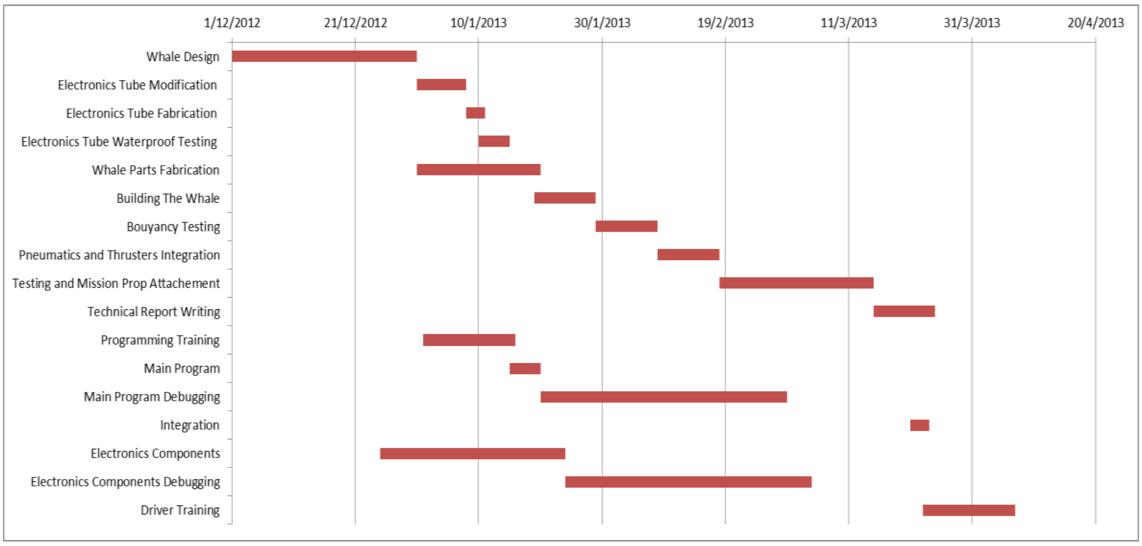
12. ACKNOWLEDGEMENTS

JOKER Inc. would like to thank the following individuals, organizations and companies for their guidance and assistance in giving the Whale a life.

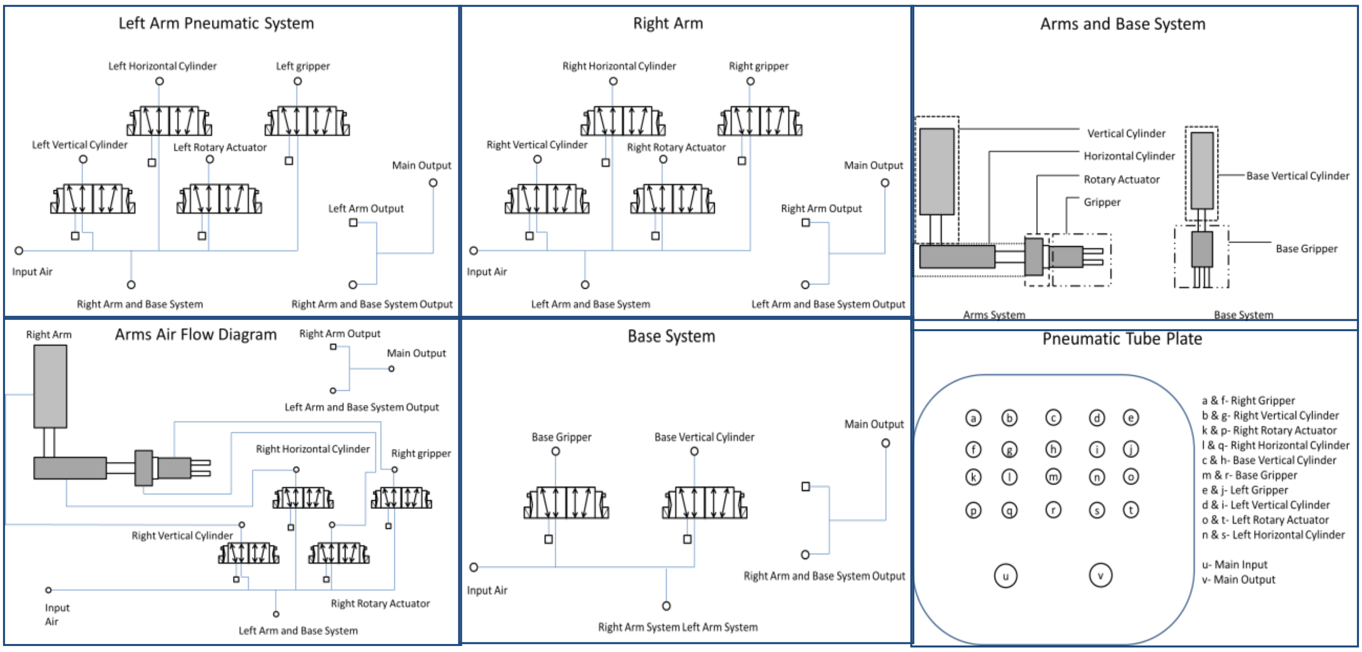
HKUST – provides funds and laboratory spaces and supports the travelling expenses of the students
HKUST Public Affairs Office (PAO) – handles interviews and press conferences
HKUST Design and Manufacturing Services Facility (DMSF)– provides technical support and suggestions
HKUST Student Affairs Office (SAO) – provides the swimming pool for testing our ROVs
Prof. Kam Tim WOO – our mentor who guided us and advised us as we progressed through our project. We greatly appreciate his effort and support of our team in our endeavors.
Mentors– Lok Ping LEUNG, Chun Yin LEUNG, and Sau Lak LAW guide and provide us with technical advice, training and instruction during the development of the ROV.
MATE Center – organizes the international competition and provides a platform to exchange ideas
The Institution of Engineering and Technology, Hong Kong (IET HK) - organizes the Hong Kong/Asia Regional of the MATE International ROV Competition 2013 and fundraising event for Hong Kong Teams
RS Components – provides in kind donation of electronic equipment and design software for circuits.
DHL – provides in kind donation of ROV transportation for the international competition
SolidWorks- provides the SolidWorks Student Edition CAD software
Hong Kong Government Reaching Out Scheme - supports the travelling expenses of the students

13. APPENDICES

13.1 Gantt Chart



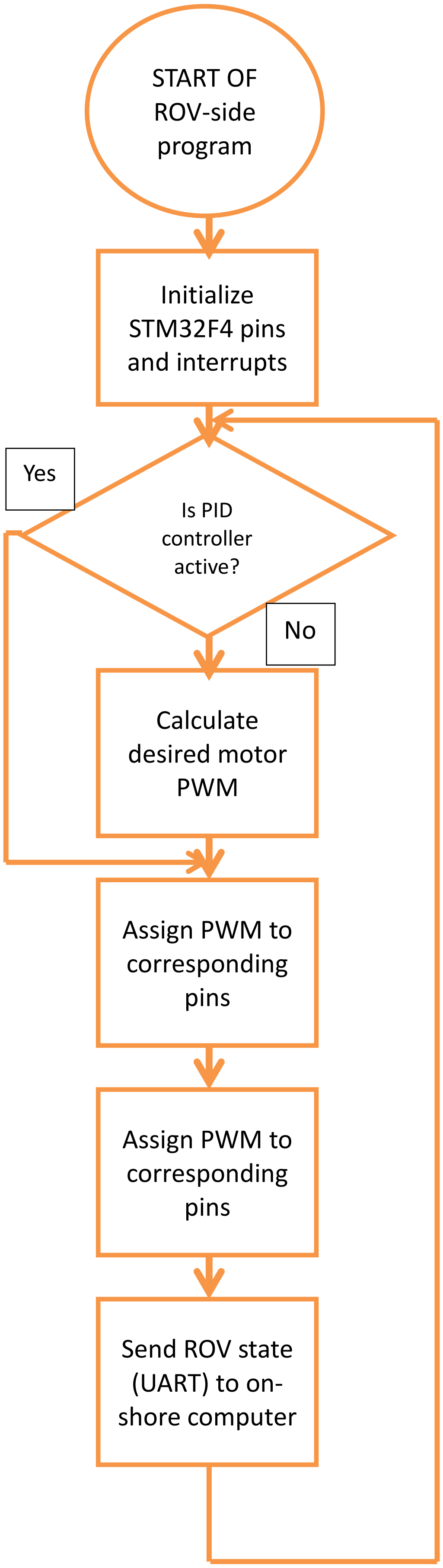
13.2 Pneumatics Diagram

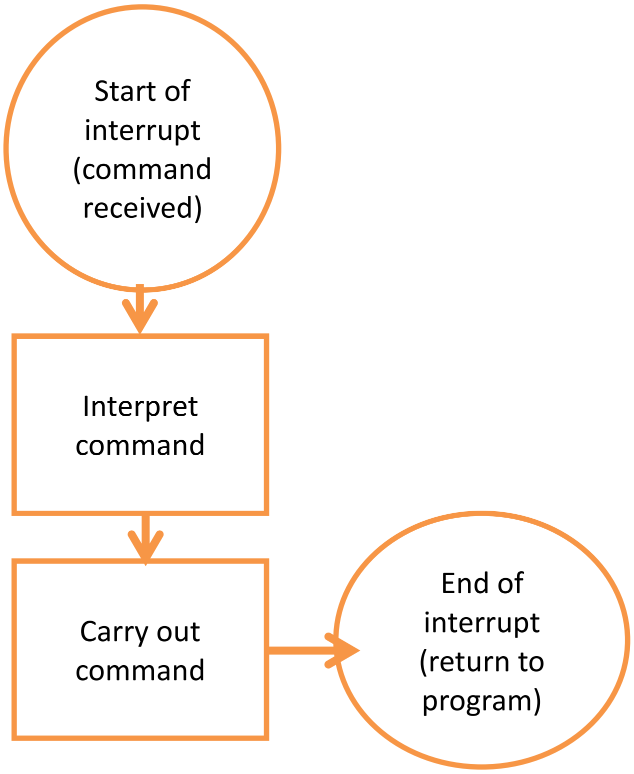


13.3 Safety Check-list

Items	Things to be checked	Checklist
1	Connect the tether to the ROV	
2	Check if there are any sharp edges in ROV	
3	Double check all waterproof connector whetehr it is tightened or not	
4	Check whether all of the cables had been properly sealed	
5	Using Digital Multimeter, check whether the 48V input and ground is connected or not	
6	Check the fuse in the emergency button	
7	Connect power supply with the tether	
8	Check whether all of the motors can be rotated	
9	clear the area around ROV before test the motor on the ground	
10	Turn on the power and see whether the ROV is functioned properly	
11	Prepare the crane to deploy ROV	
12	attached the hook and make sure everything secured	
13	Put the ROV in the water	
14	Check the electronic tube water proofing	
15	The ROV is ready for the mission	

13.4 Software Layout





13.5 Hardware Block Diagram