P.C.M.S. ROV
DELPHINUS

Macau Pui Ching Middle School Delphinus

2016 Technical Documentation

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Table of Content

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Abstract

In Macau Pui Ching Middle School ROV Team, we proudly acknowledge that innovation and environmental protection are our first priorities, we aim not only to build a functional ROV but also to create a compact, manageable working class ROV. Therefore, we utilized the knowledge and experience we have gained from the past three years and built an all-rounded ROV, Trident (Fig.1), for all situations.

Figure1: Trident – The ROV of team Delphinus

Our goal this year is to limit our vehicle size and to reduce the weight, which means that we must use minimum materials in order to complete all the tasks. This year, we make use of the Printed Circuit Boards which is more stable and easy to repair. The frame of the ROV is mainly aluminum bars, considering it's fabricability and efficiency. Carbon fiber and acrylic are also used for other applications such as the buoys, supports and tools. Different payload tools are designed to meet the needs of the missions, such as measuring the temperature and determine the depth. Moreover, manipulators are designed to retrieve the oil samples, compare coral colonies, secure the flange, etc. Lastly, with a secure waterproof design, our ROV can operate stably and efficiently in all circumstances.

Most importantly, our team has experienced several incidents such as veteran team members leaving and new members joining the team, we had a hard time readjusting the team but we still get through it and managed to build Trident and present it to the international competition.

Company Structure

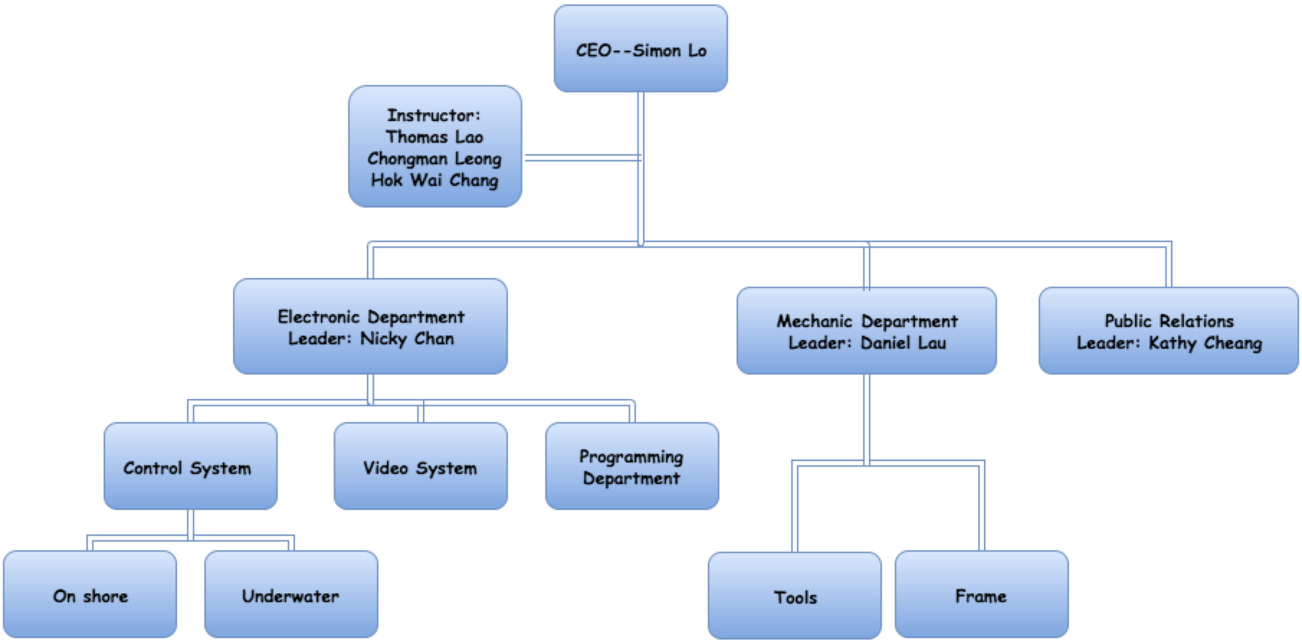


Figure2: Organize station chart of Delphinus (Names of other teammates can be found on the cover page)

Design Rationale

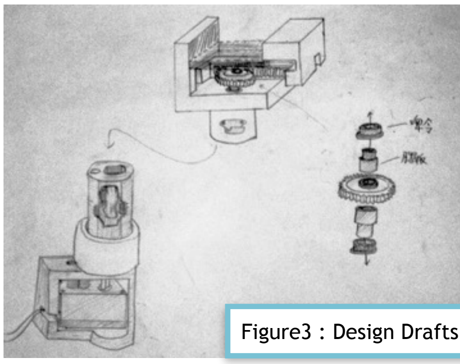


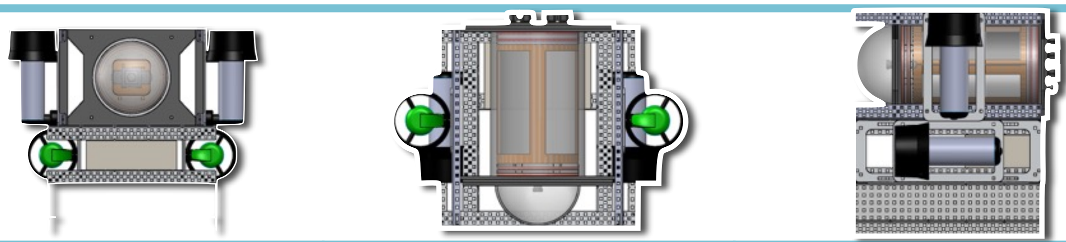
Figure3 : Design Drafts

Like most of the teams, we hope to complete the missions and get points as much as we can. Therefore designing an efficient and meticulous ROV is a must for us to achieve our goals. To design this ROV, we first understand the mission and know about the requirements for building the ROV and tools. Then we gathered all the ideas we came up, filtered them and started to draw out our design on a draft paper (Fig.3). The first problem that came up is the size restriction of the ROV, which is also the first requirement listed in MATE Ranger Handbook. To solve this problem, we decided to give the ROV a taller shape instead of a wider base to obtain the additional points. After taking some suggestions from our tutors and making a series of adjustments, we then started working on our 3D sketch by using 'SolidWorks' so we can have a clearer vision of the ROV for us to build it (Fig.4).

Besides, after understanding the missions, we determined that the ROV should have the two main features: First, due to the wide variety of tasks needed in this year's mission, we needed to design several detachable tools specified for each tasks, and attach only the ones we need. Next, we wanted to limit the components needed in each system, thus reducing its size and weight.

Also, to avoid the electronic system from being damaged by water infiltration, we separated the system into two -- the control system and camera system, which allow us to shrink the size of the main housing and avoid the whole system being destroyed at once. Also, we designed a layer frame system for the sake of convince and modularity.

Figure 4: Three-view Diagram



Front view | **Top view** | **Side view**

Overall Vehicle System

Frame

When we started to build the frame, the first challenge is to limit the size of our ROV. In order to reach the size requirement, which is being able to fit inside a circle hole with a diameter of 48cm, we have to fully access the space inside the frame and shrink the parts. To solve the problem we decided to separate the frame into three mini-frames.The first mini-frame contains the control system and the vertical thrusters; the second for the video system and horizontal thrusters and the last for the tools (Fig.5). As it turns out, the frame was built in 31cm x 31cm x 35cm. Although the thrusters we used have large sizes, their efficiency and stability really

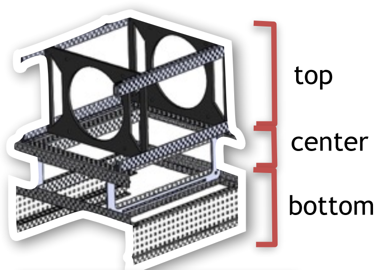


Figure 5: Frame of the ROV

help us to be able to control the ROV easily, so it is really essential for our system.

The second challenge is the material of the frame, To build a firm and stable frame, we need to select a tough and light-weighted material, since we don't want it to have an overly heavy weight which may exceed the set weight of the rules (11-14kg). After doing some research and testings on different materials, we finally settled on VEX aluminum pieces. These pieces are light-weighted yet has a solid and flexible structure, which are suitable to build up the frame. Furthermore, the size of these pieces are standardized, which help us to mount the pieces on each other easily and compatible with the official VEX screws and blind rivets. As the result, the frame is light-weighted, easy to build and be able to withstand crashes and collision.

More on the multi-layer system, the main goal of this system is to have a better use of the space inside the frame, also we can have a easier way to maintain the ROV and detach unnecessary parts. Because the main control system is fixed inside the top layer, we can just detach the top layer while repairing the control system. Moreover, if needed, we can detach the bottom layer for simple roving. In addition, draw latches are used to connect the layers instead of screws in previous design, thus detaching mechanism is much easier and less time consuming.

Buoyancy

In order to achieve neutral buoyancy, we first calculated the mass and volume of Trident which is 13.4 kg and 0.005m^3(estimated by Solid-Works) respectively, and thus its weight is 13.4 x 9.81 = 131.5N. The volume of Trident alone produces about 0.049N for buoyancy and it needs about 0.02 N more force to afford its own weight.
High density styrofoam sheets (Fig.6) wrapped with Carbon Fibre (Fig. 7) Reinforced Polymer are reused from previous products. Comparing with PVC tubes we used in the first two years, we found that the density of styrofoam sheets is lower than the PVC's, which is 40.3 kg/m3 for the styrofoam and 78.9 kg/m3 for PVC tubes, so we selected styrofoam sheets as buoyancy.

We made eight buoys and calculated their buoyancy with the following formula: B=ρvg.
(B=buoyancy,ρ=density, v=volume, g=gravitational acceleration)

Buoyancy of Styrofoam Sheets

Length (m)	Width (m)	Height (m)	Volume (m^3)	Buoyancy (N)
0.36	0.14	0.03	0.001512	14.8176
0.13	0.105	0.025	0.0003412	3.34425
0.29	0.17	0.03	0.001479	14.4942
0.33	0.095	0.03	0.0009405	9.2169
0.36	0.13	0.03	0.001404	13.7592
0.16	0.16	0.025	0.00064	6.272
0.34	0.09	0.03	0.000918	8.9964
0.185	0.14	0.023	0.0005957	5.83786

Figure6: Buoyancy provided by different size of styrofoam

Figure7: spreading the mixture

Propulsion

Four reused BTD-150 SeaBotix motors are installed for supplying the propulsion system in two pairs. One of the pairs performs vertical movement(T1,T3) while the other one takes charge of horizontal movement(T2,T4) (Fig.10). Metal cutter (Fig.8) is used to cut the 1mm aluminum plates (Fig.9) for attaching the thruster on to the aluminum bars.

These thrusters are chosen for their high efficiency compared to bilge pump. They are waterproofed and stable such that we can reused them for a long amount of time (3 years). SeaBotix motors are able to produce 21.56N thrust at just 2.8A while the bilge pump can only acquire about 17.7N thrust at its maximum current. With these data, we consider SeaBotix thrusters as the best choice to perform the propulsion system be-

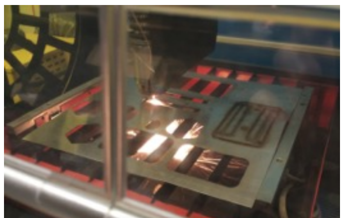


Figure8: Cutting aluminium on metal laser cutter

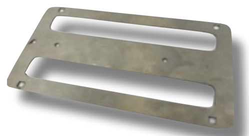


Figure9: 1mm aluminium motor mounts

cause they are stable and they output enough thrust to move the ROV quickly. All ROV movements are listed in Fig.11 below. While some of our teammates have argued that four thrusters propulsion system is more stable and provide more movements, we remain on two thrusters for horizontal movement due to the limitation on weight and size.

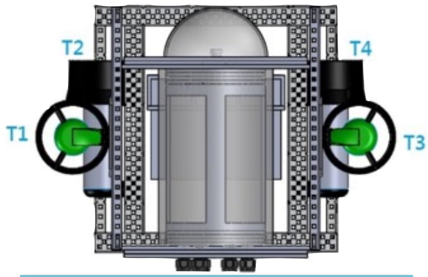


Figure10: placement of the thrusters

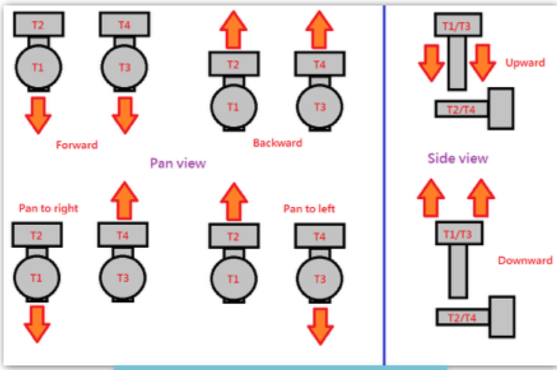


Figure11: Movement of the ROV

Control System


Figure12: Arduino MEGA

Our control system is constituted by the onshore control system and the underwater control system. The onshore control system sends control signals to the underwater, while the underwater control system feedbacks camera data to the onshore control system. A tether is used to connect them and conveys data. Fibre is used in transmitting data because of its stability and the ability to send signals and video at once.

Considering that Arduino MEGA (Fig.12) has a relative small size, yet still remains a large quantity of I/O ports and a wide variety of controllable modules, our both onshore and underwater system uses Arduino MEGA as Micro Controller.

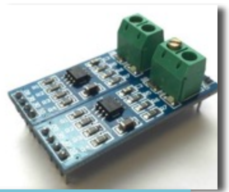


Figure13: MAX 485

As the Arduino serial couldn't communicate over a few meters of length in a stable situation, we chose to use MAX485 (Fig.13), which can set up communications between a long distance up to 2km. It is placed both onshore and underwater control systems.

Improvements have been made in our control systems based on the previous designs. We have designed a brand-new communication protocol, Printed Circuit Boards (PCB) for the underwater control system, and the controller is integrated into the onshore control box.

Onshore


Figure14: The onshore control system

In order to make the onshore control system(Fig.14) more unified, we combined the control panel into a single box. We also add connectors for optical fiber and power plug respectively so that the tether and onshore control box can be separated easily. The onshore system is composed by Arduino Mega, a voltage transformer,two MAX485 boards and a optical fibre converter.

Instead of using PS2 controller which has lots of buttons last year, two joystick modules are chosen for controlling the movements of the ROV since joysticks provide a more realistic environment to the pilot. One is for going forward,backward and turning left and right while the other is for vertical movement and rotating the manipulator. With this unified, easy-to-use control panel, everyone could be able to drive the ROV.

Similarly, when the onshore control system receives sensory signals from underwater, and converts the signals from electronic signals to real sensory data with units, then display it on the computer.

Underwater

Learnt from previous experiences, the optical fibre is too fragile and the size of optical fibre convertor is too big for the interior design of the housing. So we divided the underwater control system into two parts which is the control housing and the video housing.

The control system (Fig.15) is mainly composed by Arduino Mega for analyzing the data and control motor boards, three Pololu Motor Controller Boards for control the motors and tools, a MAX485 boards for communication to the shore. As for the video housing, it includes an optical fiber converter which transmits the control signals and video signals in light signals, and a voltage dropper. Both housing used PCB as circuit integration, and we will discuss that in the following chapter.

Figure15: The underwater control system

Control Housing

- *Printed Circuit Boards*

After reexamining the difficulties in previous housing constructions. Problems like unstable wires, the net weight produced by every single wire and the amount of wires, have caused several problems inside the housing and need to be fixed as soon as possible. Most importantly, jump wires are unstable and really easy to fall off from the ports. Therefore, we use printed circuit board(PCB) as the wire integration board. Unlike the circuit boards welded by ourselves, using PCBs can decrease the number of wires significantly and give us a clearer view on the circuits. Moreover, there are less error and avoid sudden short circuit. PCB is thinner than wire terminal strip, which is used in last year's design, so we can save up more space for other elements. In addition, PCBs are more convenient for mass production and fairly stable, as a result, the work needed to debug is lessen.

We use DesignsPark as the PCB design software (Fig.16). First, we use this software to make the module of the elements we need. After designing, we use the auto routing function to finish the blueprint of the circuit (Fig.17). Finally, we send our documents to electronic manufacturers to produce custom PCBs. After the PCBs were manufactured and delivered by the manufacturers, we still have to solder the headers on the PCB (Fig.18) by ourselves.

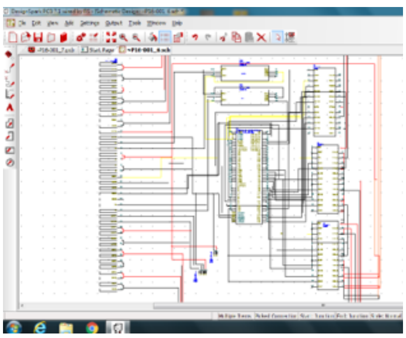


Figure16: PCB's circuit scheme

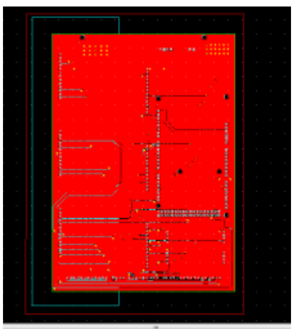


Figure17: PCB's design scheme

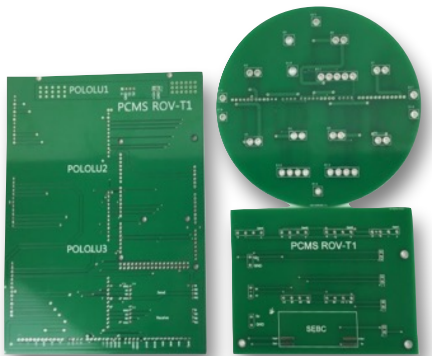


Figure18: PCBs designed by us

- *Motor Control Board(Pololu Dual VNH5019)*

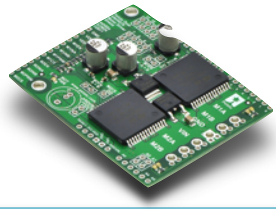


Figure19: Pololu VNH5019

We use a new motor control board named Pololu Dual VNH5019 Motor Driver Shield (Fig.19). It can deliver a continuous 12 A (30 A peak) per motor. This motor driver shield and its corresponding Arduino library make it easy to control two bidirectional, high-power, brushed DC motors with an Arduino or other micro-controller. The efficiency and stability of motor control boards has been a big issue for us since the the first year, we've tried several boards and this Pololu control board is by far the best control board we've ever used.

Software Design

Communication Protocol

We used the serial port built in Arduino for the communication between the shore and the ROV. In the past three years, we sent characters for different movements of the ROV, such as character 'w' for forward and character 'd' for backward. Its performance is reasonable but it still has some issues. For example, we couldn't go forward and operate the manipulator at the same time (Fig.20).

To solve this issue, we designed a new communication protocol based on packets. We sent orders of independent thrusters instead of a whole movement. The protocol contains a header and a type identifier, followed by a string of data and ender.
Moreover, our pervious design had another disadvantage. The data transmitted between the systems is so long that there are minor delays occurred during operation. Due to this problem, we have designed a new way to generate data.
The header and the ender indicate the start and the end of the packet respectively. The type identifier specify the type of the packet, in this case, the type is thruster movements. The string of data mark the movement of each thruster. The first character in Data represents thruster 1, and it's status is 1. There are a total of three statuses, 0 for clockwise, 1 for stop and 2 for count clockwise.

Using this protocol can significantly improve the performance of the ROV and thus make us easier to control it. Same protocol is also used in sensory data transmission. The type identifier varies when different sensor is used. This protocol is useful especially when more than one sensor is used.

Header	Type Identifier	Data						Ender
'*'	'@'	'1'	'0'	'1'	'0'	'1'	'1'	'#'

Figure20: An Example of a packet

Video System

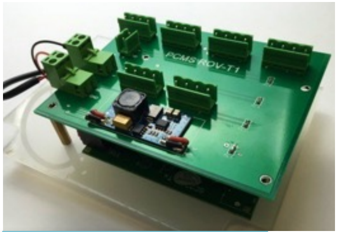


Figure21: Video system

The video system (Fig.21) was designed to be maintained easily and conveniently. We have a new attempt for the underwater section this year. The video system is separated from the control system which is put inside a box so that it won't use up much space in our main housing. PCB is also used in order to keep the connections tidily and increase the stability of the system. All cameras are connected to the system housing, then video signals will go through a fiber converter and be sent back to the shore via optical fiber. Finally, the signal is translated by the video data collector and be displayed on the computer. The benefits of this system is that the videos from four cameras can be shown on the screen at the same time. Furthermore, the computer can take a screenshot of underwater scenes which can be used in the mission.

Camera

Four cameras are installed on Trident, and they are consisted of two types of cameras, the fisheye camera (Fig.22) and the micro monitoring camera. All cameras run with 12V and were installed in various places in order to have maximum vision around the ROV. The micro monitor camera is located in the front inner part of the housing, while other three fisheye cameras were put around the tools in order to monitor them. The micro monitor camera is located inside the housing mainly because of its lack of waterproofness, yet it has the clearest vision among all the cameras, it also helps the depth sensor to acquire depth information. Being at the same level as the depth sensor, everything that is captured by the micro monitor camera will be the level of the depth shown by the pressure sensor. For other three fisheye cameras, they are all located above the tools in order to monitor the tools and the front bottom area, where we can see the corals and other mission props. And this is also why we chose fisheye cameras, which provides a wider and broader vision (170 degrees) in front of the ROV. In addition, with the small size and the ability to withstand water, we are allowed to install the fisheye cameras in any part of the ROV.

Figure22: Fisheye camera

Optical Fiber

Optical fiber (Fig.23) is used for signal and video transmission because of its flexibility and long-lasting ability. It offers a longer distance, a higher frequency band and allows control signals and video signals to transmit at the same time. With this feature, we can greatly reduce the number of wires in the tether thus keep the weight of the ROV within the mission requirementAn optical fiber converter is placed as a transformer of the optical fiber and used to transfer commands and videos.

Figure23: Optical fiber

Tether and wiring

This year's tether is similar to last year's design, which is composed by a main power cord, two optical fiber and a steel wire (Fig.24). The length is 20m, considering that the pool is 5m deep, and the props may be 5 to 7m far from the pool side, lastly adding the 4m from the controlling deck to the pool, and a couple meters more just in case the tether can't be well organized. We added in two optical fiber in case of either of the one is broken, also the steel wire is added to protect the optical fiber and preventing it bends over certain degrees (90 degrees). Lastly, the whole tether is inserted inside a nylon hose wrap in order to protect the wires and helps the tether manager to handle the tether easily.

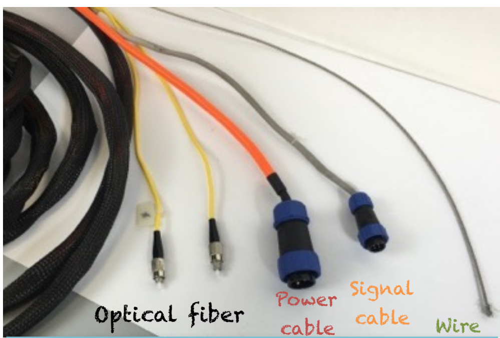


Figure24: The connectors of the tether

Mission Based Tools

a. Manipulator

Last year, we tried to use pneumatic manipulators, although it has a faster response and grab, it takes up so much spaces with is windpipes and air tank. So this year, we decided to use a electric-driven putter (Fig.25) to build the manipulator because of its simplicity and powerfulness.

Figure25: Electronic putter

In order to find the four desired serial numbers on the CubeSats, we added a waterproofed DC motor to the manipulator to made it rotate. A set of gear is used to connect the manipulator with the motor. In the mission, after grabbing the pipe on the CubeSats, the manipulator rotate to make the numbers be shown on the camera. We used CNC to cut out the aluminum parts we needed, then we fold it into a shape of 'C'. Next we placed some rubber feet on the surface of the manipulator, finally we combined the aluminum parts and electric putter to make the manipulator.

In order to make some improvements to the manipulator, we made another one by a set of worm gear and a water pump(Fig.26). It can operate fast and grip things tightly but it stop operating when the gripper reaches to its highest point. Although we put a lot of effort improving it, it cannot work well, so we won't use it in the competition this year.

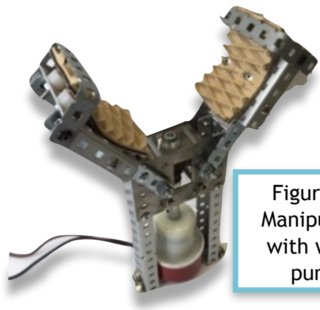


Figure26: Manipulator with water pump

Most importantly, each tools is connected onto the ROV through strong Neodymium Magnets, so that each tools are modulated and can be easily attached or detached from the ROV.

b. Oil Sample Capture Mechanism

Instead of manipulator, a capture mechanism is designed to collect oil samples (Fig.27) in Mission Task 3. The mechanism is mainly a series of bendable aluminum bars, they can only bend in one way. So when the oil sample, which is a T shaped pipe, was pushing through the bars, the bars will bend and the pipe will get into the mechanism. Then the pipe will stay inside since the bars can only bend in one way. The aluminum bars used in the capture mechanism is also VEX aluminum bars.

Figure 27: Oil sample capture mechanism

c. Magnet

Considering the carol samples will be constructed from chenille pipe cleaners and can be attracted by magnet (Fig.28). Therefore, we installed a magnet on an aluminum bar, then mounted the bar on the ROV. By using it to collect those carol samples, we can reduce the time of operating a manipulator.

Figure28: Magnet on the ROV

d. Sensor

According to the mission task, we found that we need to use a temperature sensor (Fig.29) and a pressure sensor to complete those tasks. Since we need a sensor which we are used to, as well as having the capability to simply operated by Arduino, we chose ds18b20 and KY-2-1.0MPA for our temperature sensor and pressure respectively.

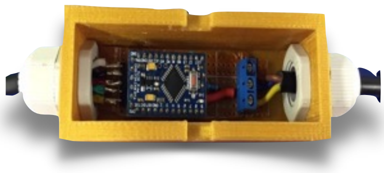


Figure29: Temperature sensor

With our design on the sensor system, we can control all sensors by only using one port. First, we use one Arduino Mini(MCU) to analyze data of one sensor because different types of sensors may have different formulas for calculations. Then the Arduino Mini h transfer the data to the underwater control system.

No matter how many sensors need to be used, only one wire need to be connected between the underwater control system and the sensor modules (Fig.30). If we need more than one sensors at the same time, the second sensor module can just plug into the back of the first sensor module and those data will be transferred back to our ROV through other sensor module. Up to three sensors are supported to use at the same time.

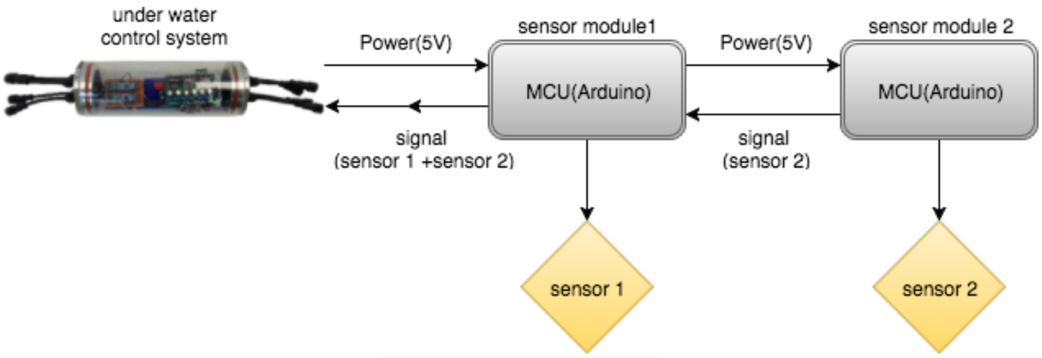


Figure30: Sensor Structure

Processing User Interface

In order to illustrate the sensors' data in a clearer way for users to observe, we have built a program by using Software Processing to show the sensor information on a monitor. The program can provide us a e user friendly interface so that we can check and calculate the data which are required in the missions (Fig.31). Moreover, as Arduino already has plenty of procedure to run, using Processing as the sensor system can help to share the workload and make the Arduino work more effectively.

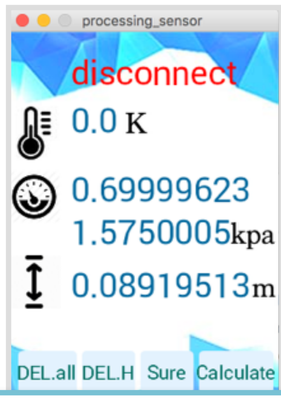


Figure31: The interface of data feedback

After receiving the analog data from the pressure sensor, We use the formula("the received data" * 5/1023) to convert it into the voltage value. According to the pressure sensor's data sheet, we follow its pattern and calculate the pressure. Though in the real situation the liquid density may be different from the ideal value. Therefore, we have made a small function for us to type the real length and the test length then using the two simultaneous formula (kPa = G*1*Height & (kPa = G*ρ*Height) to calibrate and take the accurate value of the density.

After all, we use the pressure formula(kPa = G*ρ*Height) to calculate the accurate value.

Waterproofing

To ensure the ROV can operate safely and steadily, the waterproof section should our top priority or the electronic system will be insecure. In order to make the main housing waterproof, we used two fixed O-rings, and placed them between the cap and the acrylic tube and used a carbon fiber board and screw to press it tightly (Fig.32). As shown in the figure32, the cap is attached between the gap of the acrylic tube and carbon fiber board, we also use a 26cm screw to press the board from the other side in order to gain the pressure to avoid water go inside the tube (Fig.33).

With this design, the rate of waterproof is sharply increased because of the tight press at the two end caps, and the two o-rings added inside the cap. Also, we think that one more reason for the increased waterproofness is that the main control system is being more stable than before. In the past, we have to close and reopen the housing several times in order to check or maintain the system, thus loosening the o-rings and decreases its waterproofing level. But after the implementation of PCB, the system became more stable and the number of times needed to check the system is reduced, so the waterproof level can be preserved.

For the video system, a plastic waterproof box is used. During the regional competition, we used the plastic screws which come along with the box, but those screw were so weak that the box can not be fully secured and waterproof. So after the regional competition, we changed to use a screw rod to secure each corner of the box, which turns out to be very effective and secure (Fig.34).

On the other hand, we have chosen a new waterproof connector, which is a metal connector. Different from previous plastic connectors, the metal connector is more secure and able to resist higher water pressure.

With all these new technologies and skills, our waterproof level is highest in all our designs.

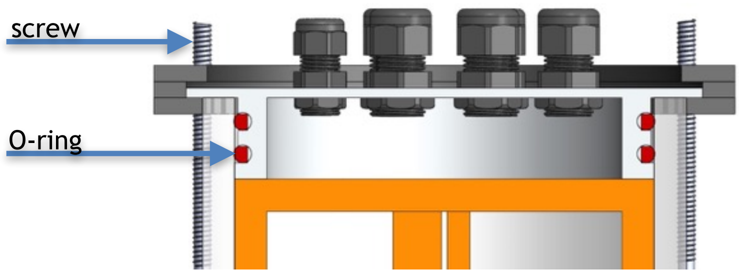


Figure32: The cap of underwater control housing (SolidWork model)

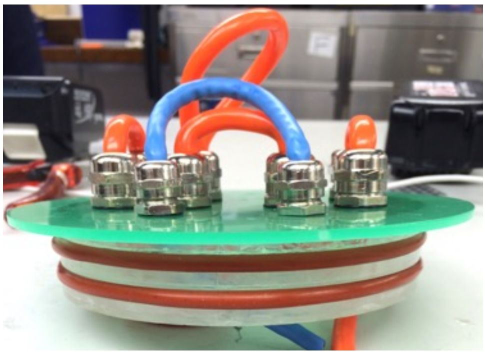


Figure33: The cap of the control housing

Figure34: Testing the waterproof level of video housing

Safety

If we ignore the safety part, things can never be well carried on, thus safety is the biggest concern in manufacturing the ROV. Our ROV was designed specifically for safety. For personal safety, we have prepared different safety gears such as goggles, ear protectors or face shields to prevent us from getting hurt. To make sure that safety measures are followed strictly, we have made a job safety analysis (JSA) to evaluate all the potential hazards, and decide which of the personal protective equipment(PPE) (Fig.35) should be worn and what safety measures should be taken. When students operates heavy machineries, they are also required to be monitored by mentors. Most importantly, new members are required to have a safety session and couple of lectures on safety and marine protection.

Considering the safety features on the ROV, there are protective shrouds covering the thrusters' blade and caution marks are put to remind people to keep a high safety awareness while working with thrusters and propellers (Fig.36). In addition, no sharp edge can be found on the ROV frame. A 25 amp fuse is used to prevent overpowering. There is a main switch on the control panel which enable us to stop the whole system immediately in case of an accident.

Lastly, we have developed a safety checklist to let teammates to make self regulations before every ROV testing, hence increasing teammates' safety awareness and keeping them from any potential hazards.

Figure35: Working with safety gears

Figure36: Caution mark on thrusters

Safety Checklist

item	check	remark
Company members		
1. All members are wearing safety goggles when using power tools.		
2. Long hair is tied up and accessories are removed.		
tether		
1. Ensure that all wires are tucked into the nylon wire mesh guard.		
2. Make sure all wires in the tether are not kinked.		
Structure		
1. There are no exposed motors and all propellers are completely shrouded.		
2. No exposed copper wire/all splices are soldered and sealed.		
3. There are no sharp edges on the ROV that can cause harm.		
4. Double check the waterproofing.		
Control system/ motor		
1. Ensure that the control box is securely attached to the tether.		
2. Ensure that there are no visible shorts or broken connections in the system.		
3. Ensure that the plugs are inserted correctly and not flipped.		
4. Check that all motors are working and thrusters are free of obstruction.		
5. Ensure all components are responding to control system.		
6. Double check the system		
Camera		
1. Ensure camera wires are not punctured or tangled.		
2. Check camera image/angle.		
3. Cameras are securely attached after fixing the image.		
4. Spray the cameras with fresh water, to get chlorine water off, which prevents corrosion.		

item	check	remark
Hardware		
1. Make sure all the connector is twisted tightly		
2. Make sure there is no sharp edges on the ROV		
3. Make sure the tether is straightened		
4. Make sure the sensors is installed		
5. Make sure the power cable is connected correctly		
6.Check if all buckles are secure		
Software		
1. Check the computer if it is showing sensory data		
2. Check if the tether is connected to the onshore panel correctly		
3. Check if the optical fibre is working (by checking the LED of the fibre convertor)		
4. Check if the vertical thrusters are working perfectly		
5. Check if the horizontal thrusters are working perfectly		
6. Check if there are signals from the cameras.		
7.Check the image of the camera		

Signature: ________________

Troubleshooting

When the ROV is not functioning normally, we use the chart (Fig.37) below to help locating the problem then solve it as soon as possible.

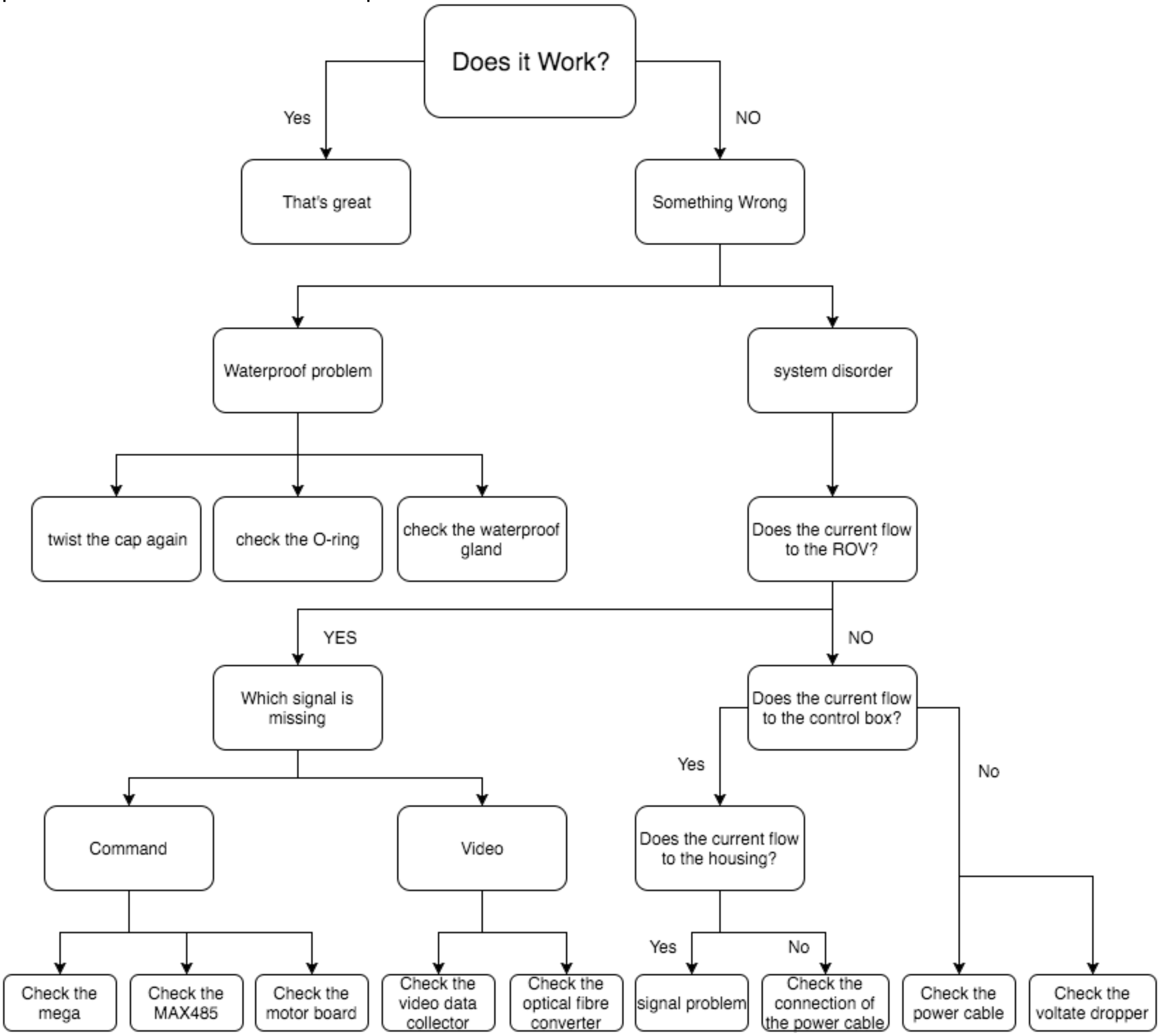


Figure37: Troubleshooting Flow Chart

Challenges

Technical

There is no doubt that challenges always come up from the surface. While designing our PCBs, we used the auto wiring function provided by the DesignSpark software, but the auto wiring always don't go as we expected. Therefore, we need to fix all the errors by ourselves.

Moreover, calibrating sensors is also a big problem since their data are wondering in a wild range. To solve this, we carried out verification repeatedly to find out a formula and make them more accurate.

Non-Technical

Non-technical task can also be the biggest problem of a team, sometimes even more difficult to solve than the technical tasks. Here are the main problems that we have got to solve.

1. New teammates and old teammates have a hard time working together.
2. Lack of concentrations while working.

After discovering these problems, we had a few discussions. New teammates are not familiar with our routine operation, and sometimes them may not find their position inside the team, so we find a veteran teammate to guide them and help them find their way to be in this team.

For keeping teammates concentration, leaders of each department are required to supervise their members. Though we suggest "Teams that play together work together", so we are still keeping a chill environment thus increasing our efficiency.

Lesson Learnt

Technical

We used Arduino MEGA sensor shield V2 as our housing terminal board last year, and there were too many wires thus making the circuit being messier than we expected. While we make the ROV this year, we found that PCB can help us to solve this problem. So, we started to learn how to design PCBs to replace them. After making PCBs this year, we may even draw circuit board for different usage by ourselves in the future and have a clearer view of the circuit tracks.

On the other hand, waterproofing of the video system is another problem for us. Instead of using the screw rod like the main housing, we used the plastic screws which came along with the box, and its waterproof level is not well enough during the regional competition. After series of adjustments, we finally settled on the same design used in the main housing, which is using screw rods on each corner of the box. After that, we have learnt that the waterproofing techniques should be more consistent and reliable.

Non-Technical

During the process of building the ROV, we have not only learned about the techniques of electronic and architecture, but also interpersonal skills.

Time management is the first thing we need to acquire. As a student, we need to handle both schoolwork and after-school activities at the same time. In the past, we spent large number of time on our schoolwork. Therefore, we have shorter time for building the ROV and the efficiency decreased significantly. After several meetings and adjustments, we wrote a schedule board and follow it. Finally, we have learnt how to balance between schoolwork and activities.

Moreover, we have learnt that we need more communication between teammates. We have got team meetings twice a week, and the department leaders would discuss and plan their upcoming schedules. In addition, we have a Facebook group to let us post our questions and progress, so that everybody can know how others are doing. A team cannot be raised up by only one person, so improving the communication between teammates is very important.

Teamwork

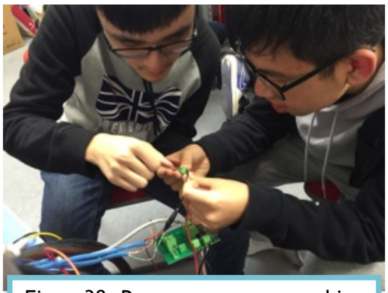


Figure38: Programmers are working together

As a team with 22 members, we have organized our team into two main departments, Structural Department and Electronic Department. Each department has a leader to follow up the progress of each teammates in the department. The two departments focus on different branches of building an ROV, then both teams help to integrate an whole functional ROV. We always worked for two to three hours after school every day. In addition, we would come back to school during the holidays. Meanwhile, all departments have individual group meetings twice a week, which allows the department leaders to monitor the schedules of the team, teammates can also discuss about the current challenges and come up solutions together (Fig.38).

Above all the departments, the CEO has to manage and coordinate the work for the departments, helping the department leaders to deal with their problems and maintain the relationships between members. Apart from the CEO, there are also independent positions such as the CFO and the PRs, the CFO is in charge of managing the financial expenses of the team, such as buying electronic components or expenditures of fieldworks like training and competitions. And the PR is responsible for contacting our sponsors and planning the itinerary of our trips.

Company Reflection

Being one of the few teams in Macau that study marine technologies and ROVs, we realized that participating in this event has really reinforced our knowledge in marine environment as well as the awareness we need to safe it. Besides, throughout the process of building ROVs, we are not only gaining technical skills but also friendships and the sense of being unified. Most importantly, mentors also taught us the attitude to face anything fearlessly and use our knowledge into the things we do.

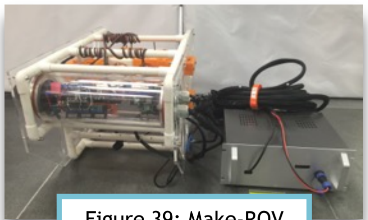


Figure 39: Make-ROV

Instead of simple switch system, we have already built a more functional and humanize ROV, and we have also designed circuit boards and different kinds of tools to optimize the vehicle.

In 2015, in order to have a bigger push on advocating marine protection and encouraging more students to experience the marine environment. We have established a research on protecting the marine environment using ROV. We have built a scalable, low-cost and stable ROV called Make-ROV (Fig.39). It allows people and especially students to do experiments, researches and explore the marine environment. Our aim is to introduce an easier way for people to explore the marine environment and thus understand the importance to protect it.

After overcoming every challenges we have met during each testings and malfunctions, that sense of achievement motivates us to set more challenge for ourselves. Therefore, progress can be made every year and our ROVs become better and better.

With all these years, we have gained more knowledge than other students in this area. By knowing the importance of environment protection and how ROVs contribute to underwater research, we believe that it would be the best for us to advocate the idea. Thus, we will put much more effort to promote our team to the society so as to let them notice the importance of marine protection.

Scheduled ROV Training

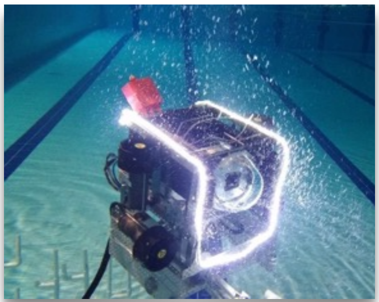


Figure40: Testing the ROV in the swimming pool

In spite of our busy school schedule, our team still managed to schedule a ROV training every weekend. During our ROV trainings (Fig.40), we use our self-made mission props and let our pilots to control the ROV in a simulated area, thus improving their piloting skills and giving us an opportunity to anticipate what problems we may encounter during actual product demonstration. For example, when we were operating the ROV, we found out that the buoyancy we've calculated based on the buoyancy formula does not always meets the actual buoyancy needed, so we have to do minor calibrations every time before the training. Moreover, we also noticed several electronic errors that we usually cannot find it out in normal testings. For instance, the current needed to operate the thrusters in water is much higher than the current needed in air, so that when the ROV operates in water, they drag so much current than usual thus failing the system. After noticing this error, we have a better understanding on considering the electronic issues, and most importantly, we can prevent this problem happen in actual competition. Apart from the scheduled trainings, we also encourage the pilots to play video games and ROV simulator in free time.

Project Management

To make our work more effective, we created a schedule (Fig.41) to contribute our progress rate after the discussion on December. By setting deadline for ourselves, the team can have a better perspective of the time left and would not spend inordinate amounts of time on particular one thing.

Figure 41:Schedule

Task Name / Month	December				January				February				March				April				May				June	
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Understanding Missions	■																									
Discussion	■																		■							
ROV Design		■																								
Frame			■																							
Mission Tools				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Control System						■	■	■	■	■	■	■	■													
Video System							■	■	■	■																
Tether														■												
Programme										■																
Testing															■	■	■	■			■	■	■	■	■	
Technicle Report																						■	■			
Marketing Display																								■		
Presentation																									■	■

Future Improvements

After finish building trident, we decided that few improvements on our rov are needed in the future. Although this year we have already implement the plan of making our own PCBs, the programming aspect is still in the vacuum. Our current system is an open loop system, which means we give the commands and runs it, no feedbacks and no algorithms to adjust the output. If we build up the system to a closed loop system, we would enhance the ROV's stability by programming in some controls such as PID control. With the PID, we could get the ROV's status such as angular positions and tilting degrees by a gyroscope, then readjust it through the PID control.

On the other hand, we will try to simplify the way of rotating the manipulator since the recent one is too complicated to complete this action. Moreover, more driving method of the manipulator would be attempted in the future, such as using waterproofed servo motors instead of D.C. motors and gear sets.

Budget

When estimating our budget, there are three main criteria:

- First, we disassembled previous ROVs, gathered all components and reuse the ones will good conditions, so we can know which new components we will need to buy this year.
- Then, we used previous financial reports as reference and predict the cost we may spend.
- Lastly, we used SolidWorks to make a sketch of the ROV, and we can predict how many materials will be needed in a rather precise way. Moreover, it can prevent us from wasting materials due to falsely estimated designs.

Thus, we've gathered all reused components and projected to use only 611.04 USD for buying new components this year. For travel expenses, we've estimated to spend 70,000 USD for 25 people on a 7 days trip to Houston. Adding the expectation on new components fees and travel expenses, we have a total budget of 70,611.04 USD (Fig.42).

After we've got our budget, we started to write proposals to our sponsors. Our sponsors include Pui Ching Middle School, Macau Foundation, the Education and Juvenile Bureau, Macau Science Development Foundation. In our proposals, we included the budget, our previous achievements such as taking part in several international competitions and holding public ROV workshops. Thanks for the high appreciation from our sponsors, we are able to raise 56,000 USD for travel expenses and 620 USD for components from the school, which is 56,620 USD sponsored in total. The budget we have calculated is 70,611.04 USD.

Figure 42: Budget Sheet

Installation Position	Category	Resource Name	New Purchased [piece(s)/bottle(s)]	Total Amount [piece(s)/bottle(s)]	Expense per Each (USD)	Total Expense (USD)
Underwater	Housing	Carbon Fibre Sheets	3(sets)	3(sets)	103	309
Underwater	Housing	O-ring	1(pack)	1(pack)	1.33	1.33
Underwater	Housing	Acrylic Cylinder	1	1	11.51	11.51
Cable	Housing	Optical Fibre 15m	2	2	3.1	3.1
Underwater	Control System	Printed Circuit Board	10	10	12.83	128.3
Onboard	Control System	Joy Stick	2	2	7.68	15.36
Onboard,Underwater	Control System	Video Audio Data Converter	2	2	13.3	26.6
Cable	Control System	Optical Fibre 1m	1	1	0.62	0.62
Underwater	Camera	Mini Surveillance Camera	3	3	6.45	19.35
Underwater	Manipulator	Putter	1	1	36.87	36.87
Underwater	Manipulator	Putter Bracket	1	1	1.08	1.08
Underwater	Manipulator	Flange Bearings	3	3	1.15	1.15
Underwater	Manipulator	Copper Worm Gear Set	2	2	5.99	11.98
Underwater	Mission Props	Pressure Transmitter Sensor	1	1	44.79	44.79
Budget:	Travel Estismated:	Total Budget:				
611.04	70,000	70,611.04				

Our final financial report(Fig.43) includes the cost for new purchased components and travel expense, the components fees is 698.63 USD, which is 78.93 USD higher than our budget. Adding the cost of reused components (3,757.05 USD), the total cost of the ROV is 4455.68USD. Also, due to the unpredictable and fluctuated air tickets and hotel prices, the travel expense added up to 71,575 USD, which adds the total expenses to 72,273.63 USD. Therefore, each teammates have to give 626.15 USD, which is mainly filling up for the travel expenses. (Detailed financial report is attached in Appendix 5)

We are thrilled that we could gather reused components worth of 3,757.05 USD and successfully reduced this year's building fee to only 698.63 USD.

Income Source	Total (USD)	Expense	Total (USD)
School (Components fees)	620	New Purchased Components	698.63
Other sponsors	56,000	Travel Expense	71,575
Team members (Including 22 students and 3 mentors)	15,653.63		
Total Income	72,273.63	Total Expense	72,273.63
		Balance	0

Figure 43: Financial report

Acknowledgement

Our ROV Team would like to thanks (In no particular order):

- MATE Center: Thank you for holding the competition
- SoildWorks: Thank you for offering this software.
- Monetary Donations (Macau foundation, DSEJ of Macau, FDCT of Macau): Thank you for sponsoring our travel fee.
- Macau Pui Ching Middle School: Thank you for the money support for building our ROV.
- IET HK and MATE Hong Kong: Thank for holding the Regional MATE Competition

Dr. Robin Bradbeer:

Help us to join the ROV competition.

Thomas Lao and his lovely family:

Thank you for giving us opinions, the support from the spirit and giving up his time after school.

Derek Leong & Chongman Leong:

Thank you for spending such a long time on teaching so much valuable technique for us.

Our families:

Thank you for supporting, encouraging and allowing us to study on what we doing.

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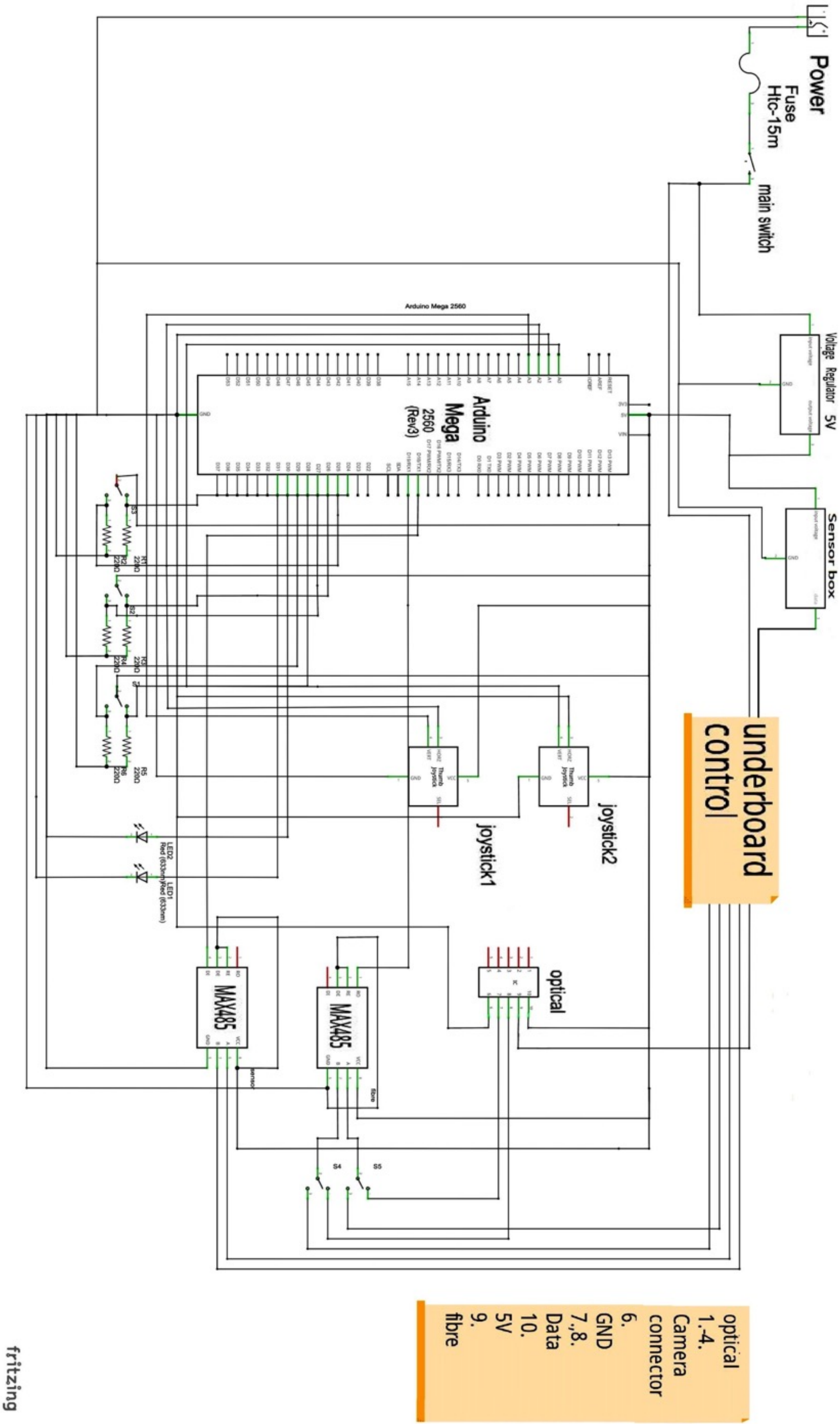
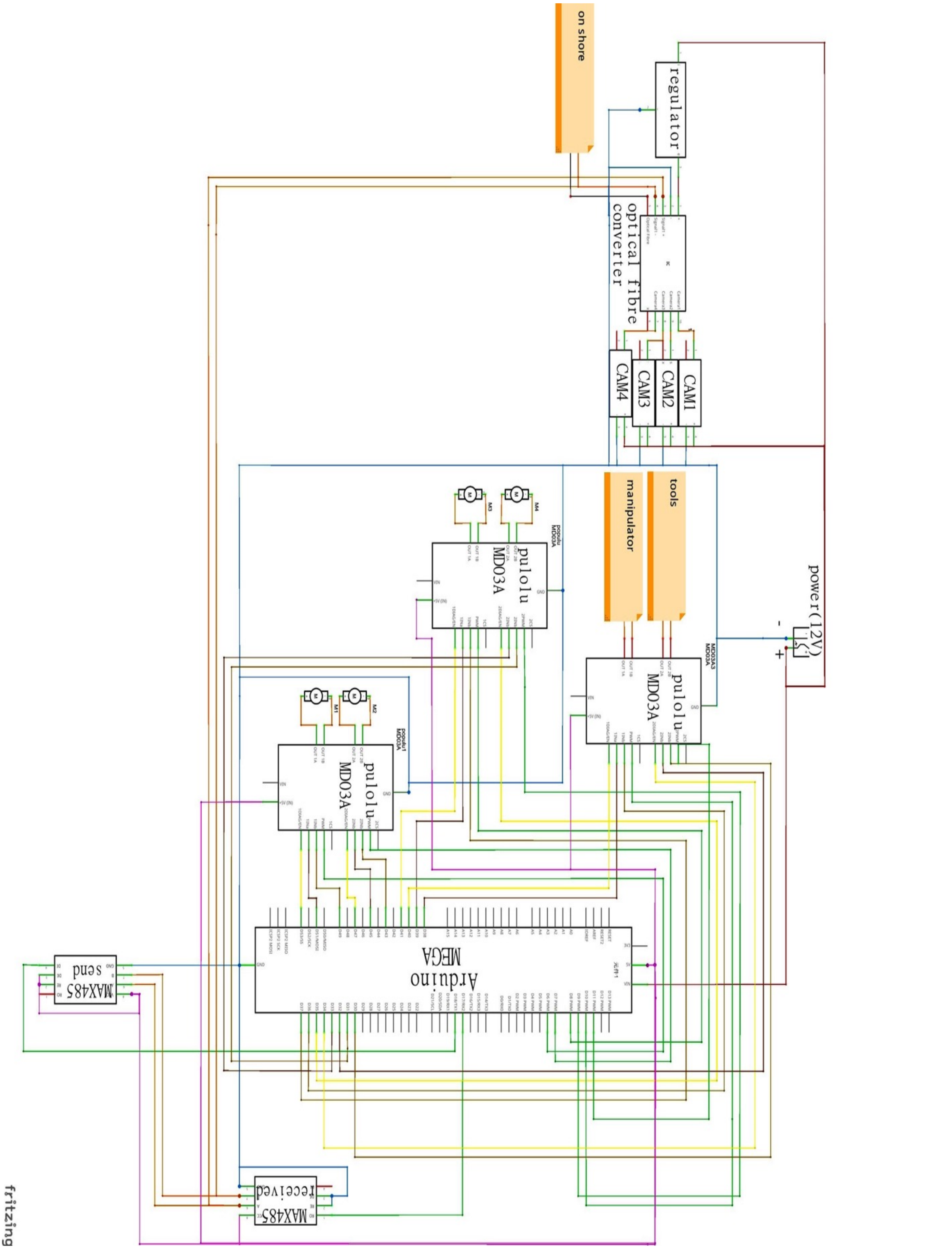
Appendix

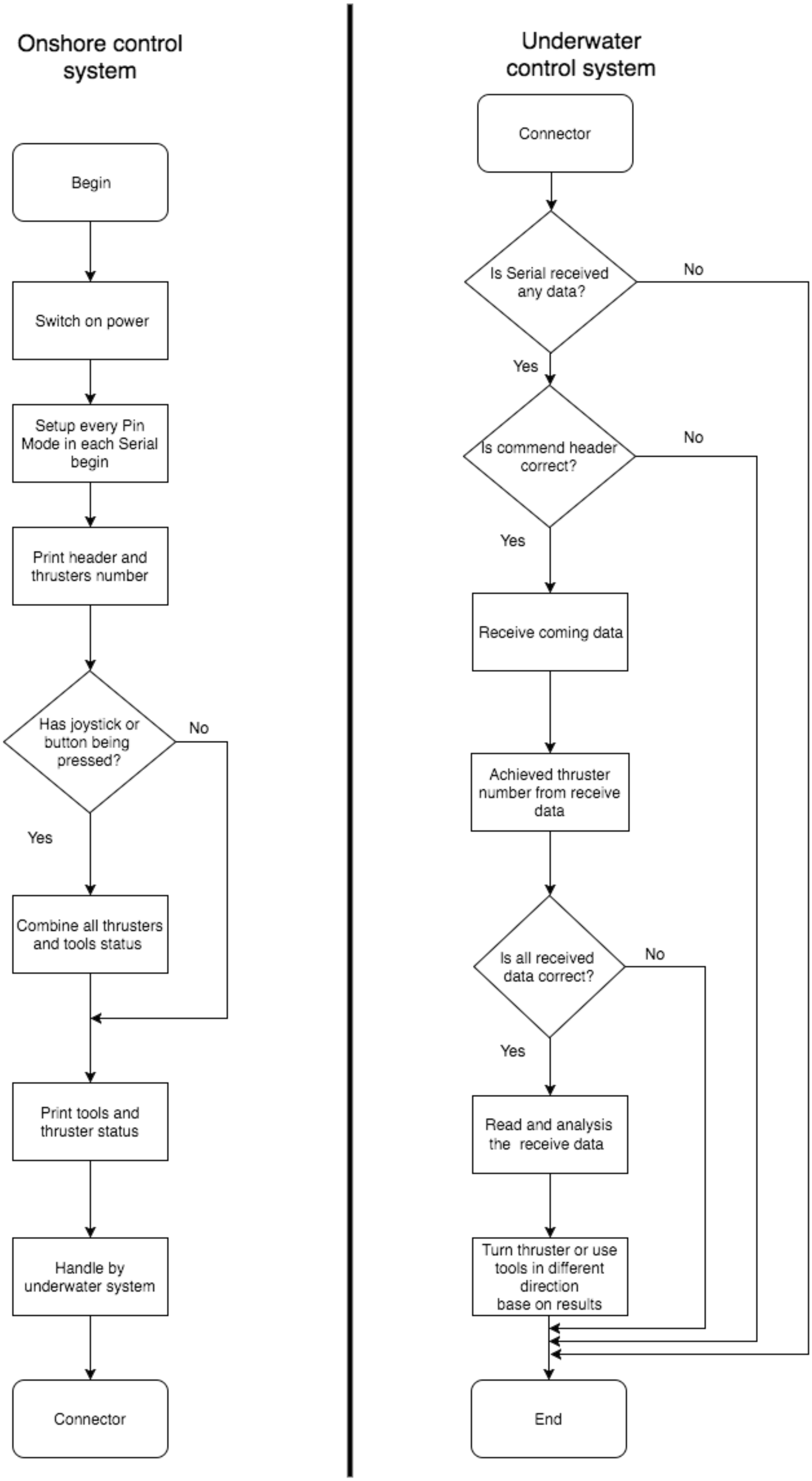
Appendix1: Onshore Control System



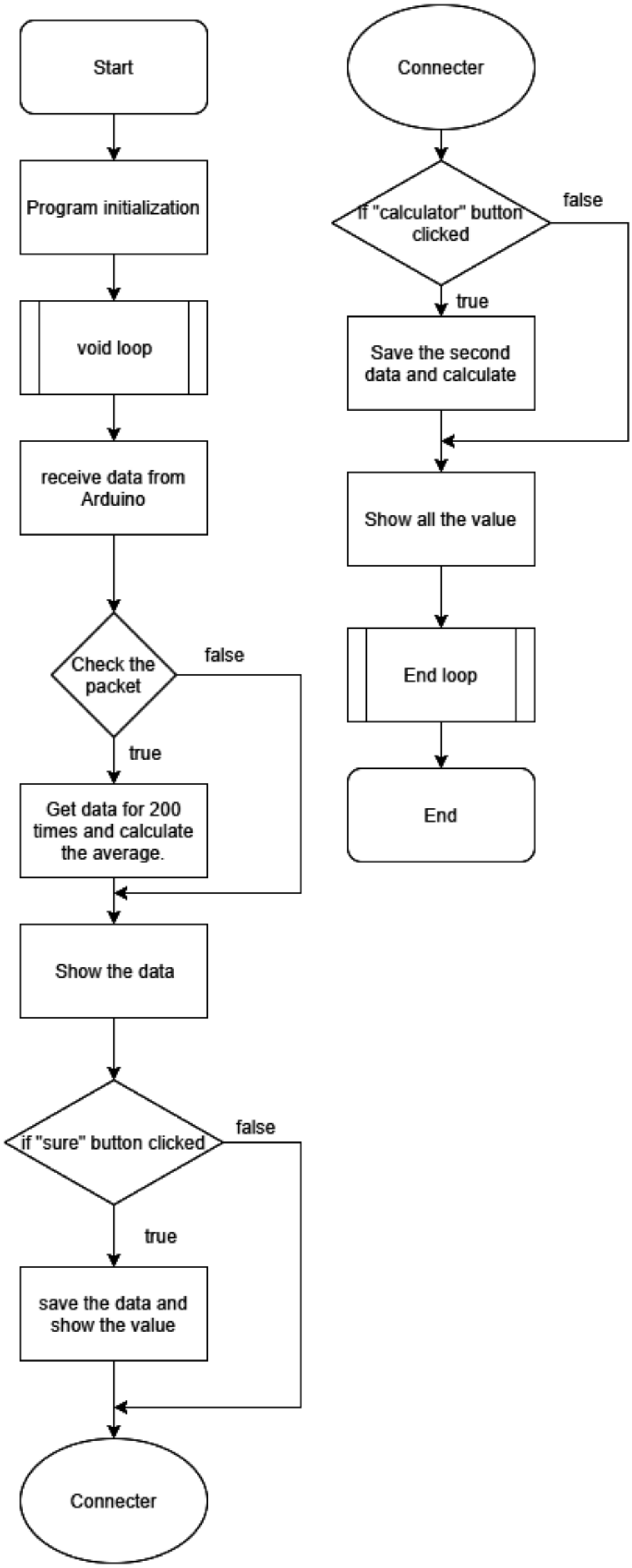
Appendix2: Underwater Control System



Appendix3: Program Flowchart



Appendix4: Software Processing Flowchart



Appendix5: Financial Report

Category	Resource Name	Reuse	New	Donated	Total Amount	time of purchase	Expense per Each (USD)	Total Expense (USD)
Structure	Seabotix Thruster	4	0	Reused	4	Oct,2015	800.00	3,200.00
Structure	2mm * 3mm pneumatic hose pipe	0	15(m)	Self-purchased	15(m)	Oct,2016	0.16	2.42
Structure	VEX Aluminum Bar	1(pack)	0	Donated	1(pack)	Sep,2014	29.99	29.99
Structure	VEX Aluminum C Channel 1x2x1x35	1(pack)	0	Donated	2(pack)	Sep,2014	34.99	69.98
Structure	VEX Aluminum Angle 2x2x35	1(pack)	0	Donated	1(pack)	Sep,2014	17.99	17.99
Structure	Nut 8-32 Nylock	1(pack)	0	Donated	1(pack)	Sep,2014	3.99	3.99
Structure	Screw 8-32 x0.250"	1(pack)	0	Donated	1(pack)	Sep,2014	7.49	7.49
Structure	Nylon Cable Tie	0	3(packs)	Self-purchased	3(packs)	Sep.2015	0.52	1.55
Structure	Hexagon Tip Set Screws	1(pack)	0	Reused	1(pack)	Sep.2016	0.97	0.97
Structure	Araldite Epoxy Adhesive (5mins)	0	3(packs)	Self-purchased	3(packs)	Oct,2015	1.45	4.36
Structure	Safety Nut(M3,M4,M5)	0	3(packs)	Self-purchased	3(packs)	May,2016	2.08	6.25
Structure	Acrylic Sheets	2	0	Self-purchased	2	Mar,2014	0.48	0.97
Structure	Screw Rod	0	1(pack)	Self-purchased	1(pack)	Jan,2016	1.05	1.05
Structure	Metal Mount	0	4	Self-purchased	4	Nov,2015	1.52	1.52
Structure	Light	1	0	Reused	1	Jan,2015	0.45	0.45
Structure,Housing	Carbon Fibre Sheets	0	3(sets)	Self-purchased	3(sets)	Feb,2016	103	309
Housing	Cable Gland PG7	0	1(pack)	Self-purchased	1(pack)	Nov,2015	2.46	2.46
Housing	O-ring	0	1(pack)	Self-purchased	1(pack)	Feb,2016	1.33	1.33
Housing	Acrylic Cylinder	0	1	Self-purchased	1	Jan,2016	11.51	11.51
Housing	Waterproof Cable Connector VL19A 3 core	10	0	Reused	10	Sep,2013	0.49	4.9
Housing	Waterproof Cable Connector VL19A 5 core	10	0	Reused	10	Sep,2013	0.72	7.2
Housing	Waterproof Cable Connector VL19A 4 core	10	0	Reused	10	Sep,2013	0.61	0.61
Housing	Round insulation terminal	16	0	Reused	16	Sep,2013	0.03	0.48
Housing,Tether	Optical Fibre 15m	0	2	Self-purchased	2	Nov,2015	3.1	3.1
Housing,Control System	Multi-core Wire (red and black)	4(packs)	0	Reused	4(packs)	Sep,2013	16.14	64.56
Control System	Printed Circuit Board	0	10	Self-purchased	10	Feb,2016	12.83	128.3
Control System	Arduino Mega	2	0	Reused	2	Mar,2014	6.29	12.58
Control System	Arduino Sensor Shield v5.0	1	0	Reused	1	Mar,2014	1.37	1.37
Control System	Pololu Dual VNH5019 Motor Driver Shield for Arduino	3	0	Reused	3	Oct,2015	49.95	149.85
Control System	Waterproof Metal Joints	0	8	Self-purchased	8	Feb,2016	0.31	2.47
Control System	Valve	0	1	Self-purchased	1	Feb,2016	3.09	3.09
Control System	DINKLE Pluggable Terminal 4P 5.08mm	7	0	Reused	7	Sep,2013	0.39	2.73
Control System	DINKLE Pluggable Terminal 2P 5.08mm	3	0	Reused	3	Sep,2013	0.07	0.21
Control System	MAX485	4	0	Reused	4	Sep,2013	0.36	1.08
Control System	15A Fuse	1	0	Reused	1	Sep,2013	0,02	0.02
Control System	Arduino LCD Monitor	1	0	Reused	1	Sep,2013	7.42	7.42
Control System	Rocker Switch 16A 250V 31x25mm	1	0	Reused	1	Sep,2013	0.12	0.12
Control System	Rocker Switch 16A 250V 31x14mm	5	0	Reused	5	Sep,2013	0.14	0.7
Control System	Joy Stick	0	2	Self-purchased	2	Mar,2016	7.68	15.36
Control System	Waterproof Air Plug & Socket 2 Core SP21	0	2	Self-purchased	2	Feb,2016	2.4	4.8
Control System	Waterproof Air Plug & Socket 2 Core SP12	0	1	Self-purchased	1	Feb,2016	2.4	2.4
Control System	Video Audio Data Converter	0	2	Self-purchased	2	Oct,2015	13.3	26.6
Control System	Optical Fibre 1m	0	1	Self-purchased	1	Nov,2015	0.62	0.62
Tether	30mm Nylon Webmaster	1	0	Reused	1	Sep,2013	1.95	1.95
Buoyancy	High Density Styrofoam	1	0	Donated	1	Feb,2015	N/A	N/A
Buoyancy	Carbon Fibre Reinforced Polymer	2(m)	0	Reused	2(m)	Nov,2014	16.13 (per/m)	32.26
Buoyancy	Dupont Kevlar fabric	1(m)	0	Reused	1(m)	Nov,2014	28.55 (per/m)	28.55
Buoyancy	Black Bright Type Pouring Sealant (include group A: epoxy and group B:curing agent)	2(packs)	0	Reused	2(packs)	Nov,2014	14.19	28.38
Buoyancy	Toughening Agent (Dibutyl Phthalate)	1(kg)	0	Reused	1(kg)	Nov,2014	9.19	9.19
Buoyancy	Reactive Diluent (4-butanediol Diglycidyl Ether)	2	0	Reused	2	Nov,2014	1.13	2.26
Buoyancy	Coupling Agents(Ð£ - aminopropyltriethoxy Silane)	1	0	Reused	1	Nov,2014	4.03	4.03
Buoyancy	Protective Polishing Agent	1	0	Reused	1	Nov,2014	8.71	8.71
Buoyancy	Antioxidants	1	0	Reused	1	Nov,2014	6.94	6.94
Camera	Mini Surveillance Camera	4	0	Reused	4	Nov,2015	6.45	25.8
Manipulator	Putter	1	0	Reused	1	Feb,2016	36.87	36.87
Manipulator	Putter Bracket	1	0	Reused	1	Feb,2016	1.08	1.08
Manipulator	Flange Bearings	3	0	Reused	3	Feb,2016	1.15	1.15
Manipulator	Copper Worm Gear Set	2	0	Reused	2	Feb,2016	5.99	11.98
Manipulator	Slip Ring (4 wires)	0	2	Self-purchased	2	May,2016	3.83	7.65
Mission Props	Rivet	1(pack)	0	Reused	1(pack)	Nov,2014	3.03	3.03
Mission Props	Magnet	0	8	Self-purchased	8	May,2016	2.75	2,75
Mission Props	Screws, Screw Nut	1(pack)	0	Reused	1(pack)	Sep,2013	4.84	4.84
Mission Props	Pressure Transmitter Sensor	0	1	Self-purchased	1	Feb,2016	44.79	44.79
Safety	Safety Spectacles	25	0	Reused	25	Sep,2013	2.9	72.5
Travel Expense	Ferry Tickets	N/A	N/A	Donated	25	May,2016	43	1075
Travel Expense	Air Tickets	N/A	N/A	Donated	25	May,2016	1350	33750
Travel Expense	Hotels	N/A	N/A	Donated	25	May,2016	210(per night)	36750

Travel expense: **71,575** Expense of Reuse: **3757.05** Expense of New Purchased: **698.63** Total Expense: **75,845.68**