2016 MATE international ROV competition

RANGER Class

AQUA Discovery

EGYPT, Menofia
SHEBIN EL -KOM
IDEL SCHOOL

OPERA ROV

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Omar Shiref Kebaly (new)
Ahmed Amir El Sakhawy (new)
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Table of Contents

Table of Figures

1. Abstract

OPERA is a remotely operated underwater vehicle (ROV), designed by AQUA Discovery Company as a deliverable for the 2016 MATE International ROV competition , NASA and Oceaneering Space Systems (OSS), to perform tasks relevant to ROV operations in the harsh environments of both the deep ocean and outer space, while maximizing safety, reliability, serviceability and cost effectiveness.

OPERA is designed to be able to Survive transport to Jupiter's moon Europa and operate in the ocean under its ice sheet to collect data and deploy instrumentation, Find and recover critical equipment, Collect samples and analyze data from oil mats, Photograph and collect samples of deep-water corals and Prepare a wellhead for decommission and conversion into an artificial reef.

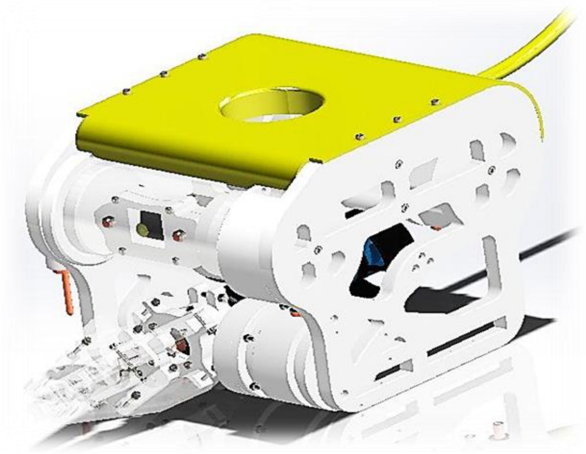


Figure 1 : OPERA ROV CAD DRAWING

Two waterproof 4 inch acrylic Canisters contain the ROV's electronics. The ROV integrates three Blue Robotics T100 thrusters with blueESC, two HD 720 pixel wide screen cameras, 2 DOF manipulator with four claw gripper and incorporated main payload tools to accomplish the challenging mission tasks set by the MATE Center.

By 20 m tether cable Rov is connected to the station and the pilot control it by a joystick.

Major innovations were the using of T100 thrusters for maximum efficiency, developing the four claw gripper and using advanced vision system using HD cameras.

During this process, company members learned essential technical skills and utilized "outside-the-box" brainstorming techniques to ensure a quality end product.

The design and fabrication of OPERA cost nearly 1602. $

Figure 2 : AQUA Discovery Company

2. Mission Strategy and Technical Requirements

OPERA is designed to conduct the mission tasks as specified in NASA and Oceaneering Space Systems (OSS) request for proposals (RFP), while maximizing safety, reliability, serviceability and cost effectiveness. AQUA Discovery managed to create a contemplative strategy for completing the missions as fast as possible in the order mentioned in MATE competition manual.

These mission tasks include:

TASK #1: OUTER SPACE - MISSION TO EUROPA: Measure the temperature of water emerging from a vent; determine the thickness of the ice and depth of the ocean; and connect an Environmental Sample Processor (ESP) to a power and communications hub.

TASK #2: INNER SPACE - MISSION-CRITICAL EQUIPMENT RECOVERY: Use serial numbers to identify mission-critical equipment and transport the equipment to a collection basket for later recovery.

TASK #3: INNER SPACE - FORENSIC FINGERPRINTING: Collect two samples of oil from the sea floor, return the samples to the surface, and analyze gas chromatographs to determine the samples' origin.

TASK #4: INNER SPACE - DEEPWATER CORAL STUDY: Take still photographs of two coral colonies and evaluate those photographs to determine whether the coral colonies are growing, stable, or decreasing in size. Collect two samples of another coral species and return the samples to the surface.

TASK #5: INNER SPACE - RIGS TO REEFS: Attach a flange to the top of a decommissioned wellhead, install a wellhead cap to the top of the flange, and secure both the flange and the wellhead cap with bolts.

AQUA Discovery takes into account Main technical and performance requirements for OPERA to conduct these tasks as needed and completes it as fast as possible; these requirements involve small size, maneuverability, stability, durability and velocity. And make the payload tools suitable for these tasks.

3. Step-By-Step Development and Design Process

Designing an ROV requires lots of time, a good knowledge of robotics, high financial spending and, of course, a solid team of workers with their endless flow of ideas as we face many challenges such Keep Eye on the Mission, Use the Design Spiral, Being Proactive about Project Planning, Management, and Safety. The development process was done in several consecutive steps:

1. Identifying the Mission Tasks.
2. Establishing Technical and Performance Requirements.
3. Identifying Constraints.
4. Listing Vehicle Systems.
5. Generating the Concept Design.
6. Design (thrusters, pressure hulls)
7. Software development.
8. Development and testing of auxiliary tools.
9. Assembly of the ROV.
10. Testing and troubleshooting of all systems.
11. Aesthetic decoration and design.

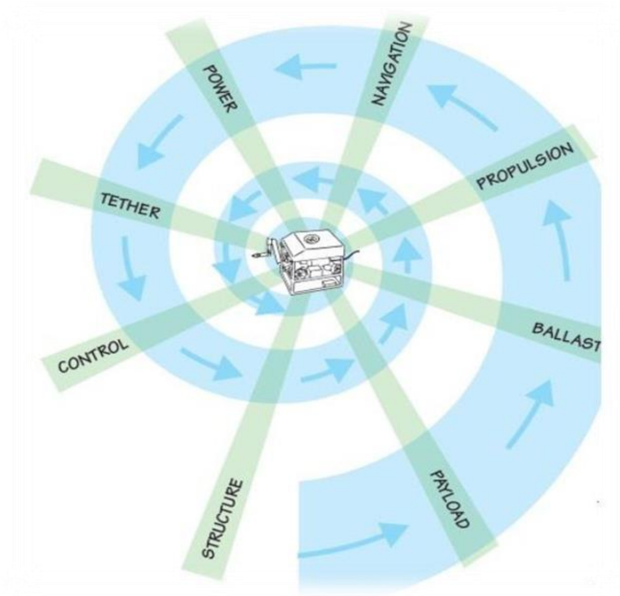


Figure 3: Design Spiral

4. Management Triangle

AQUA Discovery believe in that good project management result into success work so, we focused in our company to carefully utilize available resources include money, time to successfully build full functionality Rov with acceptable quality.

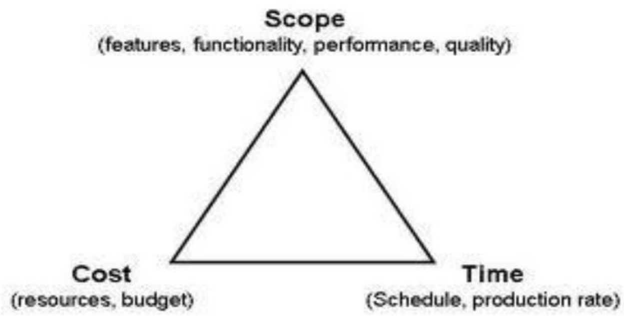


Figure 4: Management Triangle

4.1 Budget Sheet:

Company Name: AQUA Discovery
Reporting period: 05.10.2015 – 20.03.2016
School name: IDEL School
Supervisor: Dr. Eman Shedeed

- **All Items are purchased.**

Electrical
Electronics
Mechanical
sensors
General
Cables

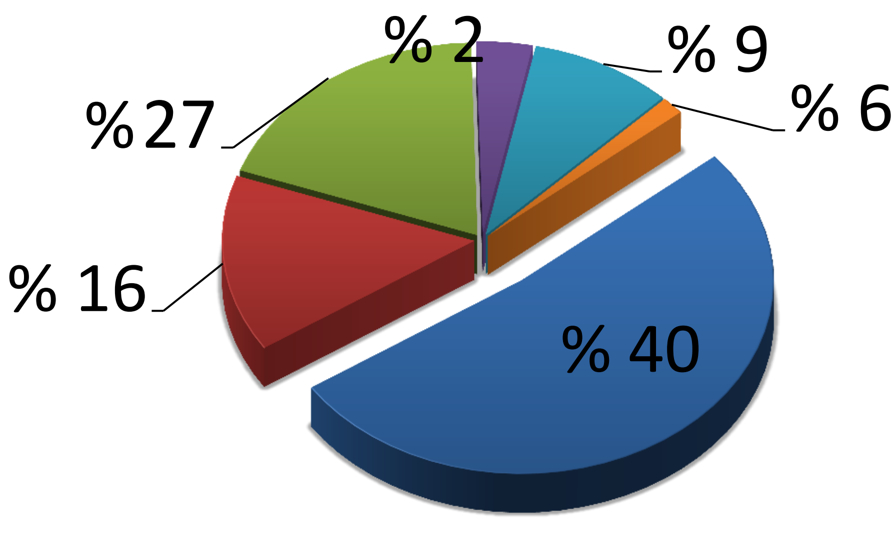


Figure 5: Budget Illustration

Category	Item	Number	Cost
Electrical	12v-5v Dc-Dc-Converter 10 watt	1	35
	12v-7v Dc-Dc-Converter 10 watt	1	35
	12 v power supply	1	250
	Electrical Equipment’s	---	680
	T100 Thrusters with BlueESC	3	7000
	Blige pump motor	1	500
	40 kg.cm Servo motor	1	500
Electrical Category Total Cost			9000 LE
Electronics	Arduino NANO	1	160
	Video Balun	2	70
	HD CCTV Camera	2	500
	Electronics Components	---	1400
	LCD Screen	1	450
Electronics Category Total Cost			2580 LE
Cables	CAT5E Cable	20 meter	60
	Tether Cable 6 mmX2 for power	20 meter	200
Cables Category Total Cost			260 LE
Mechanical	Materials (Acrylic + Polyethylene +…)	---	1470
	Lathing Work	---	950
	Laser Cutting	---	200
	CNC Router work	---	700
Mechanical Category Total Cost			3320 LE
Sensors	Laser	2	88
	Water Pressure Sensor	1	540
Sensors Category Total Cost			628 LE
General	Transportation	---	1000
	T-Shirts	---	600
General Category Total Cost			1600 LE
TOTAL COST : 17388 LE , 1602.60 $			

Figure 6: Budget Sheet

4.2 Time Management:

Checkpoint											Dry Test			first Wet test
time line	5-Oct	5-Nov	8-Nov	13-Nov	20-Nov	25-Nov	27-Nov	2-Dec	4-Dec	18-Dec	1-Jan	8-Jan	15-Jan	5-Feb
workshop														
frame			design				build				done			
electronics			design				build				done			
isolation system						design				build		done		
cameras							design	build		done				
software			design						build		done			
SCU								design	build		done			
bouyancy												design	build	done
testing and troubleshooting											testing and troubleshooting			

Figure 7: Development Timeline

5. Design Rationale

5.1 Mechanical :

5.1.1 Frame :

The main feature of OPERA that it has a modular structure, with separate units. Each unit can be easily removed from the main frame for repair and maintenance, provides Easy handling of ROV. Also it provides compact shape, low pressure, steady streamline water flow and high stability features. Design of dimensions 0.30 m x 0.28 m x 0.27 m was built using polyethylene, which has proven its efficiency, as well as, it is Low cost, readily available, excellent corrosion resistance, Ease of machining and fabrication, and Moderate strength-to-weight ratio.

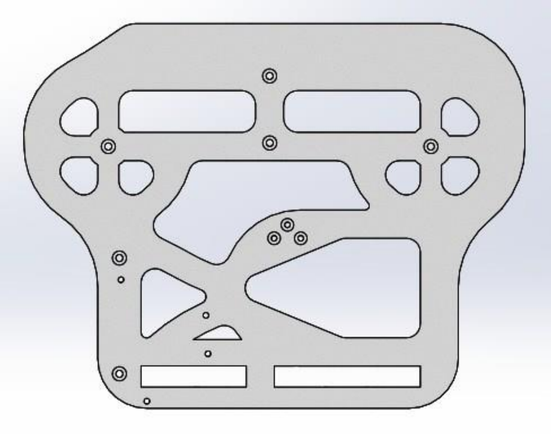
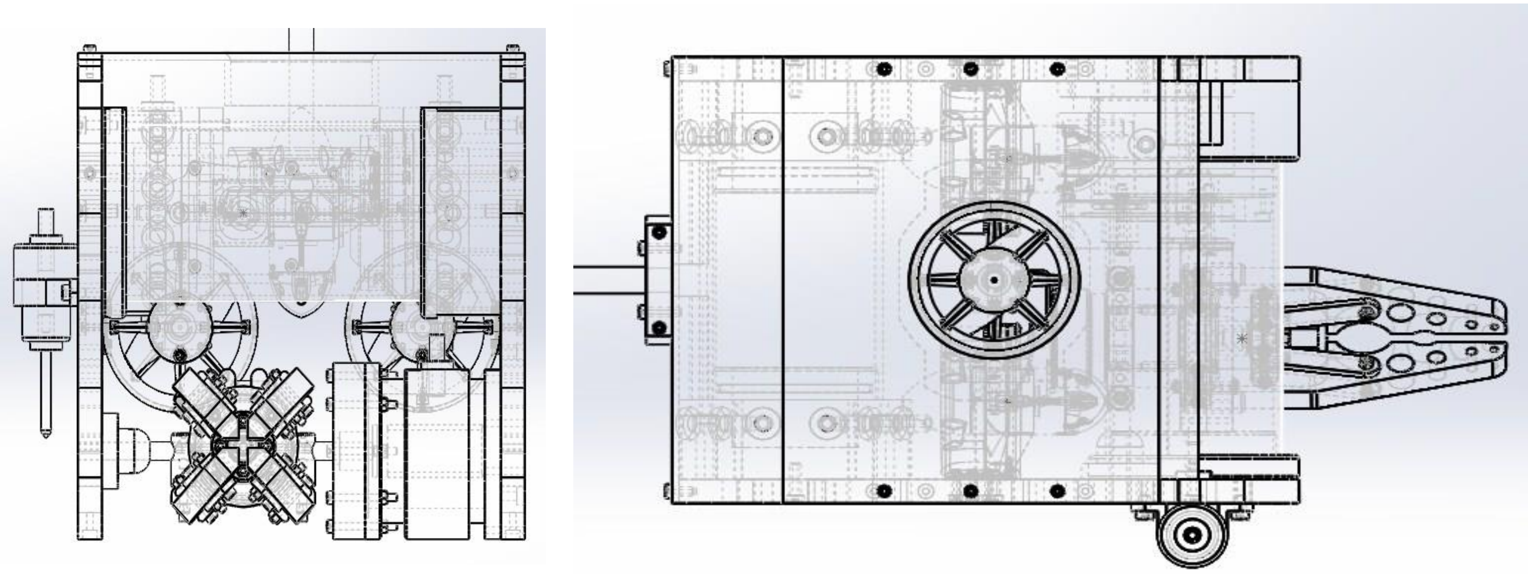


Figure 3: ROV Frame

OPERA's frame is composed of 2 identical horizontal plates. All Rov components (thrusters, waterproof canisters, payload tools, and manipulator) secured and attached to these plates. This design makes ROV more configurable with the possibility of attaching extra devices to it.

Stress analysis on the frame was done to see points of maximum stress and ensure safe design. (Using SOLIDWORKS)



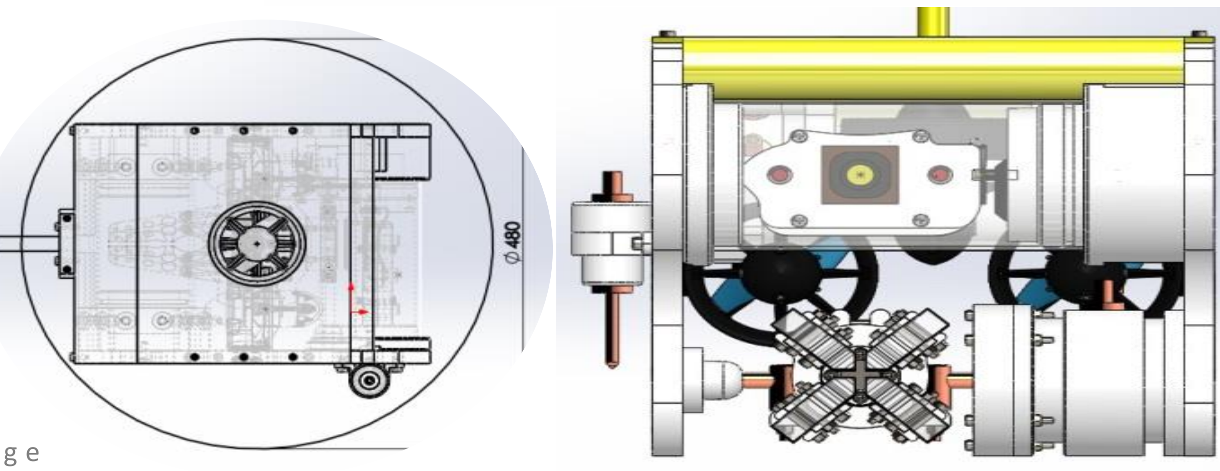


Figure 9: ROV Design

5.1.2 Electronics Canisters :

OPERA design involves two optically clear acrylic cylinders of an inner diameter 0.094 m and thickness 0.003 m. The electronic cans are used to enclose all the electrical system of ROV.

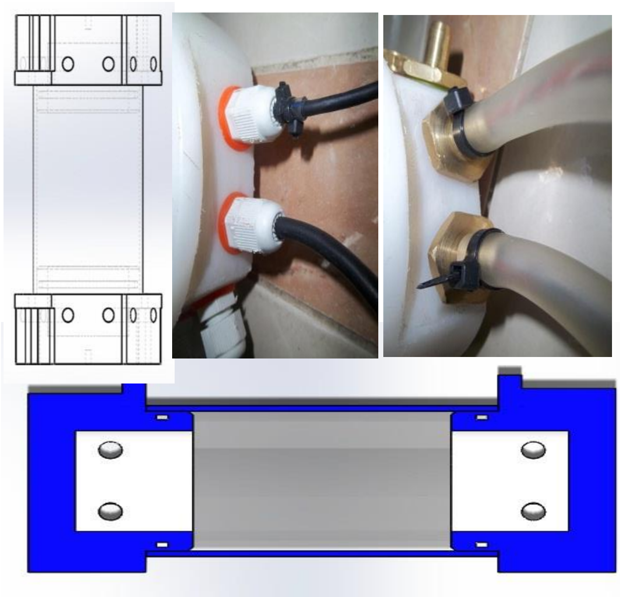


Figure 10: Electronics Canister & End Cap section view

Acrylic has proven to be a very suitable material, due to its various purposes:

1. Strong, lightweight, and more resistant to impact than glass.
2. Highly weather and chemical-resistant.
3. Can be used for canisters for 100 meters deep in water.

The cans are tightly closed with 2 polyethylene end caps of diameter 0.12 m and thickness 0.05 m. Each cap has single O-rings incorporated in it, sustaining complete sealing.

For sealing the cables, we used nozzles and hoses system used in gaseous application. This idea was so effective and used for sealing the cables of the whole ROV except the tether connections and thrusters cables, we use glands for them.

Figure 11: Nozzel

Stress analysis on the canister was done for pressure of 5 bar to see points of maximum stress and ensure safe design. (Using SOLIDWORKS)

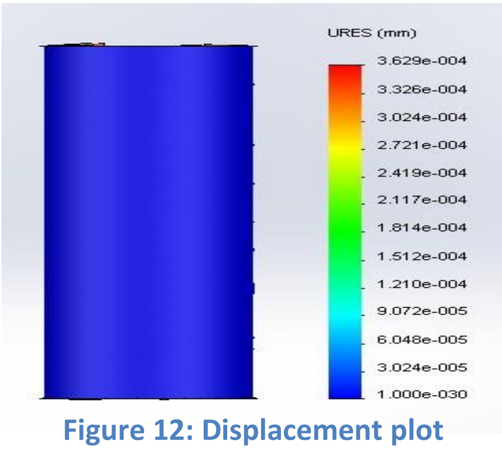


Figure 12: Displacement plot for the canister

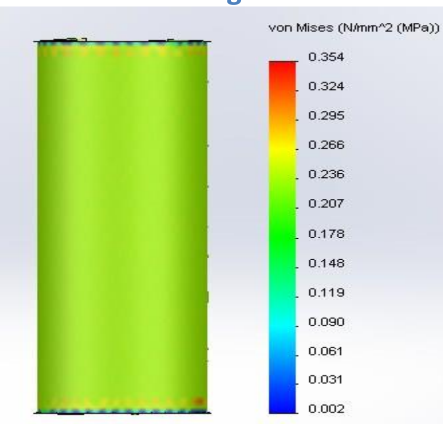


Figure 13: Stress plot for the canister

5.1.3 Buoyancy and ballast system

Buoyancy unit which made of Foam is fastened on the frame along with other equipment. This unit balances the ROV. Its geometry was calculated by solidworks then tested by real experiment to provide neutral buoyancy of whole vehicle and absence of any torque about the pitch and roll axis. As a result, the slightly positive buoyancy of OPERA ensures its return to the water surface even in the case of thrusters' failure.

5.1.4 Stability

Stability was a major concern during the design process. AQUA Discovery managed to build a very stable ROV which is essential to conduct missions required. This is maintained through a number of factors as equal distribution of forces which gives very high stability in water, aspect ratio (total mean length of the vehicle versus total mean width of the vehicle).In addition, the distance between the center of buoyancy and center of gravity of the vehicle determines the ROV's stability; as it is a factor of the righting moment. The fourth factor is the tether pull point; the tether pull point is on the same horizontal plane of the horizontal thrusters, which reduces the moment on the body, therefore reducing the turning effect.

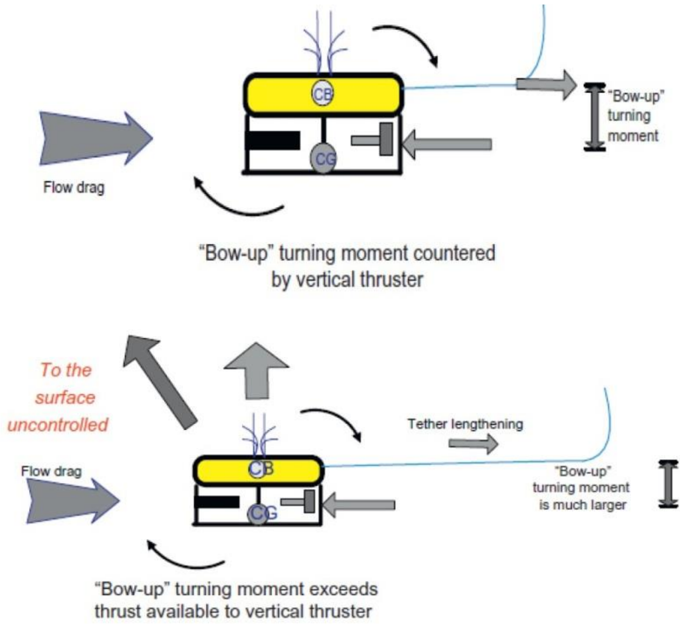


Figure 14: Tether Pull Point

5.1.5 Propulsion

OPERA is driven by three Bluerobotics T100 thrusters with Blue ESC, two for the horizontal movement and one for the vertical movement.

The T100 is basically a brushless electric motor; this motor is purpose-built for use in the ocean and was designed specifically for use on ROVs, AUVs, and robotic surface vehicles.

The T100 is made of high-strength, UV resistant polycarbonate injection molded plastic. The core of the motor is sealed and protected with an epoxy coating and it uses high-performance plastic bearings in place of steel bearings that rust in saltwater. Everything that isn't plastic is either aluminum or high-quality stainless steel that doesn't corrode.

A specially designed propeller and nozzle provides efficient, powerful thrust while active water-cooling keeps the motor cool.

Figure 15: T100 Thruster

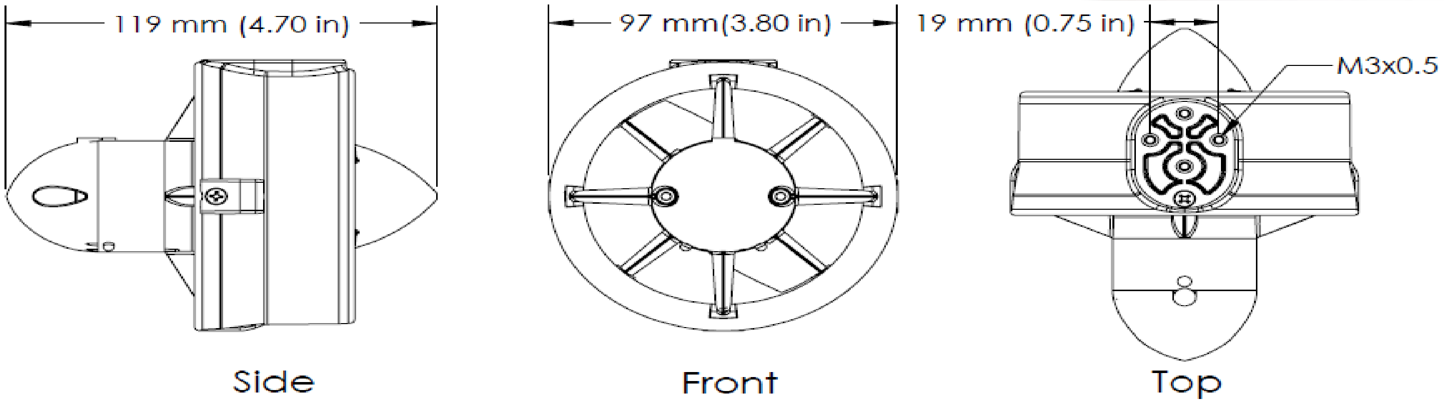


Figure 16: T100 Thruster with Blue ESC Design

T100 Thruster Specification:

Performance		
Maximum Forward Thrust	2.36 kgf	5.2 lbf
Maximum Reverse Thrust	1.85 kgf	4.1 lbf
Minimum Thrust	0.01 kgf	0.02 lbf
Rotational Speed	300-4200 rev/min	
Electrical		
Operating Voltage	6-16 volts	
Max Current	12.5 amps	
Max Power	135 watts	
Phase Resistance	0.24 +/- 0.01 Ohms	
Phase Inductance (@ 1 kHz)	0.120 +/- 0.008 mH	
Physical		
Length (without BlueESC)	102 mm	4.0 in
Length (with BlueESC)	113 mm	4.45 in
Diameter	100 mm	3.9 in
Weight in Air (with 1m cable)(without BlueESC)	0.65 lb	295 g
Weight in Air (with 1m cable)(with BlueESC)	0.84 lb	378 g
Weight in Water (with 1m cable)(without BlueESC)	0.26 lb	120 g
Weight in Water (with 1m cable)(with BlueESC)	0.37 lb	167 g
Propeller Diameter	76 mm	3.0 in
Mounting Hole Threads	M3 x 0.5	
Mounting Hole Spacing	19 mm	0.75 in
Cable Length	1.0 m	39 in
Cable Diameter	6.3 mm	0.25 in

Figure 17: T100 thruster Specification

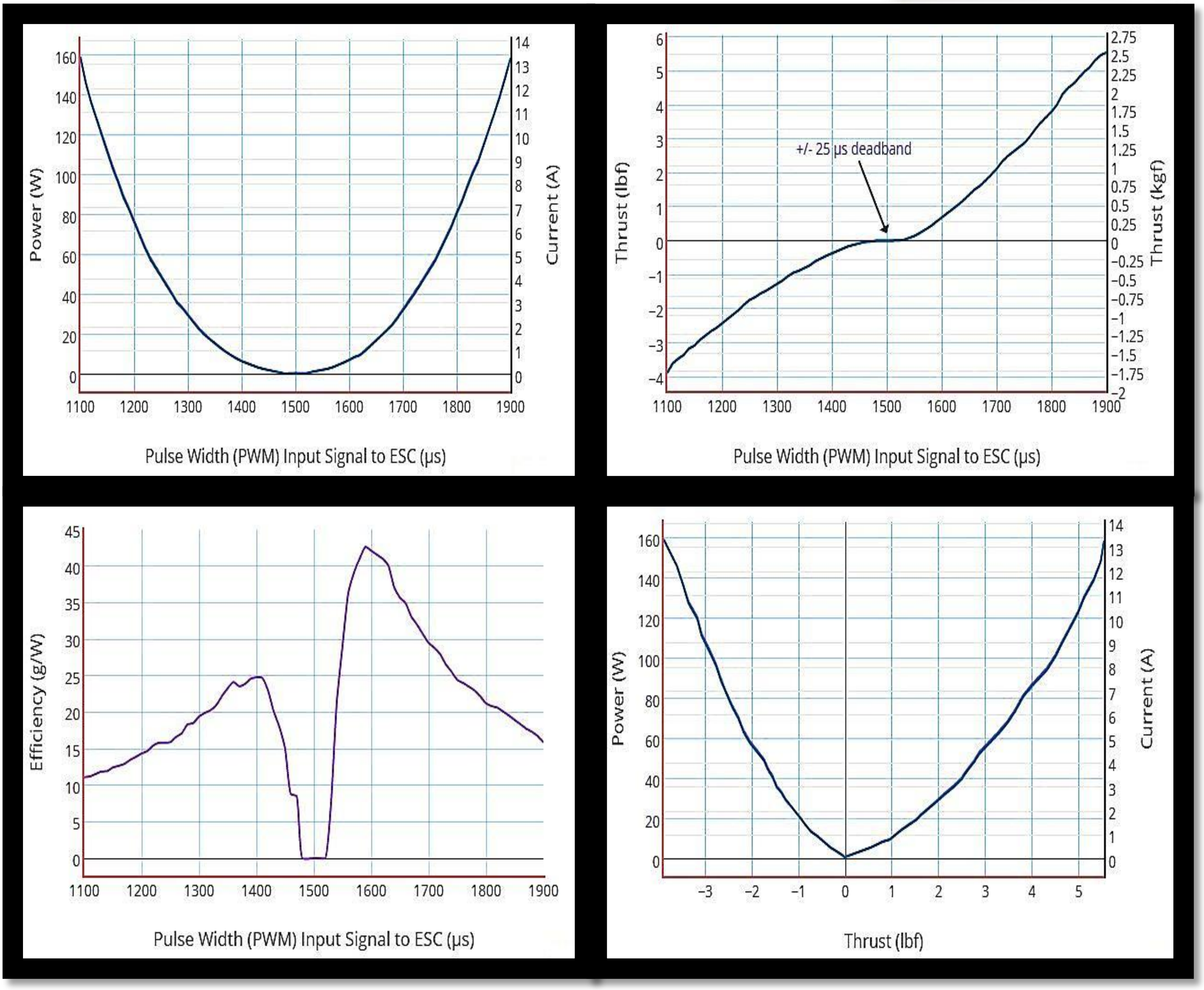


Figure 18: T100 thruster Performance Charts

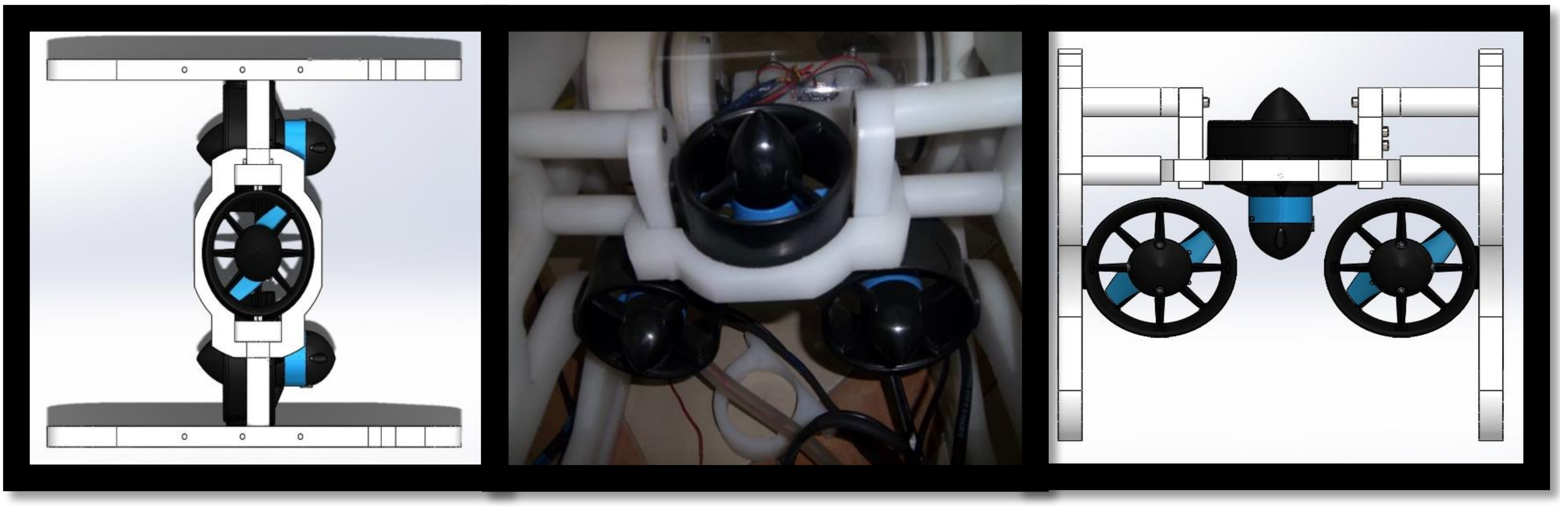
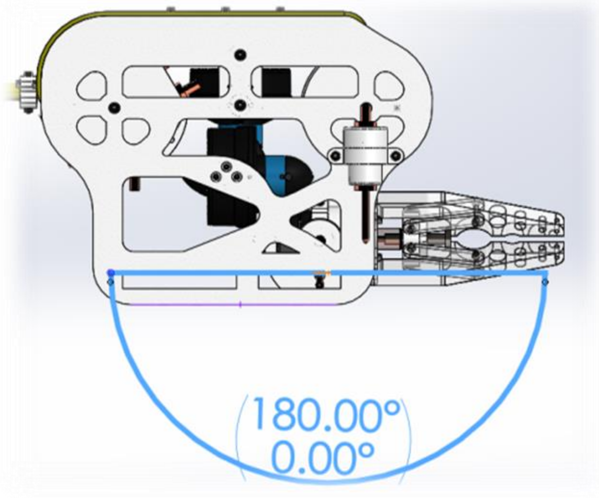
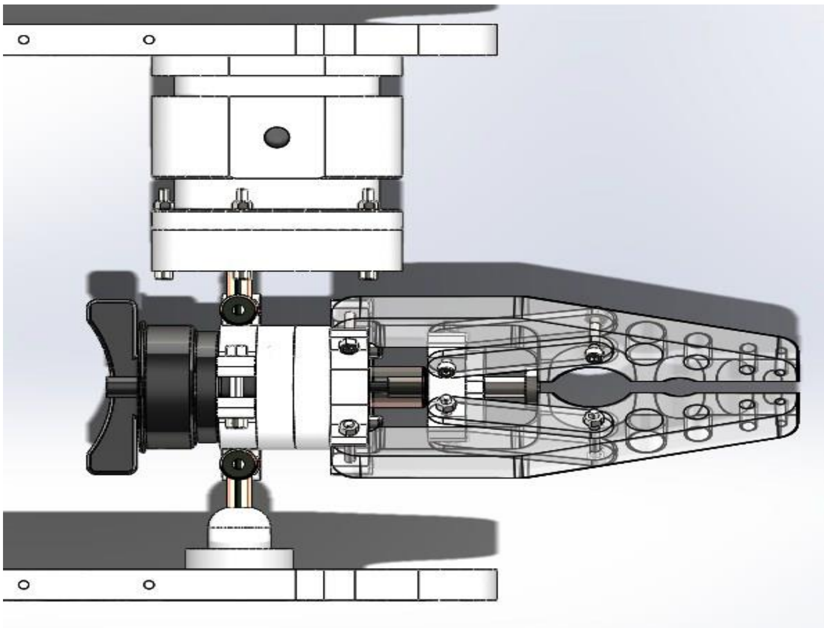


Figure 19: Thrusters Configuration

5.1.6 Manipulator

OPERA is equipped with 2DOF manipulator with electromechanical Gripper driven by power screw mechanism. This gripper has a modular design with four corrugated fingers made of Polyethylene with opening of 0.10m in both X, Y axis that allow gripper to handle small objects, also has the ability of holding larger objects. The gripper is powered by 12 v bilge pump motor. The gripper is needed for performing mission tasks as a multi-functional device. Servo motor is used to rotate the gripper for 180 degree.





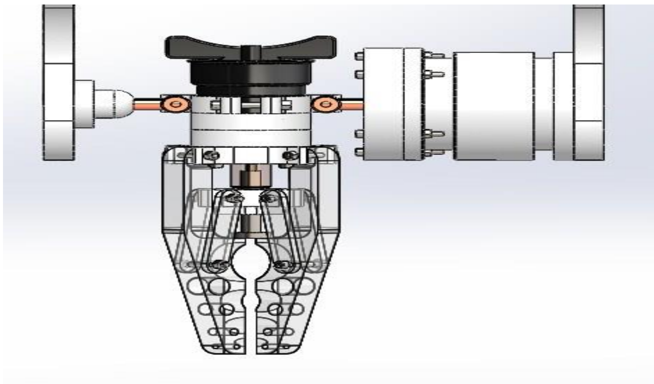


Figure 20: manipulator

5.2 Electrical :

5.2.1 Dc-Dc Converters:

All conversions take place onboard of the ROV. In total, 2 buck converters are used to step down the voltage from 12 V to the specified voltage. The converters are classified as follows:

1. 12 v to 5V, 10 Watt Dc-Dc Converter:

AQUA Discovery purchased this converter to supply the electrical power needed for Sensors and Serial communication.

Figure 21: dc-dc converter

2. 12 v to 7V, 10 Watt Dc-Dc Converter:

AQUA Discovery purchased this converter to supply the electrical power needed for the Servo motor used for the manipulator.

5.2.2 Power Control Unit:

Using "PCU" Co-pilot will be able to monitor the input voltage to the ROV, the supply current as he can disconnect the ROV if he detects any error in the power system. 25 Amp fuse has been installed on the 12 V line within less than 30 cm.

5.2.3 Electrical System Diagrams:

1. Power System Diagram:

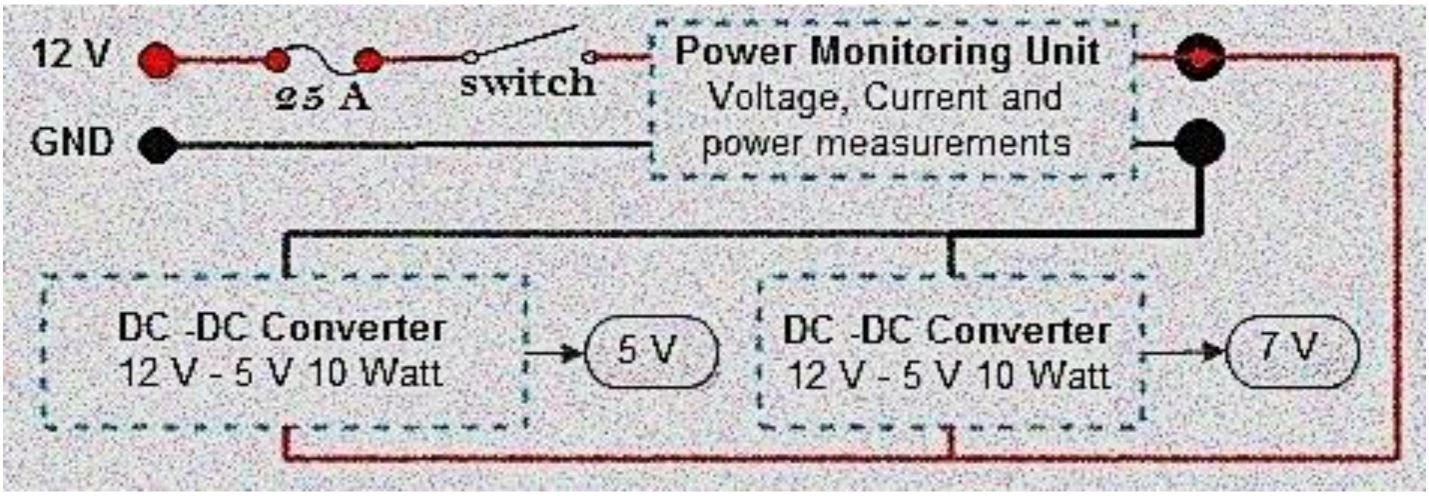


Figure 22: Power System

2. Tether Electrical characteristics:

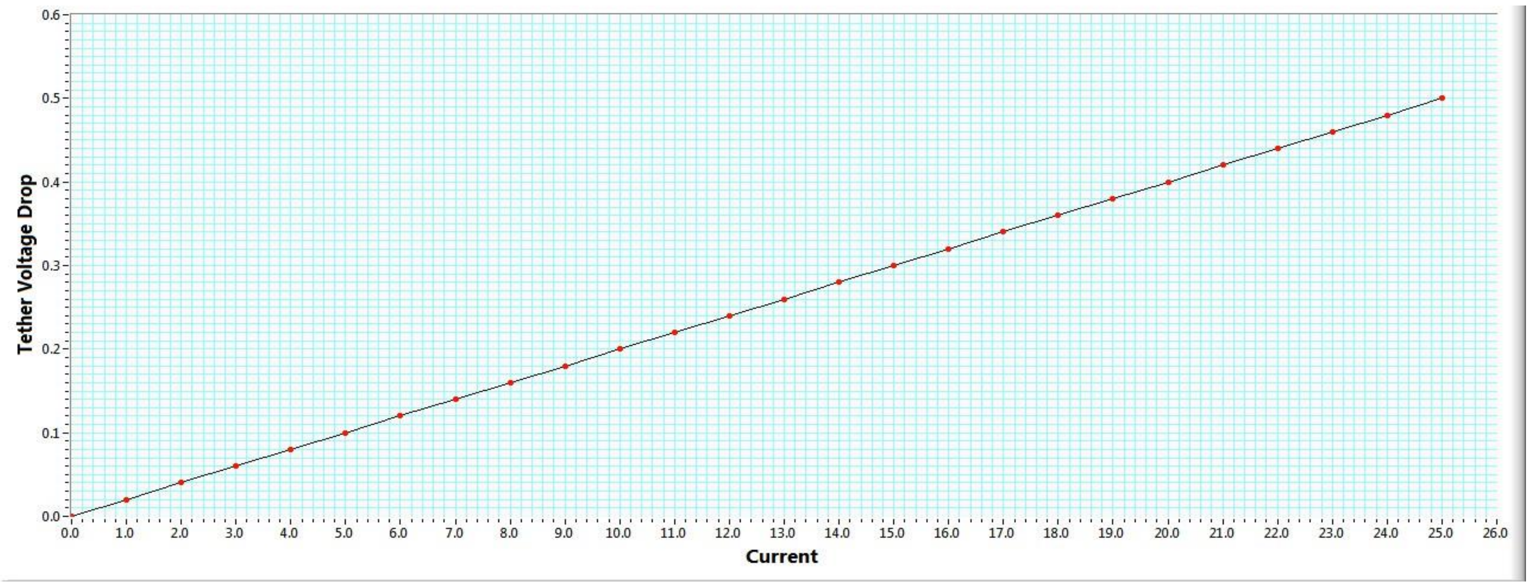


Figure 23: Tether Electrical characteristics

5.3 Control System :

The software team of AQUA Discovery has developed a control system for OPERA based on Labview and Arduino NANO board. The communication between Arduino and labview is through Rs-232 serial communication. We used single joystick to control the ROV, to control the basic movements for the rov; and to control the manipulator.

We use the measure tool in MATLAB to determine the distance using mission prop dimensions as reference.

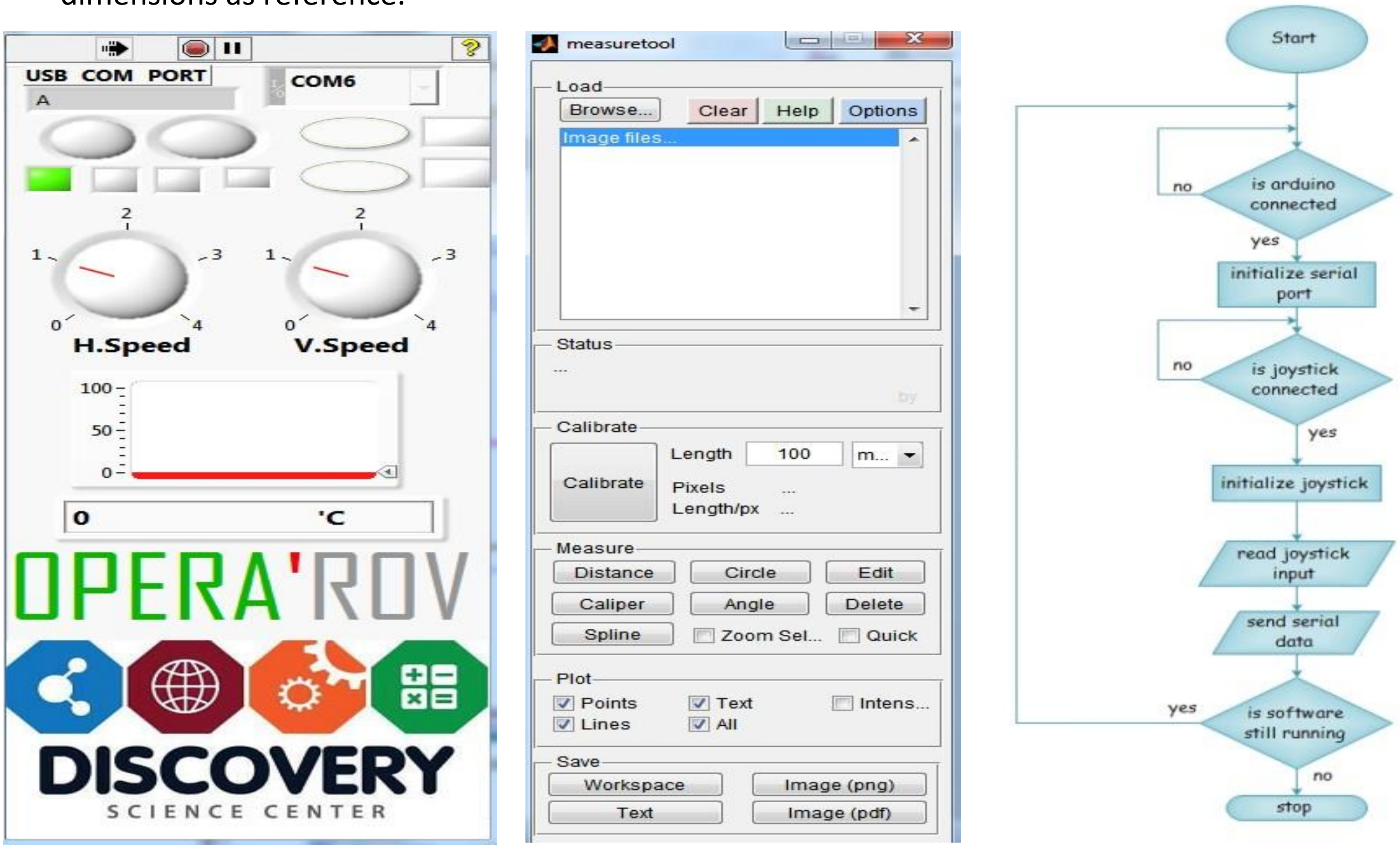


Figure 24: Rov GUI & mission's programes & flow chart

5.4 Tether :

OPERA is tethered with 20 meter multi cables; 6 mm x 2 cable for power and CAT5E cable for communication, Tether is supported by 0.005 m thin steel wire attached to the rov with it to increase its strength. And allow the tether man to pull the rov from it if necessary.

Figure 25: Tether & Tether connections with rov

5.5 Vision System :

One of the primary aspects AQUA Discovery focused on while designing OPERA is to provide a clear vision for the working area and the ROV's payload tools. Therefore, two 720P HD Wide Screen cameras are installed. Each camera supports 2 MP video resolution output and has a 170 degree wide view angle. One camera is on the front canister and the other is on the back one. The front camera is attached to a tilt system that allows rotating the camera along the vertical axis; rotating range is 180° (from -90° to +90°) to be able to view objects on the same level of the ROV and beyond the level of the ROV such as the ROV's gripper, and other structures during the missions' execution. The back camera is mainly used to aid the pilot in navigation and to focus on the gripper.

Figure 26: Camera

5.6 Payload Tools and Mission Tasks solutions :

5.6.1 Temperature Sensor Probe :

AQUA Discovery developed Temperature Sensor Probe for completing the task:

1. Measuring the temperature of the venting fluid.

Mechanical Design:

It consists of a polyethylene waterproof housing for the lm35 temperature sensor with a copper lead probe .The tool is fixed to Rov frame in front of the rov.

Operation:

This tool is held by the gripper and then the Rov move down until the custom tool inserted into the venting fluid so we got the temperature reading with error +/- 0.5°C and Linear + 10 mV/°C scale factor.

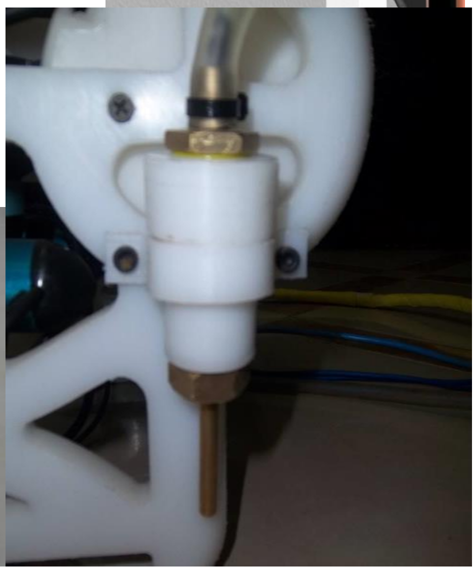


Figure 27: Temperature Sensor Probe

5.6.2 for the tasks:

1. Inserting the temperature sensor into the venting fluid.
2. Connecting the ESP to the power and communications hub.
3. Recovering the four mission-critical CubeSats and placing them in a collection basket.
4. Collecting one sample of two oil mats on the seafloor.
5. Returning the samples to the surface.
6. Returning two coral samples to the surface.
7. Installing a flange to the top of the wellhead.
8. Securing the flange to the wellhead with one bolt.
9. Installing a wellhead cap over the flange.
10. Securing the cap to the flange with two bolts.

We use the manipulator to complete them.

5.6.3 for the tasks:

1. Finding and identifying the serial numbers of the four mission-critical CubeSats.
2. Photographing two coral colonies.

We use the ROV front camera to complete them.

5.6.4 for the tasks:

1. Determining the thickness of the ice crust.
2. Determining the depth of the ocean under the ice.

We use the pressure sensor readings to calculate it or we can use the measure tool to determine that using the mission prop dimensions as reference.

5.6.5 for the tasks:

1. Analyze a gas chromatograph of each sample to determine the oil's origin.
2. Comparing the photos to photos from previous years to assess their condition.

The Co-Pilot will complete these tasks using the Oil fingerprinting handbook and Coral colony handbook provided by MATE.

6. Safety precautions

1.1 Personal:

AQUA Discovery staff managed to follow some safety precautions in order to avoid injury and stay safe throughout the whole working duration:

- Wearing eye goggles during cutting and building the mechanical body.
- Using fixed tools, like the drill station instead of the drill to avoid any injuries.
- Wearing gloves and lab coats while printing and welding the electric boards.
- Wearing ear blockers while using the saw station to block its high sound from the user.
- The workshop contains a first aid box for any injuries.
- Make sure that all the components are securely attached to ROV before operation.
- Carry the ROV from its handle only.

1.2 Vehicle:

6.2.1 Mechanical:

- All edges are smoothed.
- Kort nozzles are attached to the motors with safety stickers.
- A handle is used to safely handle the ROV.
- A safety rope is tied to the ROV to pull the ROV in water when needed.
- O-rings are incorporated into the end caps to maintain complete isolation at very high pressure.

6.2.1 Electrical:

- 25A DC Circuit breaker.
- 10A fuse connected to the power line placed in PCU within 30 cm.

7. Team Management

AQUA Discovery staff has setup a full working system and schedule from the first day of work.In addition, a development timeline was scheduled in details after making a general flow chart for the work progress, in order not to have a stitch in time, a weekly To-do list was hung in the workshop so that if any delay occurred it would not affect the whole time plan. At the beginning of the technical work, tasks were divided so that the mentor works with a new staff member in order to transfer experience to them. On the first meeting each department explains its work to other members and the logistics director discusses the general progress rate. This helped to ensure that the ROV was completed in time to practice before the competition as possible. The report content was divided among the whole staff and revised by the technical writing director.

8. Troubleshooting

After building OPERA, AQUA Discovery started to test all functions on it in a swimming pool at a depth of 5m. No leakage occurred, but there is a problem with the vertical movement of it so we revised the design and found that the bottom plate makes unneeded drag force so we removed it, also we found that we must increase the DOF of the manipulator and we change the orientation of the back camera for better view.

9. Challenges

9.1 Technical:

Shaft sealing

As we met a problem with the shaft sealing of servo motor using oil seal when testing rov in 5 meter depth. Our control team identified that problem when they recognized an increase in power consumed. To solve this problem our mechanical team did a deep search for a solution and after testing many types of sealing at 5 meter depth they find that adding a bearing with it to hold the shaft in position is suitable for this job.

9.2 Non-Technical:

Swimming pool problem

There isn't a suitable swimming pool for testing our ROV in our town so we have to move our ROV to another town to do wet tests and come back again so we waste a lot of time and money.

10. Lessons Learned

10.1 Technical:

Our team members made a deep search each one in his/her field to learn more about the science of marine technology such that:

1. The best choice to isolate our thruster specially shaft sealing and ease of its maintenance.
2. working on multiple software programs at same time like labview and matlab
3. Using the latest technology like CNC, Laser cutting to fabricate components of OPERA as frame, acrylic plates.

10.2 Non-Technical:

Normal operations dictate that team members focus on tasks that they feel comfortable and familiar with, but certain jobs such as ROV software, electronics, and workshop tools require detailed understanding. Therefore, it became evident that we must cooperate to teach each other and pass on our knowledge. Besides we all learned important skills we will need in work like Time Management, Team Building, Leadership, Presentation, and Documentation. As we learned that the good work completed with good planning and continuous observation of the outside environment effects on both us and the work.

11. Future Improvements

AQUA Discovery members are willing to implement some future improvements in designing and building their ROVs in the future as well as managing the work plans.

1. Increasing the stability of the vehicle.
2. Reducing the water resistance and drag forces on the body by enhancing the design.
3. Using a hydraulic manipulator with six degrees of freedom.

12. Reflections

"Never trust information until you search for it and find it yourself", Kareem Ahmed Baibars

"Try and error this is how you build your experience", Leena Ahmed Baibars

"Good planning for any project is the most important success factors", Yahiya Ehab Swelam

"The real problem is not whether machines think but whether men do", Ramy Ahmed Attia
"It has become obvious that our technology has exceeded our humanity", Farida Hossam

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14. Acknowledgements

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15. Appendices

1. Safety check list:

Before work

- ✓ ROV connected to tether.
- ✓ All cans are sealed
- ✓ ROV submerged 5 minutes in water, and then checked for any leakage.
- ✓ All cables properly sealed.
- ✓ Using digital Multimeter, check for input and ground connected.

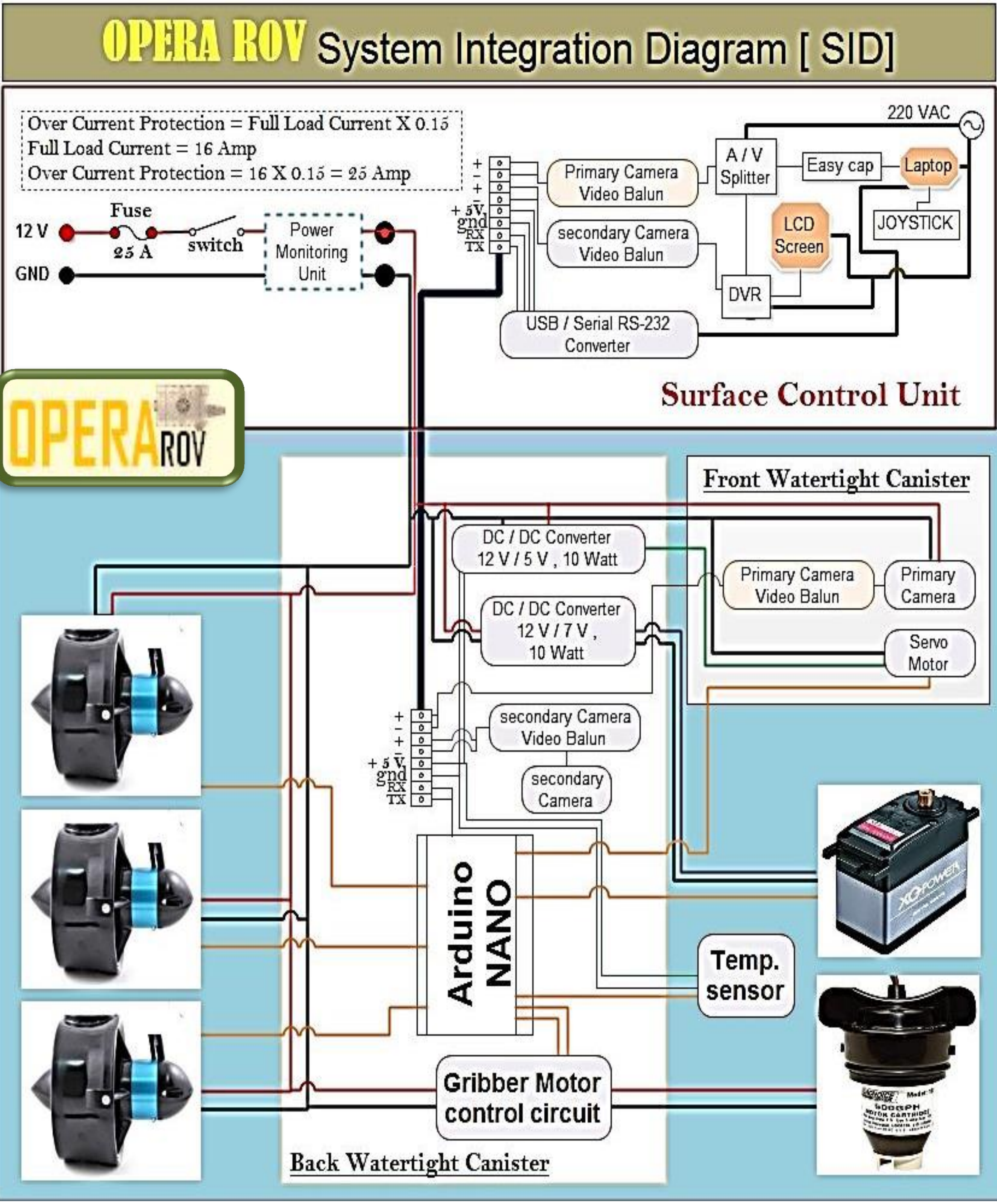
During work

- ✓ Wear gloves
- ✓ Wear eye goggles
- ✓ Wear lab coat
- ✓ Make sure all equipment are firmly attached to ROV

After work

- ✓ Two team members remove ROV from pool.
- ✓ Ensure electronics/thrusters are off.

2. System Integration Diagram (SID):



3. Electrical Schematic :