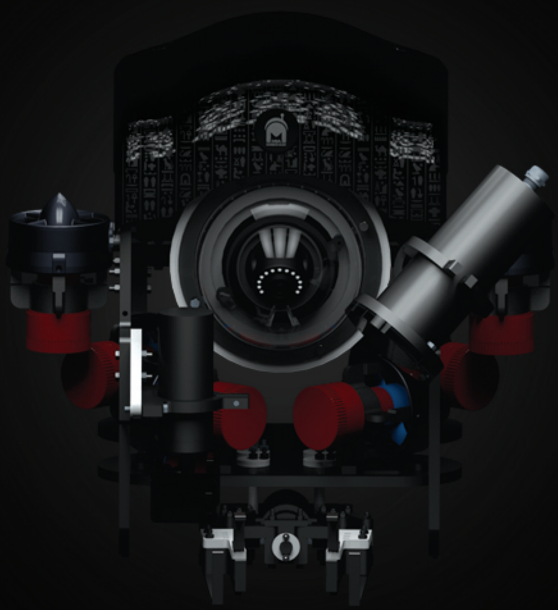
OSIRIS

TECHNICAL DOCUMENTATION

Made in Alex (M.I.A.)
MATE ROV 2018
Alexandria University
Alexandria, Egypt



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Osiris

Technical Documentation

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1. Abstract

Underwater exploration is a feat that has been of interest to man since the advent of humanity; starting by Magellan's attempt to measure the depth of the Pacific Ocean, and ending with James Cameron's *Deepsea Challenger*; the quest never stopped.

Embarking on this quest as well is the Applied Physics Laboratory (APL) after it issued a request for an ROV that can operate in salt and fresh water and is capable of performing multiple tasks underwater.
In response to that request, M.I.A developed Osiris. Osiris is a Remotely Operated Vehicle that has been tailored to execute the various tasks set forth by APL under the allocated time frame. The tasks range from gathering seismic data to collecting plane debris from seabed to installing tidal turbines. It was designed with the user in mind, down to each bolt and up to the most intricate line of code; we incorporated usability and serviceability in each bit of design by providing special features like a dedicated software, a base station, and a custom-built power supply unit.

This document scrutinizes the company's philosophy, technicalities, and challenges.

2. Company Overview

a. Structure

Our company is comprised of two teams working in parallel
- A mechanical team and
- An electrical team. Each team consists of **7** members. The first is responsible for the design, based on analysis, selecting materials, and methods of housing. The latter consists of two subsets:
- The hardware and
- software teams, these two subteams are responsible for building the complete electrical systemincluding the circuitry, fabrication, and code.

Figure (1): MIA ROV Team members

During the past months, the **14**-person company spent more than **2500** man-hours in a tireless educational journey, starting with employees who could barely code in C/C++/Python and can now program a fully-fledged ROV that has a computer interface and can perform image processing. Also, there were others who knew very little about sealing and product design and can now build a stable submersible vehicle that can stand more than 60 hours of water test.

b. Project Management

We believe a successful project starts by an unwavering trust and a clear line of communication between all team members. By setting realistic short-term goals to keep team members goal-oriented, and keeping track of the priorities, a timeline was laid out by experienced team members who competed in the MATE ROV competition before. While developing the project plan, we ensured that each member in the company has a specific responsibility that represent his/her strength. The design process was done by specific members who were well trained to design and simulate underwater vehicles. The testing and troubleshooting team carried out many trials and errors along the whole project in order to validate objectives.

In early September prior to joining the team, new members were trained from scratch to participate in the competition. By the end of the training, and under the guidance of our seniors, they began working within the team. The training helped them learn quickly the process of building an ROV from scratch.
The mechanical team started by searching for improvements based on previous years' designs. Beginning by the thrusters, testing many prototypes took place before selecting the best design. Along the way, senior members would offer their feedback to correct design flaws in order to avoid operational issues that might appear later in fabrication. Furthermore, after fabrication it went through many modifications before finding the most efficient design.
The electrical also had a from designing circuit boards, selecting components into fabrication. But before going to the fabrication phase, it must be approved from the electrical leader in order to avoid problems encountered in the previous years. The design of the electrical system has to satisfy also the restrictions that mechanical teams put (i.e. the dimensions) that's why weekly meetings were held between the two teams to approve the design of the system and the suggested modifications. Before integrating the system, a unit testing must be applied on every sub system.

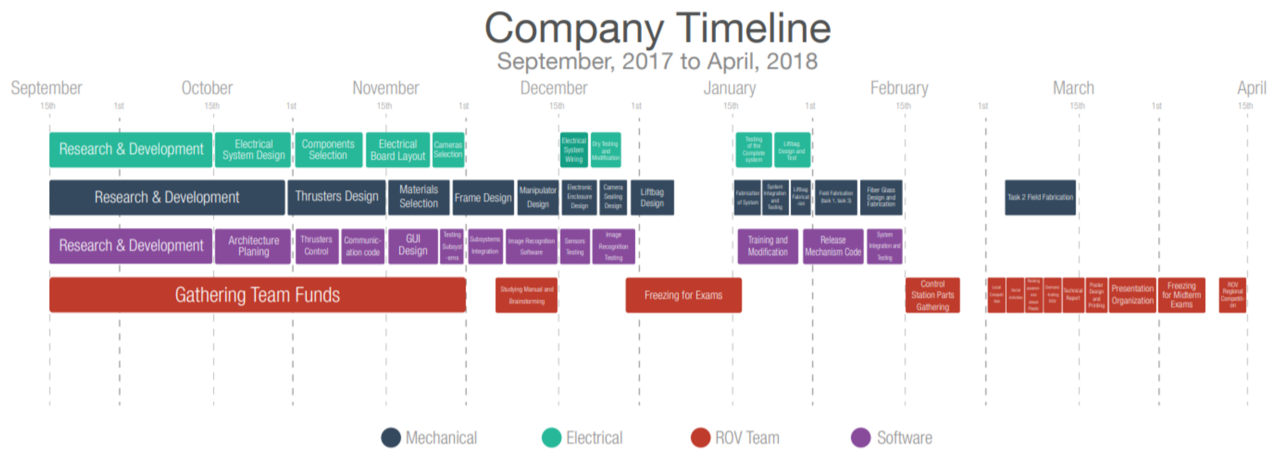


Figure (2): Company's ROV Timeline

In the software Team, we start by designing the architecture of the system. Keeping in our mind the efficiency of achieving the task, the system must be flexible to accept changes, modification, adding features to the last minute. It must satisfy unit testing to be able to test any part separately (i.e. sensors) and to be able to add new features anytime like this year task "image recognition"
All these subteams works together in the non technical part as a team, each member is responsible for a specific task beginning from gathering team funds, reviewing the competition rules and making sure that they are understood and followed by everyone, keep tracking of the deadlines, organizing places to test in, to organizing social activities inside and outside college like Raising awareness about plastics we made early this year.

3. Budget And Cost Accounting

Analyzing the previous four years' income statements and reviewing their financial performance, we were able to project future expenditures and seek methods of income either through self-funding or external sources. First, we focused on building our expected budget excluding the re-used items in order to accurately estimate the total funds needed this year. Putting into consideration possible component failure and replacement, the budget for electrical and mechanical components was calculated with a margin of error. Based on this year's competition tasks, additional costs were allocated for designing and fabricating some non-ROV devices like the lift bag, inductive coupling connector, and other connectivity modules.All in all, the costs were mostly allotted for the electronic components since fabrication was funded through external sources. Figure (3).

Budget	Electrical Components				$1,300.00		
	Mechanical Components				$2,500.00		
	Travel Costs (10 persons)				$12,000.00		
	General Costs				$500.00		
	Subtotal				**$16,300.00**		
	PROJECT TASKS	**# Of Units**	**rice Of Units Used**	**TYPE**	**)TAL PER UNITS**	**SOURCE**	**Notes**
Electrical Components (ROV)	Rule 1100 GPH Bilge Pump	10.0	$40.00	Reused	$400.00	MIA TEAM	Motor
	Rotation Motor	1.0	$40.00	Reused	$40.00	MIA TEAM	Motor
	Arduino Nano	2.0	$5.00	purchased	$10.00		Electronics
	DC-DC Converter	2.0	$30.00	Reused	$60.00	MIA TEAM	Convert 48v-12v
	Hikvision Analog Cameras	2.0	$60.00	purchased	$120.00		Cameras
	LED Light	2.0	$4.00	purchased	$8.00		Electronics
	Solenoid Non-return Valve	1.0	$9.00	purchased	$9.00		
	Directional Solenoid Valve	1.0	$7.50	purchased	$7.50		
	Power Board	1.0	$6.00	purchased	$6.00		Hardware
	Signal and Communication Board	1.0	$5.00	purchased	$5.00		Hardware
	HC-05 Bluetooth Module	1.0	$5.00	purchased	$5.00		Electronics
	ESP8266 Module	1.0	$5.00	purchased	$5.00		Electronics
	Cytron DC Motor Driver	4.0	$26.00	purchased	$104.00		Electronics
	Pressure Sensor	1.0	$38.00	purchased	$38.00		Sensor
	Buzzer	8.0	$1.00	purchased	$8.00		Electronics
	PCB Design and Fabrication	-	$3.50	purchased	$3.50		Hardware
	2*mm Cable(30 Meters)	2.0	$0.3 per meter	purchased	$18.00		Cables
	Ethernet CAT6 (30 Meters)	1.0	$0.25 per meter	purchased	$7.50		Cables
	Anderson Connector	1.0	$40.00	purchased	$40.00		Connector
	USB-TO-TTL module	3.0	$2.50	purchased	$7.50		Electronics
	Station Including DVR + Screen Monitor	1.0	$135.00	Re-used	$135.00		
	Fuse + Fuse Holder	1.0	$12.00	purchased	$12.00		Power
	Subtotal				**$1,049.00**		
Electrical Components (NON ROV DEVICES)	Arduino Nano	1.0	$5.00	purchased	$5.00		Electronics
	HC-05 Bluetooth Module	1.0	$5.00	purchased	$5.00		Electronics
	Sound Sensor Adafruit	1.0	$10.00	purchased	$10.00		Sensor
	Directional Solenoid Valve	1.0	$7.50	purchased	$7.50		
	2*mm Cable (30 meter)	4.0	$0.3 per meter	purchased	$36.00		Cables
	Wireless Charger	2.0	$6.90	purchased	$13.80		
	Anderson Connector 12V	2.0	$16.00	purchased	$32.00		Connector
	Fuse + Fuse Holder	2.0	$12.00	purchased	$24.00		
	Subtotal				**$133.30**		
Mechanical components	Piston	1.0	$12.00	purchased	$12.00		Hardware
	3D-Printed Thruster Parts	10.0	$6.00	purchased	$60.00		Hardware
	Acrylic Dome	1.0	$9.00	purchased	$9.00		Hardware
	T100 Nozzle	10.0	$15.00	Reused	$150.00	MIA TEAM	Hardware
	T100 Propeller	10.0	$9.00	Reused	$90.00	MIA TEAM	Hardware
	Metal Glands	25.0	$1.50	purchased	$37.50		Hardware
	Thruster Guards	20.0	$2.25	purchased	$45.00		Hardware
	Subtotal				**$403.50**		
Mechanical components (NON	Acrylic Tube (Electrical Enclosure)	1.0	$18.00	Reused	$18.00	MIA TEAM	Hardware
	Acrylic Tube (Lift Bag)	1.0	$30.00	Reused	$30.00	MIA TEAM	Hardware
	Piston	1.0	$12.00	purchased	$12.00		Hardware
	Metal Glands	10.0	$1.50	purchased	$15.00		Hardware
	Connector Casing	1.0	$5.00	Parts Donated	$5.00		
	Subtotal				**$80.00**		
Common components	Pneumatic Tubes			purchased	$35.00		
	Pneumatic Fittings			purchased	$7.00		
	Bolts and Nuts			purchased	$45.00		
	Materials			purchased	$120.00		
	CNC Laser Cutting			Parts Donated	$85.00	Alexandria Fertilizers Company	Hardware
	Lathe Machine			Parts Donated	$145.00	Alexandria Fertilizers Company	Hardware
	Subtotal				**$437.00**		
General Expense	Local & Mate Registration &Fluid Quiz			purchased	$435.00		
	Subtotal				**$435.00**		
Travel	Flights (5 tickets)	5.0	$1,100.00	Cash Donated	$5,500.00	WE	
	Flights (5 tickets)	5.0	$930.00	Partially Cash Donated	$4,650.00	Alexandria University	
	Hotel Rooms (3 rooms, 6 nights, $120/ night/ room)			Cash Donated	$2,160.00		
	Travel Costs (10 persons)			Purchased	$1,800.00		
	Rental Vehicles & Gas (1 vehicle, 350$/ vehicle)			Cash Donated	$350.00		
	Subtotal				**$14,460.00**		
Subtotals					**$16,997.80**		
Total Items Re-Used					**$923.00**		
Total Expenses - Re-Used Items					**$16,074.80**		
Total Income	Alexandria Fertilizers Company donation	1.0	$300.00		$300.00		
	Alexandria University Donation	1.0	$4,370.00		$4,370.00		
	Self Fund	14.0	$250.00		$3,500.00	MIA ROV TEAM	250$ from each one
	WE Sponsorship	1.0	$8,085.00		$8,010.00		
Total Income					**$16,180.00**		
Net Balance					**$105.20**		
OSIRIS TOTAL COST					**$1,889.50**		

Figure (3): Company's Budget and Cost Accounting

4. Design Rationale

a. Design Evolution

Osiris went through several transformations prior to becoming what it is now. It is the result of three years of successes and failures. This year, the team spent two months in research & development to ensure we create the best version of Osiris. Figure (4).

Reflecting back on last year's design, we made radical changes to the design, thrusters, housing, and communication protocols. Starting with the materials, we decided to use a light-weight nylon derivatives; Polyamide and acrylic. Continuing on to the communication protocols, we converted the systems to Serial communication since last year's TCP/IP had multiple software and hardware complications. On the software side, the code for TCP/IP communication protocol was complex and memory inefficient; eating up a big chunk of the microcontroller's memory and hence forcing us to use an Arduino Mega as the main controller. The Mega, however, was larger in dimensions than this year's Nano, making the electrical boards bigger in dimensions, whereas on the hardware side, the TCP/IP required us to use an Ethernet shield that further increased the dimensions of our electrical boards and electrical housing which consequently increased the total weight.

ROV Name	Optimus Prime	Pica	Calypso	Osiris
Weight in air	30 kg	20 kg	17 kg	19 kg
Dimensions*	Fits in a 0.7 m circle	Fits in a 0.65 m circle	Fits in a 0.58 m circle	Fits in a 0.64 m circle

Figure (4): Comparison between Osiris and our previous ROVs.

b. Design Process

By understanding the basic roles for designing, organizing our ideas and joining our efforts, we were able to design and construct Osiris. The ROV design went through a multistage process. An interdepartmental brainstorming session took place mid-october to study the different designs that can be implemented. Based on the restrictions imposed by the MATE Center, we started narrowing down the choices based on their performance and compliance to those restrictions. Later, we started putting our ideas on paper in order to envision the applicable concepts that can solve the tasks within the shortest time interval. Another meeting was held after the manual was released; The meeting's agenda was to discuss mission-specific features that must be integrated into the ROV; this included the lift bag, gripper, imaging system, and connectivity modules.

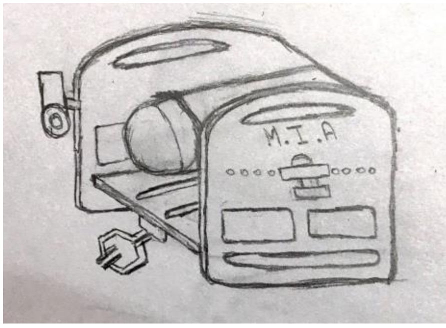


Figure (5): First Sketch of Osiris During Mechanical Team Brainstorming

Once we devised a preliminary sketch for the ROV, the design was modeled and rendered into a Computer Aided Design file (CAD) using SolidWorks. After that, the company followed the design blueprints meticulously during the fabrication process to avoid any mishaps that might occur. Depending on the part's complexity and required mechanical stress, the machining was done using the lathe machine, Computer Numerical Control (CNC) laser machine, and 3D printers.

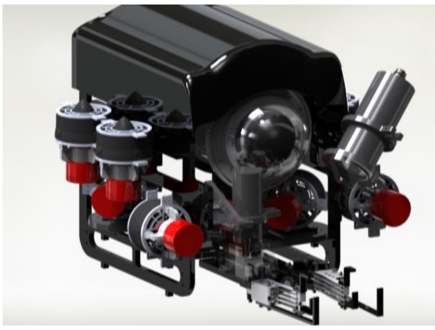


Figure (6): Osiris' final CAD

Figure (7): Osiris' Components

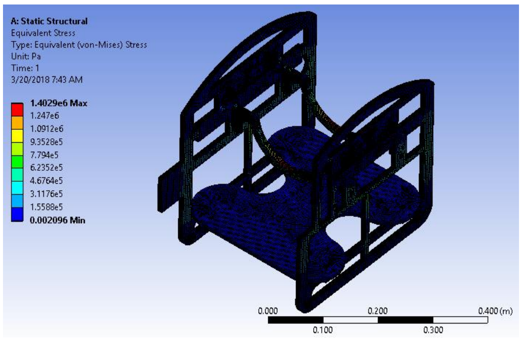
Our designs and mechanisms are based on scientific theories and ideas. While designing the 2D and 3D parts we considered the most possible loads that might be applied on it, accordingly we ran a stress analysis on every part to ensure its safety and prevent it from failure by modifying many models in order to reach the safest and most suitable one.

5. Mechanical

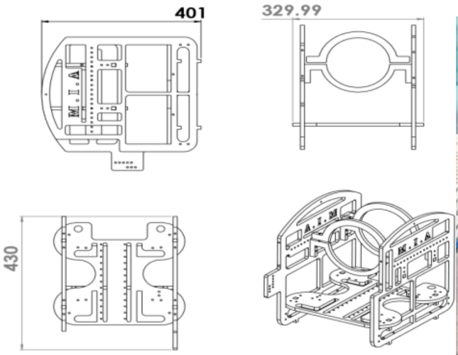
a. Frame

With the main goal of creating a robust, lightweight and compact ROV, the frame design and material choice played a central role in attaining that goal. The main requirements for the frame were low drag in water, modularity for ease of assembly, and capability of operating in salt and fresh waters. Polyamide was the prime candidate for its toughness, wear-resistance and anti-corrosion properties. Moreover, it has a density of **1.12** g/ cm3 and a tensile strength of **90** MPa, which decreases weight and increases rigidity. Adjusting the frame's thickness was determined upon running a stress analysis on it to ensure its durability. The frame consists of a horizontal base-plate and two main longitudinal side walls. The base-plate accommodates the four horizontal thrusters as well as the gripper. The two main longitudinal side walls carry the electronics enclosure, vertical thrusters and other manipulators. To overcome abrasion and rust, suitable materials were also utilized throughout the frame.

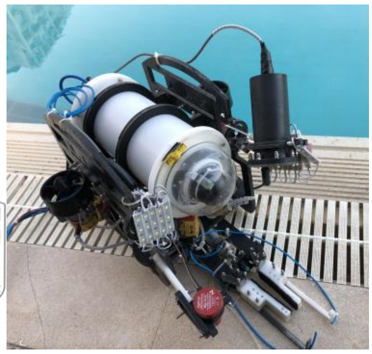
- **Frame weight:** 2 kg
- **Frame dimensions:** 330 mm x 430 mm x 401 mm



Figure(8) :Frame simulation in Ansys



Figure(9) :Frame Specs



Figure(10): Osiris during test.

b. Manipulators

i . Main Gripper

Osiris is equipped with a pneumatically-powered four-bar mechanism gripper that is designed to clamp different objects underwater. Its end effectors have internal grooves that can hold cylindrical props that are up to **95** mm in diameter. The piston's forward stroke is **199** N and return stroke is **171** N to ensure that objects are locked firmly between its ends. Like the frame, the gripper is fabricated out of an **8** mm polyamide sheet that has been machined using Computer Numerical Control (CNC) laser machine and assembled in-house.

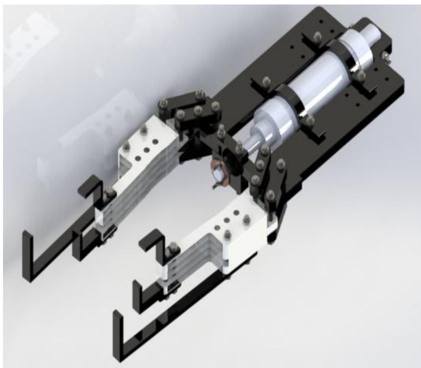


Figure (11): Main Gripper Render

The gripper's versatile design allows it to perform multiple tasks, namely handling the lift bag, transporting the I-AMP and locking it onto the stand, and installing the tidal turbine.

c. Thrusters

Addressing last year's thruster issues, the team devised a new solution to replace the faulty Blue Robotics T100 thrusters. In accordance with our principle of repurposing old materials and parts when possible, this year the thrusters are reused Rule 1100 GPH bilge pumps that have been modified to improve performance.
The bilge pumps' high RPM combined with suitable propeller pitch, pitch angle, hub diameter, and diameter made them the optimal choice. Multiple propellers were tested in-house, practically and using software, for performance benchmarking. Based on the benchmarks, a T100 propeller and nozzle were selected; the nozzle central function was to improve flow direction (reduce flow separation). Then, using SolidWorks and 3D printing, a mechanical department employee custom-built ancillary parts for the thruster. Later on, the thruster was assembled in-house using copper coupling. Subjecting the thruster to test, the following data was compiled.

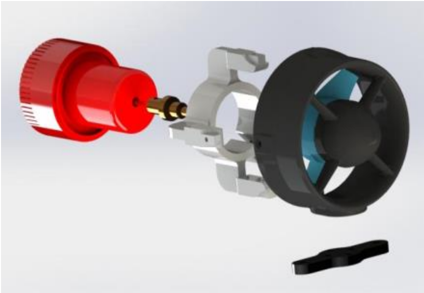
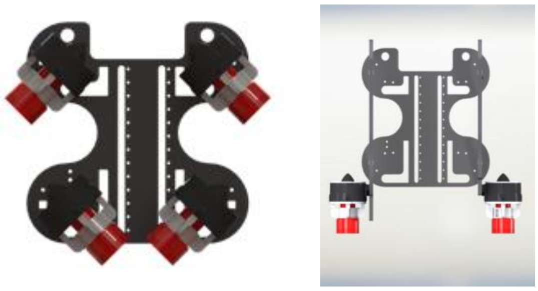


Figure (12): Osiris' Thruster main parts

- **Maximum forward thrust:** 15 N
- **Maximum backward thrust:** 14.65 N

i. Thrusters Configuration

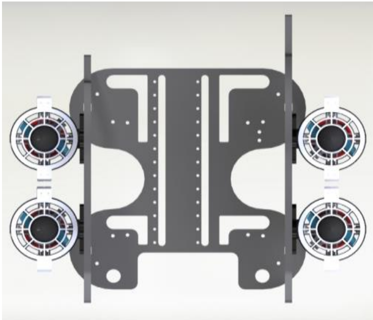
Osiris is powered by ten waterproof Rule 1100 GPH thrusters. The base-plate holds four horizontal thrusters that are vectored at 45° angles which allow the ROV to move laterally and rotate around its center shown in **figure 13(a)**. Two thrusters on the side walls to increase the forward speed shown in **figure 13(b)**. Four thrusters are installed on the side walls for the vertical movement shown in **figure 14.** The vectored configuration of the thrusters provides full three-dimensional control of Osiris.



Figure(13) (a)(b) respectively: Osiris' Thrusters Configuration

d. Buoyancy

Achieving a approximately-suspended ROV was one of the challenges that faced the company. Osiris weighs **15.583** kg (without tether) and its buoyant force is **160** N. In order to suspend the ROV, the gravitational force must equate the buoyant force, so it requires about **417** gm of additional weight to make it suspended. To resolve the issue, four lightweight aluminum boxes were attached to the frame of ROV at its corners. The ballast added in the four boxes provided as well as stability to the vehicle.



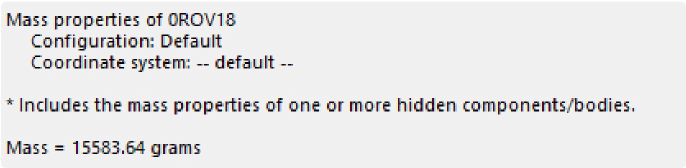
Figure(14): Osiris' Thrusters Configuration in the Vertical Direction

The buoyant force and weight of the vehicle were calculated using SolidWorks according to the following equation:

$$M \times g = \rho \times v \times g$$

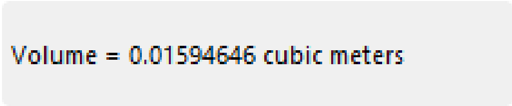
M (Mass of ROV) g (Gravitational Constant)
ρ (Density of water) v (Volume of displaced water)

The buoyant force was calculated by converting all hollow closed parts to solid ones and replacing all parts' density with that of water . The following is a sample of mass and volume calculations from SolidWorks.


Mass properties of 0ROV18
Configuration: Default
Coordinate system: -- default --

* Includes the mass properties of one or more hidden components/bodies.

Mass = 15583.64 grams


Volume = 0.01594646 cubic meters

Figure(15.a): Mass of the ROV in air

Figure(15.b): Volume of displaced water

Note

The actual mass of ROV after fabrication is **15.76** kg, Therefore, the actual weight needed for the ROV to be suspended is approximately **240** gm.

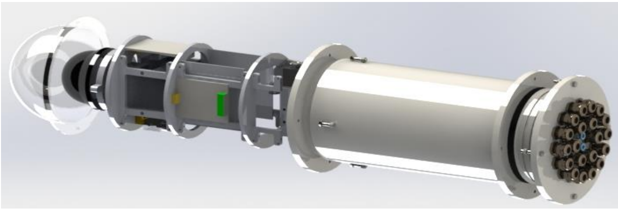
e. Sealing

i . Electronics Enclosure

The electronics enclosure is the compartment which contains the electrical wiring and circuitry that drive the ROV. It is a Polyethylene hollow tube with a **15** cm inner diameter and is **30** cm long that has been machined in-house using the lathe. The front side of the tube is sealed with O-Rings and capped by a clear Acrylic dome that acts as a camera casing. The dome's material and shape were selected with some factors in mind: clarity, low-drag force, and wide range of vision (up to **180°**).

Figure(16): Osiris' electronics enclosure machining.

The back-end cap is sealed by double O-Rings to eliminate leakage and was designed with future assembly/disassembly in mind. The enclosure was tested to ensure proper sealing by subjecting it to a high relative pressure of **1.2** bar underwater.



Figure(17): Osiris' electronics enclosure Tube parts SolidWorks.

f. Pneumatics

The pneumatics circuit includes:

- Compressor and Pressure gauge to measure its pressure.
- Pressure regulator to adjust the pressure of the air flow coming from compressor.
- Air filter to clean the air before entering the circuits.
- Lubricator.
- Non-return valve to prevent the air from flowing through the opposite direction.
- Pressure gauge to ensure the suitable pressure flow before entering the circuits.
- Pressure regulator to adjust the pressure to **1** bar to avoid leakage in the electric tubes.

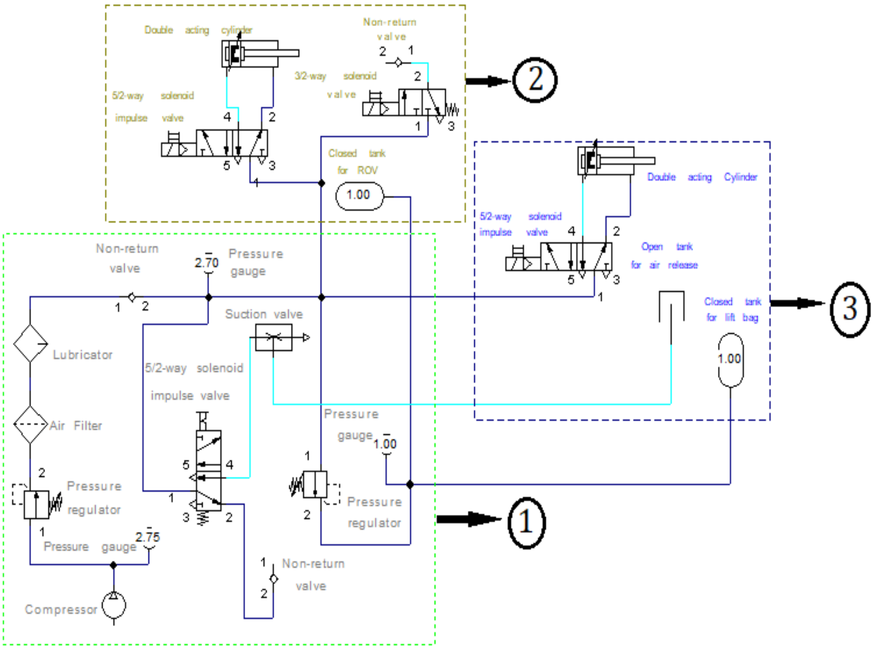
Figure(18): Pneumatic Gauge.

ROV includes:

- **5/2**-way solenoid impulse valve to control double acting cylinder of the gripper.
- Double acting cylinder to control opening and closing of the gripper end effector.
- Non-return valve solenoid that controls the air flow from the ROV to the lift bag.
- Non-return valve to avoid air from flowing through the opposite direction.

Lift bag includes:

- **5/2**-way solenoid impulse valve to control the release mechanism piston.
- Double acting cylinder to control position of the link that carries the loads.
- Non-return valve to release air from lift bag.

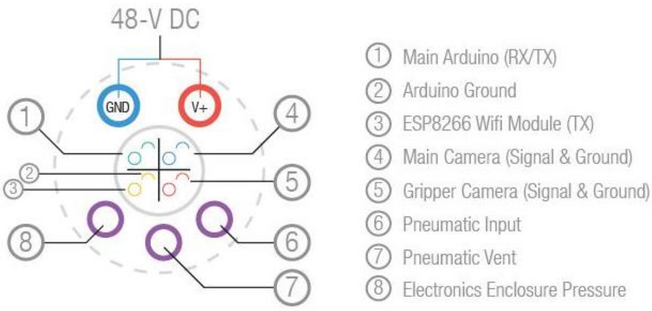


Figure(19): MIA Pneumatic Circuit Diagram (1): components of Station, (2): components of Rov, (3) components of Lift Bag.

6. Electrical

a. Tether

Osiris' tether bundles multiple cables in a single sheathing. One Category 6 Ethernet (CAT6) cable, three pneumatic pipes, and two 14 AWG power cables. All signals and commands to the Nanos are sent through the Ethernet cable. The 14 AWG power cables provide a stable 48-volts DC power. The pneumatic pipes are elaborately explained in the Pneumatics section.



Figure(20): Cross-Section Of Osiris' Tether.

b. Power Supply

Osiris uses an in-house built power supply unit. The unit makes use of four **110-240**V AC-**12**V DC power supplies that can provide up to **40 A**. A set of power switches control the output voltage with increments of **5, 12, 24, 36** and **48** volts. The unit also uses a **KRK KDA-72** digital ammeter and a **KRK KDV-72** digital voltmeter that show telemetry of current and voltage. It is equipped with **5** LED indicators to guarantee that the power supplies are operating normally.
For safety concerns, a **20A** AC fuse is installed on the main feeder, and the power supplies are fused on AC and DC to prevent short circuits. Furthermore, a toggle switch is installed on the main feeder for easy turn on or off; especially used in case of emergencies as a kill-switch.

Figure(21): MIA Power Supply.

c. Power Distribution

Figure(22): Osiris' DC-DC Converter (48-12v)

Two **48-12**V DC-DC reused converters are present in the electronics enclosure of the ROV. The power distribution of the two converters is as follows: One converter powers the lights, communication system, sensors, the OBS leveling motor, two of the horizontal thrusters as well as two of the vertical thrusters. The second converter powers the remaining thrusters and the solenoids. Five Dual-Channel Cytron Motor Drivers were used for controlling the vertical and horizontal thrusters, as well as the leveling motor.

d. Video System

i. Cameras

Figure(23): Osiris' Main Camera, Gripper Camera

This year, the number of cameras used, make, models, and placement were key factors to the mission's success. Since the goal was to avoid redundancy without sacrificing efficiency, two Hikvision **12**V analog cameras were used for navigation and image recognition. The cameras were carefully selected with some criteria in mind: weight, viewing angles, dimensions, and maximum frame rate.

In order to maximize visibility, the two cameras are situated strategically so that their viewing angles overlap as little as possible. The main camera feeds the image recognition software. The second camera - gripper camera – gives the pilot a closer look of the gripper. Their feed is displayed side by side at **25** frames per second at a resolution of 1080p. The high frame rate is a fundamental component for the video to be seamless; which consequently aids in processing and provides the pilot with a real-time experience.

ii. Positioning

Figure(24): Feed of both Main and Gripper Cameras during the Test

The main camera is situated inside the front acrylic dome and the secondary camera is situated in a custom-made polyethylene enclosure; It is tilted to give a top view of the gripper. Both cameras are tethered to the DVR through a twisted pair CAT6 Ethernet cable Video balun for noise cancellation. Accounting for future maintenance and troubleshooting, the camera's power and signal lines are detached from the thrusters' power line. Each camera's specifications were carefully examined to suit their functions. For example, the viewing angle of the main camera is **109**°, whereas that of the gripper camera is **70**°. Two LED arrays are mounted above the main camera for optimum scene illumination. The arrays were chosen for their high Color Rendition Index (CRI) to aid in image processing.

7. Software

a. Topside

As a part of our commitment to usability, we developed Orion. Orion is the topside platform that controls Osiris, displays telemetry, plots seismic data, and performs calculations. Coded entirely in C++ and designed using Qt Creator, not only does the GUI serve an aesthetic purpose, it also improves the user experience.
Another key component of the graphical user interface are the tabs; Navigating between multiple tabs, as opposed to a single all-inclusive window, adds a sense of order to the software, enabling the pilot to stay focused, keep track of the mission's progress, and save time. Orion's ability to control Osiris' rotation speed, vertical and lateral speeds, and The software was designed for Windows machines but can be compiled for Ubuntu and Mac OS as well.

Figure (25): Osiris' GUI (Orion)

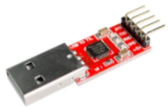
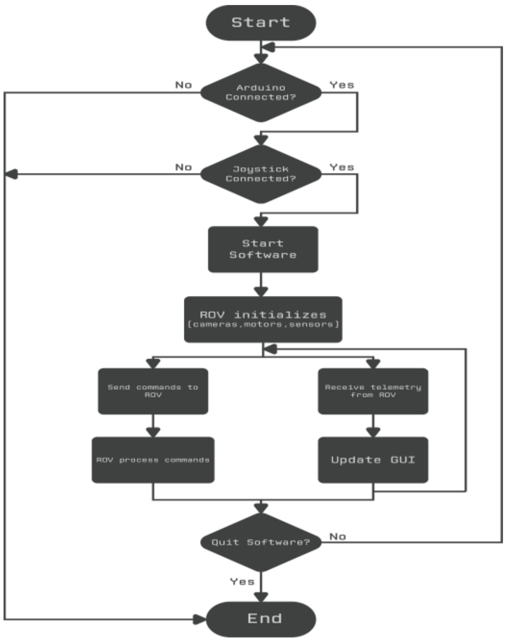


Figure (26): USB-to-TTL module

b. USB to TTL module

Using Orion as the topside software, the data is relayed using a USB to TTL UART module to the microcontrollers.The system features the ability to upload Arduino code directly to the Nanos without the need to replace them every time there is a firmware update. This goes great lengths in improving both the user experience and the serviceability of the ROV.



c. Bottom Side

▪ Microcontrollers

This year, in compliance with our principle of serviceability, we had to approach the microcontrollers differently. In contrast to last year's central control unit, this year we adopted a new modular system. Instead of using one Arduino Mega as the main control unit, we are using two Arduino Nanos to control Osiris. One Arduino Nano is connected to the various sensors and connectivity modules that Osiris utilizes, namely the HC-05 Bluetooth module or a multi-tone acoustic signal generator that is used for the lift bag release, an ESP8266 Wifi module [connected directly to laptop], and the pressure sensor. It is also responsible for the communication between Osiris and the station, as it dispatches the readings of the sensors to the station and receives the control commands sent from it. The second Arduino Nano is connected to multiple Cytron Dual Channel **10**A motor drivers that control the ten thrusters of Osiris. When a movement command is transmitted from the station to Osiris, the first Arduino processes the command and relays it to the second Arduino, which then sends out signals to the motor drivers to drive the thrusters. The modularity of the system improved troubleshooting and cut down maintenance time significantly.

8. Non-ROV Devices

1. Lift Bag

i. Mechanical

The mechanical team put in tremendous effort in research & development to conceive the lift bag's unique concept. Unlike conventional lift bags, the company's lift bag is a rigid body.

The company's lift bag is designed to attach to the debris and engine by engaging a three-pronged end effector to the U-bolt. The end effector design has developed throughout the testing course, starting by a single prong and then adding two extra prongs to facilitate the engagement with the U-bolt by increasing the contact points.

The piston is driven by a solenoid that is controlled by the built-in microcontroller. Since the lift bag is totally independent from the ROV, the inflation process takes place through the ROV, where a dedicated pneumatic pipe is tethered down from the compressor and is controlled by a solenoid.

Figure(27): 3D Model Of the Lift Bag

By starting inflation, air occupies the lift bag's acrylic tube, replacing water and in turn, pushing the lift bag upwards. Once buoyant and displaced from the crash site, the pilot can disengage the debris/engine using Acoustic release or via another release method, Bluetooth release. Both methods are discussed thoroughly in the Lift Bag Release section.

The deflation process is done by using a non-return solenoid valve and a suction valve as when a signal sent to solenoid valve the way of suction was opened then by using the mechanical button in the suction valve deflation process starts.

ii. Electrical

Our company developed two methods to control the triggering of the lift bag's release mechanism. The first method, an acoustic release, is achieved by sending out a multi-tone acoustic pulse using an array of buzzers mounted on the ROV. Acoustic waves generally propagate easily in water, which makes them very easy to be detected. Once the acoustic pulses reach the lift bag, a dedicated sensor is used to detect these pulses, which then sends out a signal to the built-in microcontroller causing it to trigger the release mechanism.

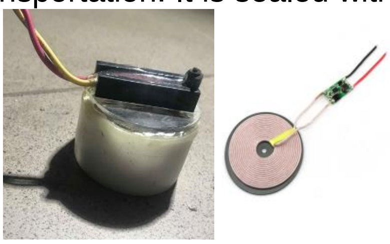
The second method utilizes a bluetooth module connected to the lift bag's microcontroller. The bluetooth module is responsible for receiving special commands sent out from the ROV's bluetooth whenever the pilot wants to trigger the release mechanism. The bluetooth module then relays these commands to the microcontroller to trigger the release mechanism.

Since for two bluetooth devices to pair under water they need to be within **8** centimeters apart, the ROV has to be in close proximity to the lift bag. For that reason, we opted for the acoustic release as the primary release mechanism, leaving the bluetooth release as a backup in case of any malfunction.

2. Inductive Coupling Connector

i. Mechanical

We constructed our inductive coupling casing considering its ease of transportation. It is sealed with epoxy to ensure its waterproofing and durability. Also, a piece of insulated lead ballast is contained inside the connector's casing, this acts as an anchor that hinders the movement of the connector and pivots it to the base, and thus the connector is kept in good proximity with the coil which in turn stabilizes the field and the induced voltage.



Figure(28): Inductive Coupling Connector.

ii. Electrical

In order to complete the tasks of the Earthquakes mission, our company had to develop its own inductive coupling connector which is used as a transmitter of a wireless charger module.

The transmitter module used is normally powered by **12**V and capable of supplying **5**V and **1**A -**1**W of power-. However, our tests showed that better transmission range is obtained by powering it with **5**V instead of **12**V while still being able to supply the same **1**W of power. So, a linear voltage regulator is used to step the **12**V input down to **5**V for powering the transmitter.

9. Mission-Specific Features

1. Mission A: Aircraft

a. Locating the crash site

After collecting flight data (Wind speed, Aircraft speed, etc...), the crash location and direction are pinpointed on the map. The parameters are plugged into the equation solver that is embedded in the GUI and hence calculates the distance and heading of the aircraft. All calculations are written in the "locating the crash site" document

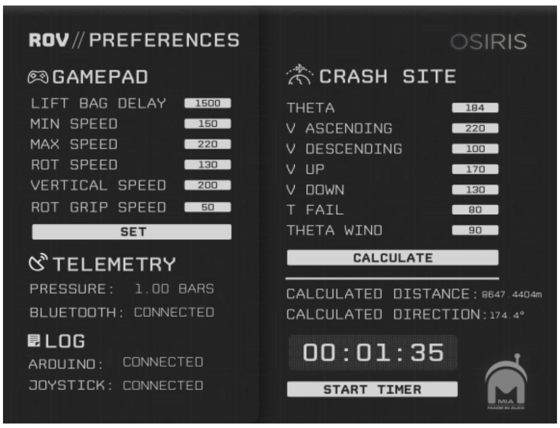


Figure (29): Crash site tab in Osiris' GUI

b. Airplane Identification

Using OpenCV and Python, we were able to develop two algorithms that discriminate different airplanes using their respective tail sections. Each of the two algorithms starts by accessing the feed of the analog CCTV camera through a Real Time Streaming Protocol (RTSP) using an Ethernet cable that connects the Digital Video Recorder (DVR) to the processing device: a laptop in our case.

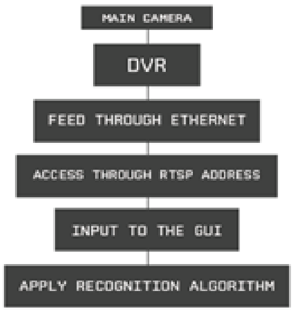


Figure (30): Image recognition data flow diagram

❑ Algorithm A: Shape/Color Recognition

The algorithm's fundamental procedures, which are explained below, are performed to distinguish shapes and colors printed on the tails. The algorithm, although has been fine-tuned for our applications and is working perfectly, is yet prone to lighting conditions. Thus, to have a better recognition, we devised another backup algorithm; Text detection. Photos of the results can be shown in Figure (31).

❑ Algorithm B: Text detection

Using Tesseract, an Optical Character Recognition software (OCR), we were able to perform text detection. We start by converting the feed into grayscale color mode and thresholding so that only the text is visible, and then pass the output into Tesseract which performs OCR returning the written text as a string. According to the detected text we are able to differentiate between different types of airplanes and display the type of the detected airplane on the screen.

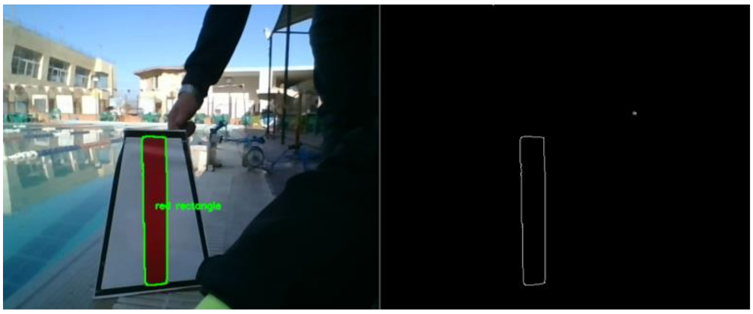
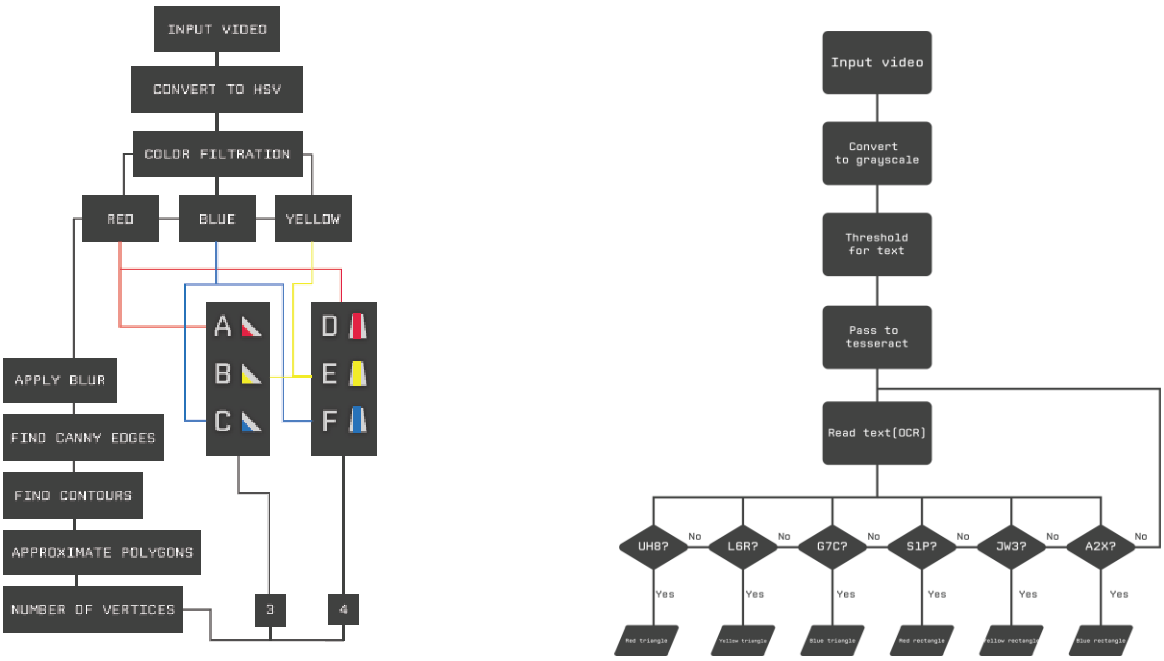


Figure (31): Shape Detection next to Canny edges



Figure(32): Shape Detection Flowcharts

c. Bluetooth Release

Two HC-05 Bluetooth modules are used for the release mechanism. The master module initiates the connection with the slave module which is integrated in the lift bag's control board. Using the joystick, the pilot sends a signal that activates the release mechanism, the master module transmits the signal to the slave that is then processed by the lift bag's control board and accordingly, disengages the debris/engine with a flick of the lift bag's arm.

Figure (33): Bluetooth Module

d. Acoustic Release

An array of buzzers situated in the ROV's dome is used To generate a double tone acoustic wave of frequencies **3.2**kHz and **6.3**kHz. After that, the wave is picked up by an acoustic sensor embedded in the lift bag which is also adjusted to operate at the generated frequencies, and in order, activates the release mechanism. Compared to the Bluetooth release, Acoustic release has a larger operating range that makes it a better candidate.

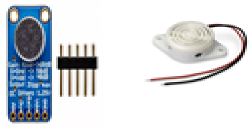


Figure (34): Buzzers and Adafruit Sound Sensor

2. Mission B: Earthquakes

a. WIFI Module

An ESP8266 wifi module, connected directly to the top side, is used to receive the leveling data transmitted by the OBS. Once the OBS is levelled, the wifi module receives the seismic data and sends them to the GUI, which plots all the data received. The wifi module is mounted on the ROV gripper to ensure that is always within the transmission range of the OBS.

Figure (35): WIFI data Plotting inside The GUI.

b. Rotation Motor

To level the Ocean-Bottom Seismometer (OBS), a custom payload design was required. An acrylic box installed on a DC motor's shaft with torque **20**kg.cm will lock the base's four handles and drive them in or out depending on the leveling needed. The required motor's torque was pre-calculated in order to select the suitable operator.

Needed raising and lowering torque calculated according to the following equations(taking friction=0.2) :

TR = F(dm/ 2) ((L + 3.14 (f) (dm))/ (3.14 (dm) - (f) (L)))

TL = F(dm/ 2) ((3.14 (f) (dm) – L))/ (3.14 (dm) - (f) (L)))

TR(Raising torque) **TL**(Lowering torque)

dm(mean screw diameter) **F**(Load)

f (coefficient of friction) **L**(Lead)

Figure (36): Rotational Motor Design on SolidWorks

3. Mission C: Energy

a. Pressure Sensor

One of the critical sensors in Osiris is the pressure sensor. Since there is a maximum depth at which Osiris can operate safely, it is essential to have telemetry of the depth at all times to avoid damage to the sealing. Using a **G1/4** Pressure Transducer Sensor, Osiris is able to determine its depth accurately.

Figure (37): Osiris' Pressure Sensor

In Addition to checking the safe operating region of the depth, Osiris make use of this pressure sensor in determining the accurate height of suspension of an Acoustic Doppler Velocimeter (ADV) for the third task.

10. Safety

Safety Philosophy

At MIA, our safety philosophy is built around the welfare of the crew, ROV, and the environment. We always strive to meet MATE's safety requirements by ensuring all MIA personnel adhere to the safety protocols and warning labels. Safety is never compromised in order to achieve schedule, budget or other objectives. Working in a safe, neat and tidy work space positively helped the company members to construct their ROV. Good ventilation and clutter-free space are utilized. Company members are well trained to adjust working within harsh conditions like dealing with slick surfaces and crowded work areas encountered in the workplace. The ROV is designed with several built-in safety features. All the electrical components on the ROV are carefully waterproofed to ensure optimal running of the system. Moreover, each part has been inspected for sharp edges that might cause any personnel harm or damage to the surrounding environment.

Safety Protocol Standards

- Assigning proper PPE and avoiding actions that carry a potential for injury.
- Inspecting equipment prior to use.
- Using proper technique when using any sharp tools.
- Using vice of proper size and capacity to hold work object.
- Using a barrier around a piece of equipment being pressure tested.
- Stop work when an unsafe condition or act could occur during operation; If in doubt, Stop the job.
- Using insulated electrical tools including insulated fuse pullers, hand tools and drills.
- Before working on any electrical equipment, it must be de-energized.
- Systematic safety checks are performed before every test.

Safety Features

We always strive to meet MATE's safety requirements. Starting from the ROV's power to the chassis, each and every aspect of safety was considered carefully. Some ancillary safety features are the thruster guards, warning labels, deburred frame edges, and bright propellers.

Figure(38); Examples of warning labels

Also, a suitable fuse is installed on the terminals of each key component. This includes but not limited to thrusters, motor drivers, cameras, and solenoids. Other safety feature include.

- Emergency kill-switch.
- Sealed electronics enclosure.
- Metal cable glands were used to seal wires.
- Deburred edges on the ROV.
- Thruster shrouds.
- Strain relief protection on wires.
- Warning labels on electronic systems and moving parts.

Safety Checklist

Pre-power test

- Area clear/safe (no tripping hazards, items in the way).
- Verify power switches and circuit breakers on TCU are off.
- Tether flaked out on deck.
- Tether connected to TCU and secured.
- Tether connected and secured to ROV.
- Tether strain relief connected to ROV.
- Electronics housing sealed.
- Visual inspection of electronics for damaged wires, loose connection.
- Nuts tight on electronics housing.
- Thrusters free from obstructions.
- Set compressor output to **2.75** bar.
- Power source connected to TCU.

Power-Up

- TCU receiving **48** Volts nominal.
- Control computers up and running.
- Ensure deck crew members are attentive.
- Power on TCU.
- Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity).
- Verify video feeds.
- ROV lights indicate “Safe Mode” (green).
- Test accessories.

In Water

- Check for bubbles.
- Visually inspect for water leaks.
- If there are large bubbles, pull to surface immediately.
- Wait **5** minutes, then check leak detector.
- Engage thrusters and begin operations.

Loss of Communication

- Cycle power on TCU to reboot ROV.
- If no communication, power down ROV, retrieve via tether.
- If communication restored, confirm there are no leaks, resume operations.

Pit Maintenance

- Verify thrusters are free of foreign objects and spin freely.
- Visual inspection for any damage.
- All cables are neatly secured.
- Verify tether is free of kinks.
- Visual inspection for leaks.
- Test onboard tools.
- Verify camera positions.
- Washdown thrusters with deionized water.

11. Challenges

a. Technical

Many challenges arose this year since the introduction of new components, systems and software. Fortunately, we were able to resolve them by reaching out to senior members of the company and searching for answers on the Internet.

❑ Webcam vs CCTV

Prior to switching to CCTV cameras, a Microsoft **480**p webcam was considered for the first mission, but was disregarded later for several reasons. The video stream was not seamless, often dropping to **1** frame every **3** seconds. The camera's response to light was poor, sometimes taking up to **3** seconds to adjust to any subtle change in lighting.Furthermore, after introducing the **30**-meter Ethernet cable, the image quality dropped significantly, and consequently, deemed impossible to perform any kind of processing on. Researching more on the matter and studying other options, we decided to use the analog cameras.

❑ Pneumatics

The pneumatic system was one of the major challenges since this is the first time the company has implemented it in an ROV. This called for seeking information about the system's advantages/disadvantages, components, symbols, and safety.

❑ Electronics Enclosure

Another challenge was the sealing and fabrication of the electronics enclosure as it consumed great effort especially the sealing of the acrylic dome since its availability is limited to few standard dimensions and shapes in Egypt, so this put us in a problem as the common used way to seal dome is by using gasket, but due to the small size of the dome's flange our company implemented another sealing method using O-rings. However, that might have been difficult if the radius of inner dimension of dome was variable.Fortunately, there was a small distance height about **0.015** m in our dome as the inner dimension radius was constant in it, so our company used this distance advantage to seal the dome by using O-rings. Also, accuracy and precision took major role during the fabrication of the electronics enclosure and the end-cap as their design required paying attention to the finest details to avoid errors. Moreover, the clearance used was tested carefully to ensure proper sealing.

❑ Thrusters

Another challenge was encountered this year, the company developed its own thruster by assembling its main parts in-house. Re-using components as bilge pump, T100 propeller and T100 nozzle from previous years enabled the company to stay in budget.

The main technical challenge is to perfectly accomplish this year's missions on time. However, achieving so requires many manipulators and electrical devices, our company maintained the minimal size and weight in order to award the bonus points regarding them.

b. Non-Technical

❑ Fund

Assuming full responsibility for funding our project was the real non-technical challenge this year as we had to pay for actual claims and not anticipated claims. Thanks to the plan that had been made we were exponentially more likely to succeed in affording the required supplies. We tried to make use of what we have, with great efficiency like making our thrusters.

❑ Societal Activities

Giving back to the local community is one of the core values that has shaped M.I.A. throughout the years. This year, we participated in a myriad of events not only to showcase our work in the robotics field, but to also raise awareness about the environment. Events like the college fair allowed the team to send their message across to the public regarding pressing environmental issues like plastic impact on the environment.

Figure(39): Flyers for the plastic awareness campaign

12. Testing & Troubleshooting

M.I.A. had a vision this year of starting work for the new season early to leave an adequate amount of time for periodic tests. The tests began by verifying Osiris' basic functionalities underwater. Afterwards, Osiris' performance and stability assessment in completing the missions took place. Throughout the testing phase, modifications never stopped in order to increase Osiris' efficiency in completing the tasks. The main advantage of long duration tests is the ability to discover hidden problems that wouldn't emerge otherwise. And here comes the purpose of the troubleshooting flowchart which starts by discovering a problem during the test, locating the source of problem by eliminating the other elements, and isolating the module causing this problem. The module is then unit-tested to diagnose the error and to assign the suitable solution for it.

Our ROV test was in steps as every subsection of vehicle tested before the ROV was assembled.

❑ Thrusters Test

The goal of this test was to calculate the max forward and backward thrust forces, we used a simple method to help in calculations. The thrust forces calculation was done using a link of 0.4 meters length connected from one end to a small digital balance and to a thruster from the other end. When the thruster is powered, the reading displayed on the digital balance is equal to the thrust force produced.

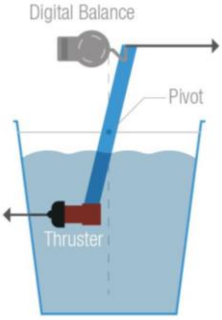


Figure (40): Thrusters' Test Illustration

❑ Electronics Enclosure Sealing Test

The aim of this test is to ensure that the electronic enclosure sealing was perfect even in a very high-pressure head range compared to the maximum pressure head ROV may reach in the competition. Test starts by filling the electronics enclosure with water and increasing pressure gradually using **hydrostatic pressure test unit** until **1.2** bars pressure is reached as this pressure is optimal for our test as it means that our ROV could be operated in pressure head reach **12** meters of water and this was high pressure head compared to maximum pressure head in competition which was 5 meters of water.

❑ Pneumatic System Test

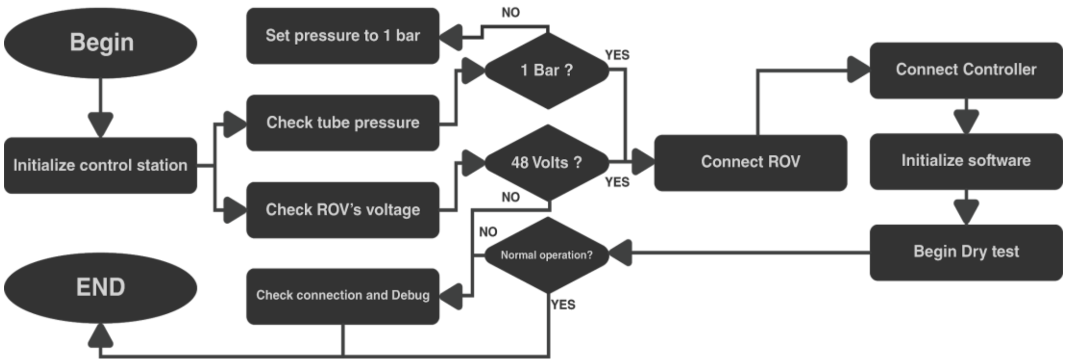
Our company put great attention to ensure proper connectivity regarding pneumatic circuits through testing them several times by assigning all needed pneumatic components to enhance safety and performance of the pneumatic system used in our ROV.

❑ Gripper Test

The purpose of this test is to check if it is suitable enough to do the required missions with the minimum power losses due to friction or any other forms of power loss. So, our company prototyped the gripper to predict any malfunctions that may occur and devise solutions beforehand. As a result, the piston stroke was found to be not suitable enough to hold objects tightly, also the friction between links was relatively large. Increasing piston diameter and stroke to overlap the friction losses fixed that issue. Another problem we encountered was that the end effector surface finish was smooth and required adding a rubber layer to provide more friction for a better grip.

❑ Electrical Test

Our main concern was the stability of Osiris's electrical system. We had to make sure that our converters can supply stable power to the system even under full load. Our tests showed that the main power-hungry component were the thrusters, each drawing over **4**A under full load.
Because of their high power consumption, and the fact that we are using ten of them, the thrusters had to be distributed such that a maximum number of four thrusters can draw power from one converter at a time. This was achieved by connecting four of the six horizontal thrusters plus two of the four vertical thrusters on one converter, while the other thrusters, as well as the communication board's power, were connected to the other converter. Since the ROV can either move horizontally or vertically at a time, this ensured that no more than four thrusters can draw power from the same converter.



Figure(41): Osiris' troubleshooting Flowchart

13. Reflections

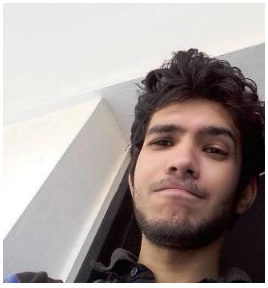
Ahmed El-Ramikh MIA Former Team Leader

I remember the first day I witnessed the robotics show that was performed by MIA inside our college, it was the day I decided I want to be one of this team! Joining MIA was a real turning point in my life; I learned through successes that hard work surely pays off! But more importantly, that failures are just the experience you need to succeed bigger next time!

When I look back now to the days I spent working with the team, I realize that this was the most precious way to invest my time. It did not only increase my technical experience and teach me the knowledge I use now in my professional work, but it also dramatically enhanced my leadership and teamwork skills! I learned in MIA what I could have never learned somewhere else, and I made the best friends with whom I share respect, belonging and loyalty. We shared together many special moments, even when we were too tired to work but we continued working anyway because we wanted to be the best! Sometimes we jumped and hugged each other when we finish the mission! And other times you find your friend supporting you and telling you that you did your best when we fail.

If I were to regret something I've ever done, is that I did not join MIA earlier.

Mahmoud Serour MIA Co-founder, MIA Chairman 2016



I was asked once in an interview: "what did the team add to you?", I said: " you never know you are strong until being strong is your only option" and from being strong, comes the values that MIA is based on. The values of being self-dependent and hard worker which make us fight till the last breath. Watching the team this year reminded me of the latest Etisalat's advertisement about world cup, I am so proud of what the team has achieved this year. Even though it has been two years since I graduated, I still have the same strange feeling – a strange mix between pride, happiness and challenge – when I see us competing in ROV. I always talk about the team in any related occasion as that will be always our legacy and our unique story.

Abd El-Rahman Zakaria MIA Chairman, 2017

The team's work was valued, and the team was allowed to grow. The new members learned about the previous experience. They worked toward the same goals, they trusted each other. The team grew professionally. They could see results from their effort. Their work was noticed in local competition when they did full mission.

Ahmed Farouk MIA Co-founder

The experience of participating in this ROV competition has changed my life improving my technical and non-technical skills. Our first participation in this competition was on 2014, we had the opportunity to participate in the international competition in Michigan, throughout the past years we have participated in the Egyptian regional competition learning new information, since then the team has developed clearly using the knowledge accumulated from previous experiences to excel this year in developing the best version of all our ROVs in all aspects including mechanical, electrical and software.

14. Lessons Learned

❑ Technical

This year was a critical year in M.I.A. history, it's the graduation year for a lot of members who participated in the ROV competition in previous years. So, it was suggested to make a call for members and accept as many as possible, making an intense training in the start of the season to be able to exploit seniors' knowledge before retiring by the end of the current competition. Improving new members' technical and problem-solving skills was a priority to be able to take the lead in the upcoming years, through the entire season, guiding, transferring knowledge and offering advices was our main goal to reach to the level where new members became more confident at voicing out their ideas.

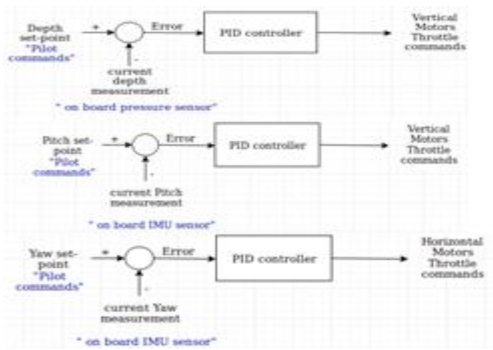
❑ Non-technical

Participating in local educational fairs improved the company members' interaction skills among other communities. The whole experience has bolstered the company members' interpersonal and management skills.

15. Future Improvements

This year has witnessed many improvements from previous years, but there is always place for further improvements.

- Developing a more **advanced Ballast system** to attain self-suspension. A feature that will improve maneuverability which in turn, enhances the user-experience.
- Using **materials with lighter weight** (i.e. Carbon Fiber, Aluminum) will help the company to include more features and achieve better overall performance.
- Making a mechanical arm instead of fixed gripper to provide more degrees of motion.
- **Dynamic stability controller**: in order to achieve fast response depth and stability controller independent on the parameters of the ROV like (buoyancy, central of mass of gravity,…etc.), a closed loop feedback stability controller should be implemented.This controller will be fed with the depth reference set-point according to the pilot driving commands and will adapt the depth of the ROV to reach the desired set-point by eliminating the error between the desired set-point and the actual depth.The feedback signal of the current depth will be fed to the controller by the on-board pressure sensor as illustrated in the following block diagram. the same concept can be applied in order to control the Yaw, and Pitch angles of the ROV. The main advantage of the implementation of the closed loop control is that the depth and the orientation of the ROV can be easily controlled without the need to know the exact parameters of the ROV also to achieve such a desired behavior other factors should be measured like the density of the water which depends strongly on the temperature. So, by applying this



Figure(42): Block Diagram of Dynamic Stability Control.

scheme of control a fast response dynamic stability control can be achieved regardless of the factors and the parameters of the ROV and the surrounding environment.

16. Acknowledgements

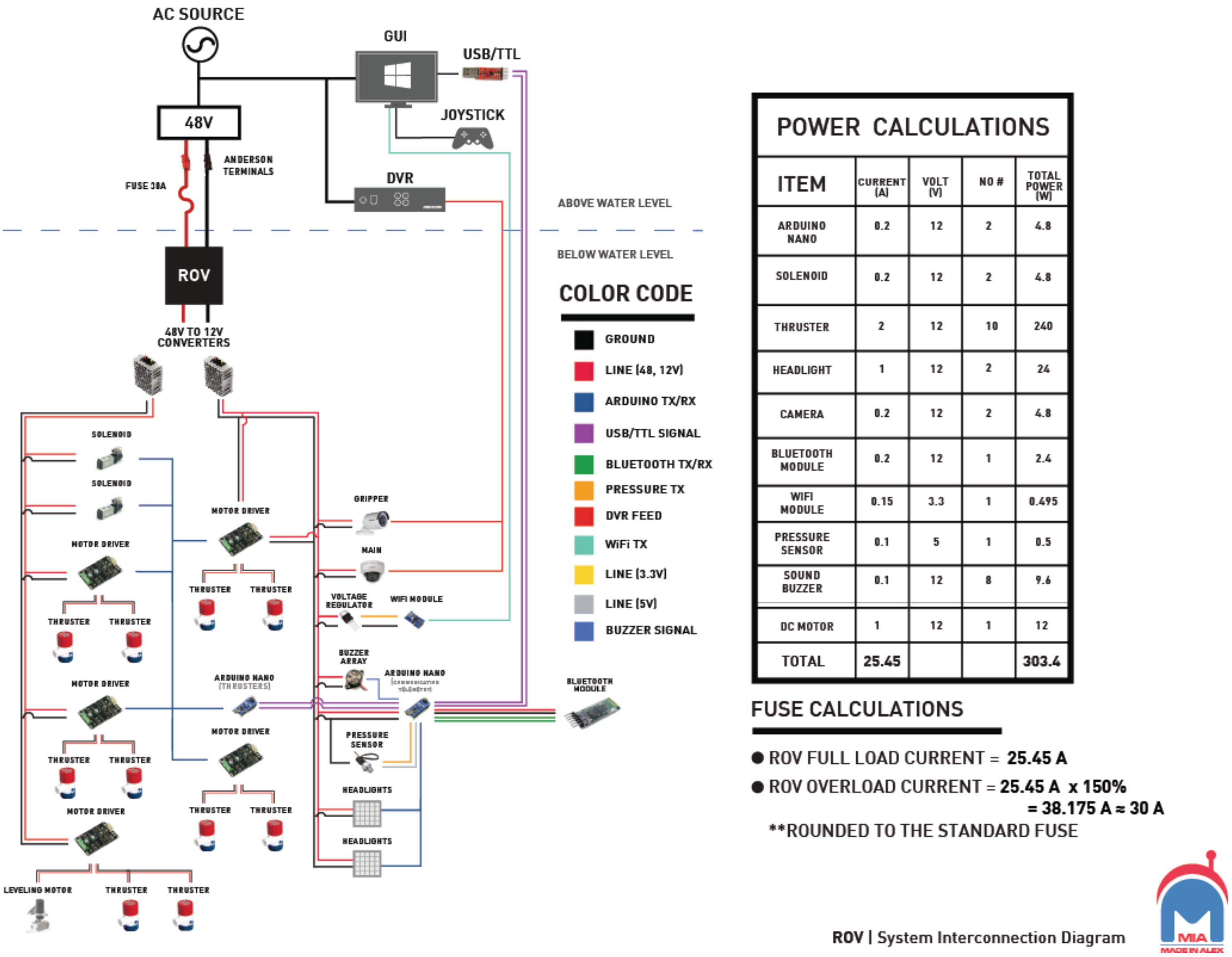
- MATE Center for organizing this year's competition.
- Faculty of Engineering, Alexandria University for their generous donations and encouragement.
- WE Telecom Egypt for their great support and funding our travel expenses to the International competition in June.
- Egyptian Engineers Syndicate for providing their swimming pool for testing.
- Arab Academy for Science, Technology & Maritime Transport.
- Alexandria Fertilizers Company for their support and sparing no efforts in order to build our ROV.
- Hadath organization for organizing the competition.
- Our supervisor: Dr. Ahmed Naguib
- Amr Raslan for his technical support.

17. References

- Microelectronic Circuits by Sedra Smith, 5th Edition.
- Johnson & EVINRUDE GENUINE PARTS (Propeller selection guide).
- The ROV Manual, Second Edition: A User Guide for Remotely Operated Vehicles 2nd Edition by Robert D. Christ and Robert L. Wernli, Sr. (Auth.), 2014.
- "Design of Machinery", Third Edition by Robert L. Norton, the McGraw Hill Companies, Inc. 2004.
- Andreas Alexander, Principles of fluid mechanics
- Munson Young & Okiishi, "Fundamental of fluid mechanics"
- http://doc.qt.io
- https://docs.opencv.org/3.4.0/
- https://pypi.python.org/pypi/pytesseract

18. Appendix

a. Osiris’ System Interconnection Diagram



POWER CALCULATIONS

ITEM	CURRENT (A)	VOLT (V)	NO #	TOTAL POWER (W)
ARDUINO NANO	0.2	12	2	4.8
SOLENOID	0.2	12	2	4.8
THRUSTER	2	12	10	240
HEADLIGHT	1	12	2	24
CAMERA	0.2	12	2	4.8
BLUETOOTH MODULE	0.2	12	1	2.4
WIFI MODULE	0.15	3.3	1	0.495
PRESSURE SENSOR	0.1	5	1	0.5
SOUND BUZZER	0.1	12	8	9.6
DC MOTOR	1	12	1	12
TOTAL	25.45			303.4

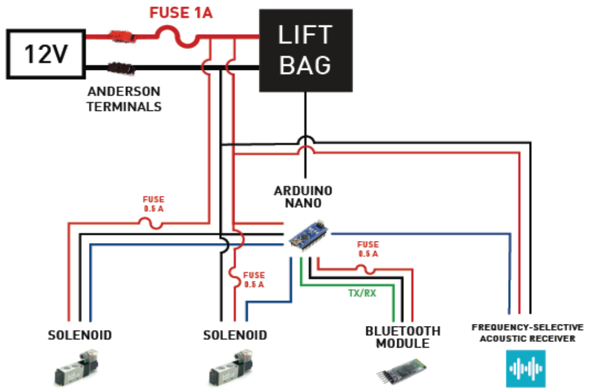
FUSE CALCULATIONS

- ROV FULL LOAD CURRENT = **25.45 A**
- ROV OVERLOAD CURRENT = **25.45 A x 150%**
  = 38.175 A ≈ 30 A

**ROUNDED TO THE STANDARD FUSE

b. Non-ROV Devices System Interconnection Diagram

Figure(43):Inductive Coupling Connector



Figure(44): Lift Bag SID