ALEXANDRIA UNIVERSITY
ALEXANDRIA, EGYPT

TORPEDO™
ROV

TORPEDO TRITON

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Abstract

Exploring areas beyond our earth requires a very stable and cost efficient ROV. Our company introduces Triton, a state of the art ROV, designed to tackle the challenges proposed this year with ease. Torpedo engineers are heavily experienced with previous projects in the robotics field. The company has got a wide variety of employer specializations; mechanical, electrical, software and naval engineers are enrolled, producing a reliable vehicle. Teamwork and responsibility taking are the main aspects of our company.

In the beginning, the main components of the ROV were designed using 3D Cad software, using Autodesk inventor, flow simulated using ANSYS Fluent. They were then manufactured and tested thoroughly. Next, our R&D department started designing mission specific tools, one of them is a multi-purpose end effector of a 2-DOF manipulator, and another is a high precision pressure sensor that measures up to 14 bar. Light weight of our ROV was a main concern, therefore, emphasis on light weight was taken into consideration in our designs.

Figure 1. Real view of Triton.

Our ROV is equipped with an analog HD camera along with a wide angle camera, providing a view of most of the surroundings. Our company manufactured a user friendly surface control unit, cancelling out the need for a professional person to operate. Wiring was as compact as possible to reduce size and weight. State of the art sensor feedback system was designed and fabricated. Overall, our systems sustain stability.

Figure 2. Torpedo team members along with Triton ROV

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Design Rationale

1-Mechanical System

A. Design Process

In order to deliver the most optimum design, our company spent hours and hours in discussion sessions, brainstorming, and sketching, where many creative ideas were proposed and developed. The main concern this year was achieving all these criteria while sticking to the dimensions and weight limitations. During the design process, we concluded that if we took the approach of the traditional vertically parallel-plate frame, we would waste lots of space where our components should fit. Therefore, we relied on a horizontally circular parallel-plate frame, usefully utilizing most of the space provided. In addition, to produce a light weight ROV, we chose light weight/high strength materials that could fulfill our needs, for example, Aluminum.

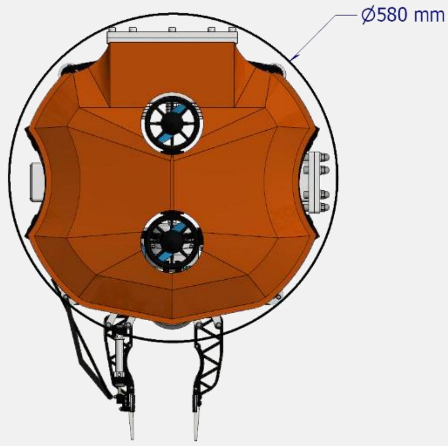

Figure 3. Plan view of Triton.

B. Frame

We faced a great challenge in trying to make the frame as light as possible and standing with stresses due to the weight of ROV. Our frame consists of 3 horizontally circular parallel plates, connected by 8 vertical columns.
We move the thrusters layer (2nd layer) up and down through a groove in the columns to ensure that the center of thrust force and the center of drag force lie on the same line of action to prevent the yaw moment. Next, we conducted stress analysis to obtain a satisfactory result of factor of safety, Figure 4, showing that maximum displacement doesn't exceed 2.131 mm at the worst point. Next, fabrication took place; we chose the frame material to be PA 6 polyamide (Artelon), which has been cut with a CNC routing machine, then we connected the top and the bottom of the frame with the columns of (Artelon), which was fabricated by a lathe machine.

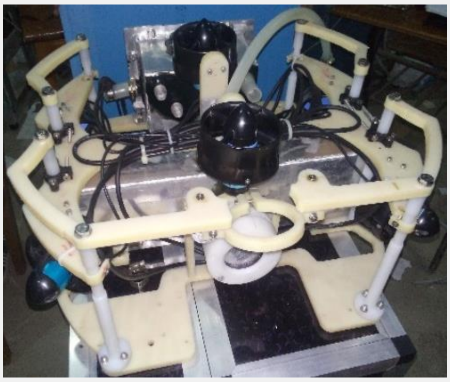

Figure 4. Fabricated and Assembled Frame.

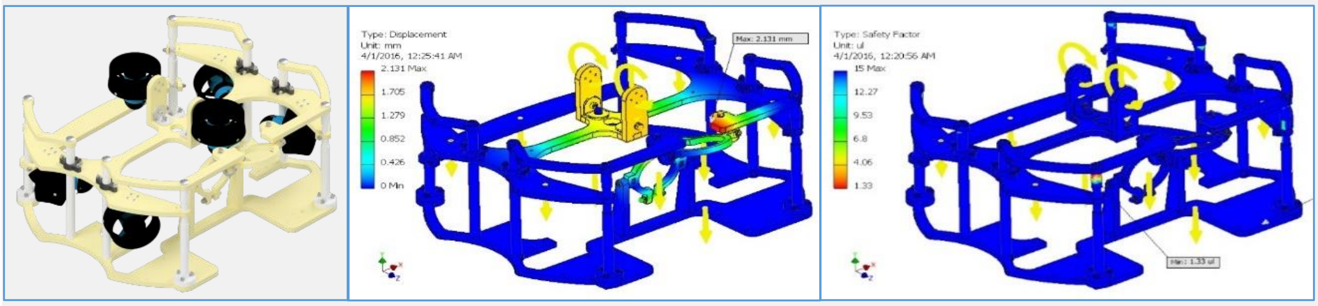

Figure 5. Frame's stress analysis.

C. Thrusters

We used six T100 Brushless Motor thrusters (Built-in ESC). Four thrusters are arranged with an angle of 30°-60° in order to make use of the greater force component in the forward/reverse direction. Two thrusters for the vertical

Figure 6. BlueRobotics T100 Thruster.

and pitching moves. This arrangement provides ***Triton*** with five degrees of freedom. These degrees of freedom ease the maneuvering for the product demonstrations, as many objects need to be deployed with a certain angle. Each T100 Thruster provides ***Triton*** with 2.36 kgf and 1.85 kgf, that allowed us to accurately compute the forward speed and the max drag force facing ***Triton,*** as shown in the next section.

D. Computational Fluid Dynamics

Predicting and controlling fluid flow is a critical aspect in optimizing ***Triton***'s efficiency. As a result, the streamline shape is one of our considerations during the design process. Computational Fluid Dynamics (CFD) was used to predict and verify flow effects on ***Triton***'s movement, such as drag and lift force values and distribution on ***Triton***, then adjust thrusters to stabilize movement. therefore, as thrust force is known, the maximum velocity of our vehicle can be determined. CFD was done using ANSYS Fluent and validated experimentally; the results are as follows: Max Velocity ≈1.15 m/s at a maximum thrust force of 71.5N. CFD results allowed us to accurately relate our motor signals to the actual speed.

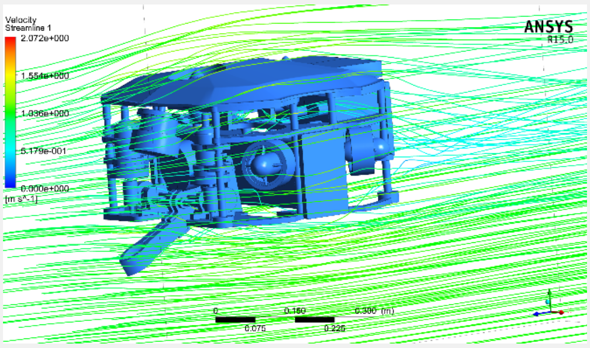

Figure 7. Triton's streamlines by Fluent.

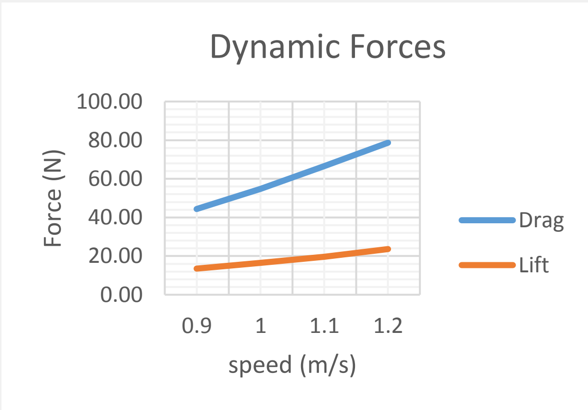

Figure 8. Drag & lift vs ROV speed graph.

E. Sealing

1- Electronics Housings

In order to have the minimum weight in air, we must keep the buoyancy force in water to a minimum, as we must neutralize the extra buoyancy force with extra weights to reach the equilibrium between weight and buoyancy force. We decided to design our Insulation boxes in a box-shape to perfectly fit our electrical components and keep the unused space to a minimum, consequently, reducing air volume and buoyancy force.

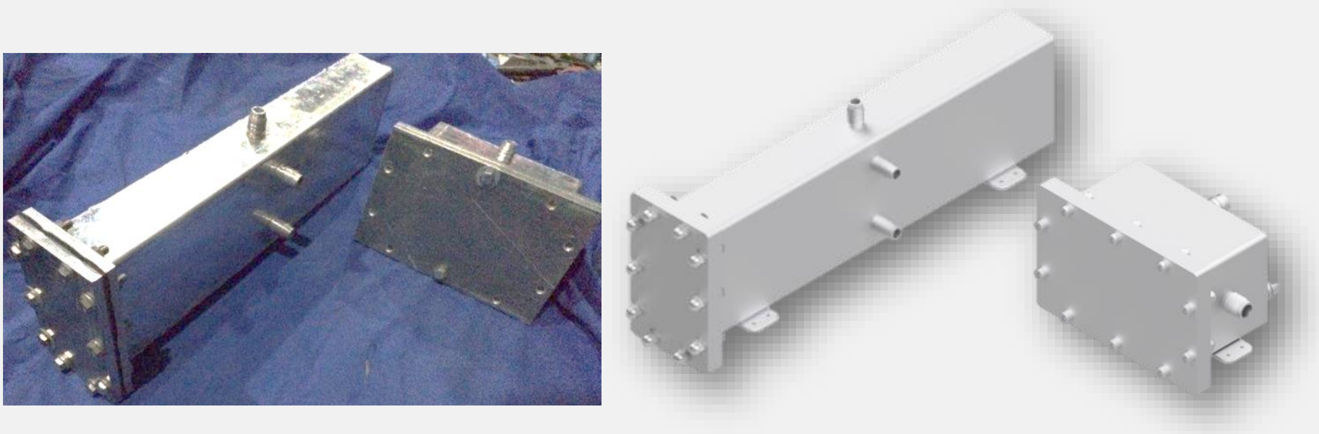

Figure 9. Electronics Housings.

Aluminum sheets of 3mm thickness were selected to be the housing material, providing minimum weight and high thermal conductivity, allowing better heat transfer for cooling the internal hardware circuits and the 1000 Watt DC-DC converters, and a 6mm thick sheet was selected to be the flanges material to handle the axial tightening force for bolt tightening without causing deflection to the flange and consequently cause water leakage. Using finite element analysis to obtain a satisfactory result of safety factor under the maximum depth of 15 meter, as shown in figure 10. One of the two boxes is for power converters, and the other is for electronic components and hardware circuits that control the vehicle to minimize the magnetic interference. Our face sealing depends upon one layer of square gaskets of rubber. The result after many times of testing was no leakage at all.

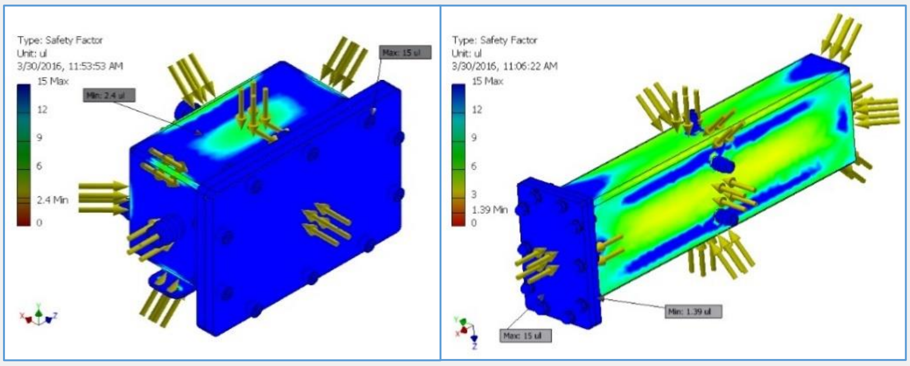

Figure 10. Stress analysis of Electronics Housings.

2- Wire Sealing

For wire sealing, our R&D department developed an effective prototype to seal the wires, using nozzles installed in each wire entering or leaving the insulation boxes, connected to a hose and rubber rings inside. To ensure zero leakage, two levels of rubber sealing are used, and hoses were bind from each side by jubilee clips.

Figure 11. Wire sealing technique

3- Camera Housing

The housing consists of five parts, male and female, made of PA 6 polyamide (the same frame material), an O-ring in between, a gasket between the male part and the 6mm glass, ensuring no leakage. Each camera's housing was tested under a pressure head of up to 20 meters to ensure complete sealing, and non-doubtable reliability.

Our R&D department has constructed a pressure vessel using our last year's huge stainless steel Electronics Housing to insure that all our sealing will withstand the 15m pressure head, so we could experimentally verify our CAD analysis.

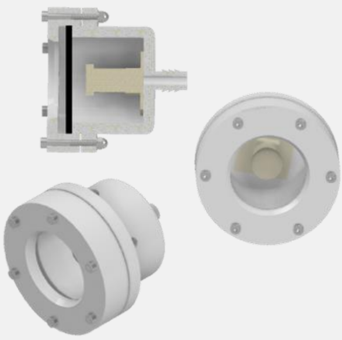

Figure 12. CAD design of the camera Housing.

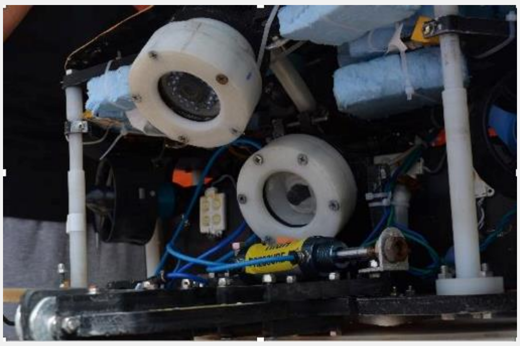

Figure 13. Cameras mounted on Triton ROV after fabrication.

F. Buoyancy and Balancing

Table 1. Buoyancy data.

Triton weight	14.990 Kgf
Buoyancy force	12.240 Kgf
Foam volume needed for about 4% positive buoyancy.	$2.750 * 10^{-3}$ m^3

According to Archimedes law, we decided to go with slightly positive buoyancy. In case of any hardware failure or the inability to communicate with the vehicle due to system failure, the vehicle will slightly rise upwards until it reaches the surface. By equalizing the buoyancy force produced by the immersed total volume of ***Triton*** to the dry weight of the vehicle, we were able to get the required volume for the floating material (Foam) with a density of 36 Kg/m^3. ***Triton*** weights are distributed in a symmetrical manner to prevent tilting moments underwater, which in return increases the stability of our vehicle. Another important part is the fiberglass, it optimizes the dynamic water flow while rising to the surface. In some instances, it is used to prevent pitching.

Figure 14. Fiber Glass Fabrication Process.

2-Electrical System

Year after another, our company's main goal is to improve system stability, portability and creation of a more intuitive design. Whether it's above or below the surface, our company makes sure every detail is being taken care of to the tiniest detail.

A. Tether Control Unit

Our tether control unit is the main station of our ROV, putting together precise control aspects, power control, safety handling above and below the surface, video distribution and lastly, voltage and current measurement for system feedback to our co-pilot, in case of any emergency situations.

One of the main TCU features is minimizing setup time by 60% to be 90 seconds, thanks to fast connectors, whether it's the main 48V or the ***Triton***'s power and communication tether. We used an XT-60 polarized power connector to avoid any miss-wiring by members

Figure 15. Tether Control Unit.

Figure 16. Polarized 8-pin connector on the left and XT60 power connector on the right.

operating the system. Also, we used a polarized 8-pin connector for our communication terminal, which proved to make extremely firm, easy and stable connection of our tether.

Safety is the main concern, therefore, our company preferred using a 25A DC circuit breaker to protect ***Triton*** from overload and short circuit hazards, also (unlike the fuse) used as a fast ON/OFF switch. For real time monitoring of voltage and current drawn from MATE's power supply, our engineers built a PCB containing current and voltage sensors and a 16x4 character LCD, we relied on a digital sensor over permanent magnet moving coil (PMMC) for the sake of space and more system integration. Our video feed is distributed using a Digital Video Recorder (DVR) and viewed through a 21” LCD monitor.

Figure 17. Company's Tether man during mission training.

B. Tether

We incorporated an Ethernet CAT6 cable for the communication tether, 2 of the twisted pairs were used for each camera to minimize noise, one for the communication (I2C) line and one is a common ground. We preferred the CAT6 type over CAT5e of last year, because of the greater transmission performance and better immunity from external noise. CAT6 is also more robust in terms of malleability and can handle harsh conditions.

As a power tether, in order to stand for the current drawn, minimize voltage drop to an acceptable rate, have the optimum weight and also the minimum cross sectional area in order to minimize the drag force. Considering derating factors of water thermal resistivity (1.17), ambient water temperature of 25°C (1.22), max current drawn from the source (20A), We were easily able to choose our tether in order to have the optimum gauge number of our cable, so we chose to use a 13 AWG stranded cable, considering a factor of safety of 1.5.

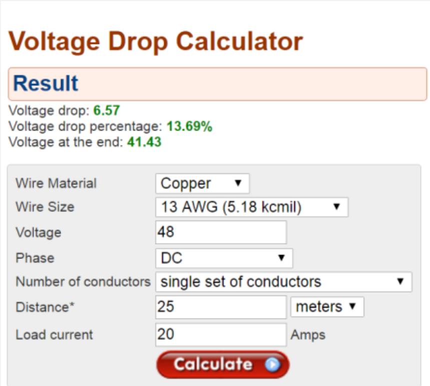

Figure 18. Voltage drop percentage at full load.

C. Joystick

As for a big change this year, we decided to use a high-end joystick. Striving for an industrial level ROV and TCU, our company’s engineers emphasized that their pilot and co-pilot should obtain the best out of the ROV by controlling it using this magnificent joystick from Saitek. The joystick incorporates X-Y-Z axis, in addition to 3 sliders and a twist axis, 17 buttons, 3 toggles and 3 hat buttons, which is more than any other normal joystick available on the market. The large number of controlling options and intuitive overall design opens up the way for more maneuvers and output options. It also has an LCD that displays mode, clock, time passed since the start.

Figure 19. Saitek X52 Joystick.

D. Electronics

Power Conversion Box

Since most of the ROV components operate on 12V, our company had to step down the voltage from 48V to 12V. After a thorough search for a suitable DC-DC converter, we chose MEAN WELL SD-500L-12 DC-DC converter, because of its high specifications and safety features like overload, overvoltage, over temperature, short circuit and input polarity protection. The converter has a high efficiency of 84%, this allowed us to accurately calculate the power consumption, allowing us to choose our elements wisely, such as the suitable power tether and circuit breaker.

Figure 20. MEAN WELL SD-500L-12 DC-DC converter.

Communication Box

Our company made sure to self-manufacture its own electric boards, using our CNC routing machine, placing components and soldering them, this way we ensured 2 outcomes, less expenses, by not sending the board out to a factory, and excellent board finish, by using our own CNC router from last year.

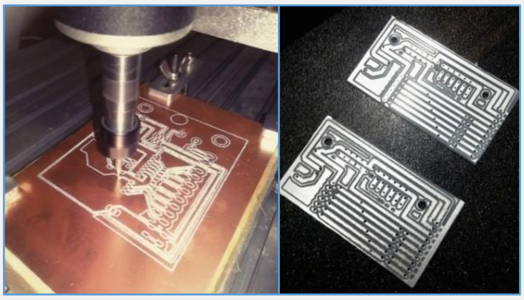

Figure 21. CNC machined PCB, manufactured by our company.

Since our company seeks firm, stable connections, and fast maintenance, our engineers proposed using a D-25 parallel port connector, as well as D-15. In the past, we used normal male-female cables, it proved to be inconvenient to us, therefore, we preferred the D-25 and D-15 solutions. All components' wires are fed into the box and distributed as follows, 4 thrusters' communication wires * 6 thrusters = 24 wires (D-25 port), while cameras, manipulators, and tether are collected and soldered to the D-15 port.

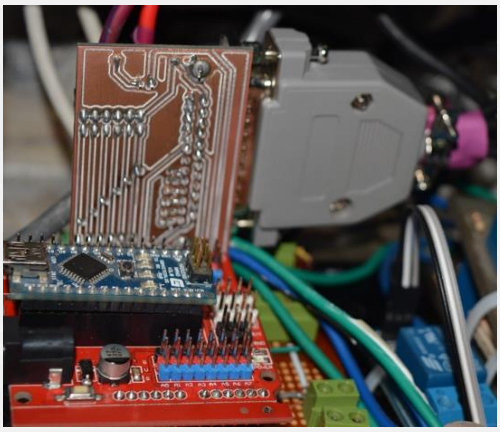

Figure 22. After installing the D25 port and connecting the 6 thrusters to it.

For processing purposes, our company needed to use 2 Arduino UNO boards, but since the huge success of the motherboard way of mounting electric boards, our company decided to repeat the procedure while taking into account the space utilization, therefore, we used Arduino Nano with a circuit board that acted as a small shield. One Nano for controlling thrusters, camera feedback, lights and manipulators, while the other is for thrusters' feedback (RPM, temperature, and current) and sensors' feedback.

Inertial Measurement Unit

Our company used the Adafruit 9-DOF IMU Breakout. This module outputs yaw, pitch, and roll angles. The feedback is sent to the onboard Arduino, displaying the data on the GUI, allowing the pilot to locate his yaw orientation, know the tilting angles, which assists in the product demonstration, mainly during keeping a stable orientation while measuring the temperature of the water flow.

Figure 23. Adafruit 9-DOF IMU.

E. Communication

Our company had 3 choices of communication during the design phase, UART with RS485, SPI and I2C. The UART method needed extra hardware, SPI needed more conductors and operates at lower ranges, and I2C has got the advantage over both of them, less hardware, long ranges, and just 2 conductors, regardless the number of slaves connected to the line (Max. 127). Firstly, I2C communication protocol featured a convenient transmission speed for our needs. Secondly, all our thrusters and sensors are interfaced through I2C, so, communication errors and difficulties are kept to a minimum and the processing power demand of our onboard controller is decreased. Moreover, 2-way communication could be achieved easily between the onboard brain and all other ROV components, like thrusters. The only obstacle faced was the increased capacitance of the long cable, we had to alter the values of the line's pull-up resistors until we reached the optimum value for line stability. All thrusters and sensors' feedback is transferred to the TCU Arduino attached to the same line.

F. Graphical User Interface

A graphical user interface is one of the ways of viewing feedback from the ROV on a screen, Providing a high level interface for the pilot and co-pilot. We designed a windows application, written in C#. It is designed to view sensors readings and send/receive commands to/from ***Triton***. It also shows progress in mission, which conserves the time of the Co-pilot for better use.

Figure 24. *Triton* ROV Graphical User Interface.

G. Vision System

In order to improve environmental interaction, our company paid attention to cameras selection, so, we relied on an Analog HD (AHD) camera to be the main camera, viewing the surroundings, and the other one is a wide angle analog camera focused on our payload tools. AHD is very cost effective, reducing total cost of vision system.

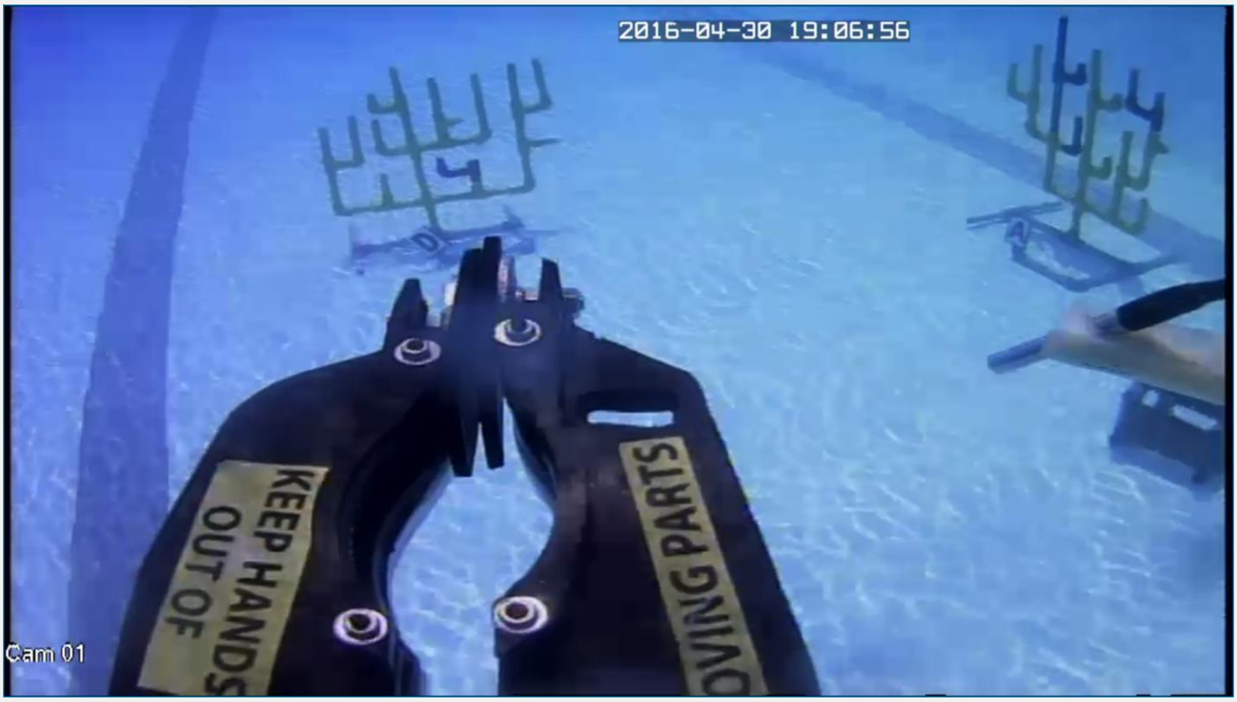

Figure 25. A screenshot of our wide angle camera, showing all details of the 2 colonies.

H. Software and Algorithm

Our company has developed more than an algorithm in order to provide our pilot intuitive maneuvering and overcome water current issues and pitch angle deviation when objects are lifted.

Thrust Vector Algorithm

Mapping the joystick signals into motor signals was the ordinary way to control the ROV, however, this way won't provide any complex movements. This year, our R&D department has developed a thrust vector algorithm that allows ***Triton*** to do compound movements, by calculating the thrust needed for each thruster, to do the desired movement such as rotating while going forward, or move in a certain degree (for example 25° with respect to forward). It isn't only calculating the thrust in case of all thrusters are working, but also it copes with thruster's failure, so in case that not all thrusters work properly, ***Triton*** still have the ability to do the complex movements.

Zero Pitching control

When grabbing objects during mission, Triton's buoyancy changes and water currents causing a large deviation in pitch angle (around 30 degrees). This problem slows down our pilot, as he has to keep readjusting the pitch angle (manually) to zero. Therefore, we developed an algorithm that keeps the pitching angle to 0° automatically, utilizing the IMU as the feedback and vertical thrusters as the actuators. The result is a decent closed-loop control system that speeds up mission performance.

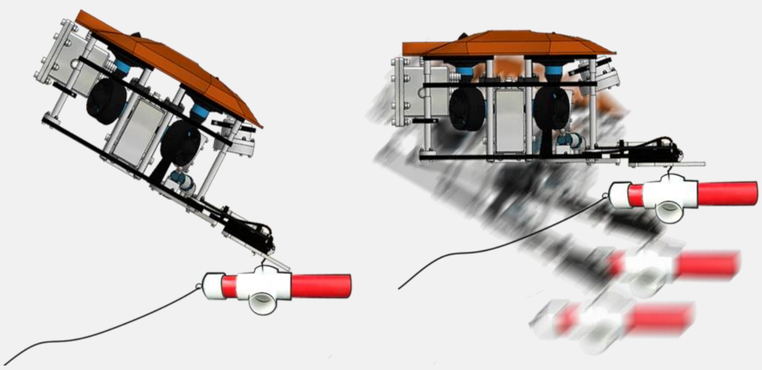

Figure 26. Illustration of Zero Pitching Control.

3-Mission Specific Tools

A. Pressure sensor

For depth measurements (ocean depth and the thickness of ice crust), we used MS5803 14BA high precision pressure sensor module from Sparkfun. A transparent type of epoxy was used to seal the electronics around the sensor itself. Interface wise, I2C was the best choice, because our system's main communication line is I2C.
We calibrated the depth sensor by comparing it to a known barometric pressure when the ROV is out of the water. The resolution of the sensor is of 1 / 0.6 / 0.4 / 0.3 / 0.2 mbar; we chose 0.2 for maximum accuracy. The sensor measures absolute pressure and converts it to height, subtracting the height difference (Surface and ice sheet bottom) determines its thickness. Depth of the ocean is calculated in a similar manner.

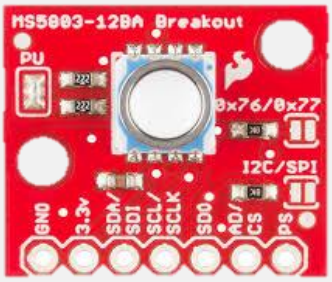

Figure 27. MS5803 14BA Pressure Sensor.

B. Temperature sensor

In order to have an accurate and reliable measuring of temperature of the venting fluid, we used a pre-wired and waterproofed version of the DS18B20 digital sensor and ensured its sealing by using our wire sealing techniques. We chose a digital sensor to avoid any signal degradation even over long distances. DS18B20 has stable range (-55:125 °C) (218:398K), resolution up to 12 bit, and ±0.5°C accuracy which is suitable for competition specifications. It also communicates with our system with one-wire protocol, that allowed ease of integration.

Figure 28. Temperature sensor before and after installation.

C. Multi-tasking Manipulator

Due to weight & dimension restrictions, we designed a light weight manipulator that could tackle most product demonstration tasks. Our research and development department developed an effective two DOF arm with minimum weight, minimum power consumption, and maximum holding force.

Basic design

As high holding force was needed, pneumatic power was used, based on 2 pneumatic cylinders, we built up our manipulator. A Four-bar mechanism was used to perform the parallel motion in the x-direction with only 20 mm in y-direction which gives high accuracy and intuitive control to our pilot. End effector consist of a vertical groove to hold cylindrical elements(flanges) with a maximum diameter of 140 mm. A unique second degree design was performed without turning all end effector which would need a large piston cylinder & space. the light actuator is held by the end effector to rotate the objects only with unique design.

Figure 29. Multi-tasking Manipulator.

Materials and Manufacturing

Our manipulator parts were designed based on the steel structure idea to use minimum material as possible, 10 mm & 6 mm Artelon plastic sheets were used for the main parts and manufactured by CNC laser cutting.

Actuators

- Main actuator: A Double acting piston with Ø25mm to achieve maximum holding force of 24N at 2.75 bars (40 psi), which is suitable for our situation (minimum weight & high holding force).
- Second degree: A single acting piston with Ø12mm for turning objects in 0-90 degrees.

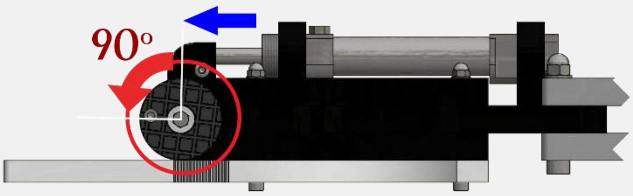

Figure 31. Illustration of the 2nd degree.

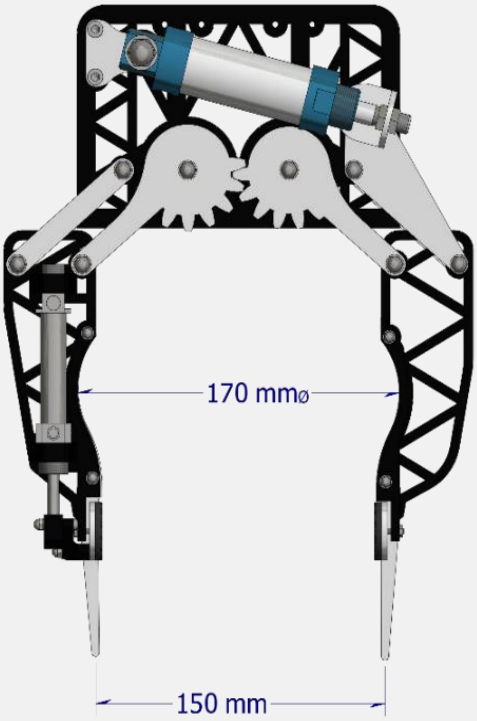

Figure 30. Top view of manipulator in CAD.

Special Design to perform tasks

Specially designed end effector enabled our designers to reduce the number of DOF needed to perform tasks efficiently.

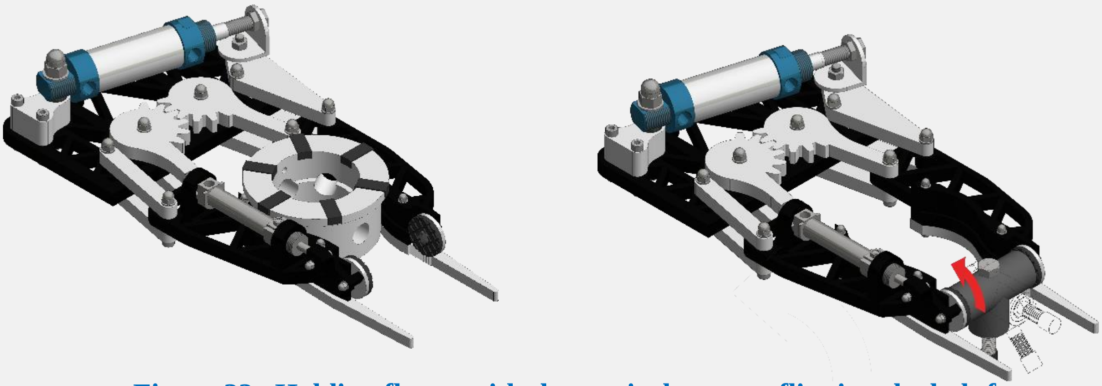

Figure 32. Holding flange with the vertical groove, flipping the bolt from the vertical position to the horizontal using the 2nd degree.

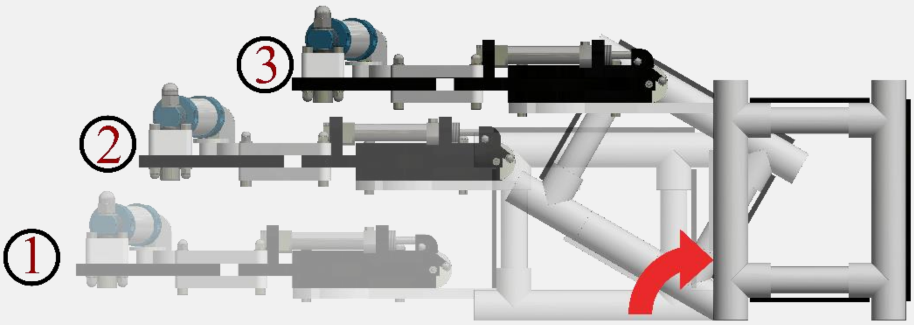

Figure 33. Turning over the CubeSat with the end effector.

Safety

A-Design Safety and Philosophy

As safety is the main priority to our company, safety procedures are strictly imposed during the designing, manufacturing, handling and testing. Our mechanical team designed safe parts with fillets to prevent sharp edges, ensured well sealing and used covers for moving parts, so all propellers are shrouded with kort nozzles. Screw caps for no sharp ends of bolts and warning stickers were also added to highlight dangerous components.

B-Workshop

Our team members' safety comes first, so as to keep everyone safe without injuries or accidents. We had put some rules to follow, all members must wear personal protective equipment (PPE), such as gloves, goggles, and face masks while existing in the workshop during manufacturing. Cords are kept out of aisles and walkways to keep the area neat and prevent tripping. We also followed the instructions of material safety data sheets for every product used in the production phase.

Figure 34. Mohammed Attia wearing PPE while working.

C-Electrical Safety

1. All electrical equipment has been enclosed in a sealed housing with padded insulating material. All hardware circuits are connected to fuses according to the maximum load.
2. A 25A circuit breaker in order to avoid short circuit or overload hazards.
3. Polarized 8-pin connector and XT60 power connector to avoid any accidental miss connection.
4. We also have a feedback from all of our thrusters to avoid any overload to any.
5. Our TCU is equipped with an emergency switch, in case of any urgent situation.

D-Operational and Safety Checklists.

Pre-power:

- ✓ Check Area is clear/safe (no tripping hazards or tools blocking the way)
- ✓ Ensuring Main switches and circuit breaker on Surface Control Unit are off.
- ✓ Checking that tether is connected thoroughly to and from ROV.
- ✓ Double check that electronics housings' nuts are well tightened.
- ✓ Double check that all jubilee clips are well tightened.
- ✓ Verify air compressor is regulated to the intended working pressure.
- ✓ Ensure air compressor is securely connected to Surface Control Unit

Power-Up

- ✓ Power source is switched on and connected to Surface Control Unit.
- ✓ Verify voltmeter is reading 48 volts on the LCD.
- ✓ Ensure GUI is started and codes are ready to run.
- ✓ Informing team mates on deck that power is on.
- ✓ Perform a dry test for the gripper and thrusters and confirming the status to the deck.
- ✓ Verify DVR is working properly.

In Water

- ✓ Tether man attentively places ROV in water.
- ✓ Check for bubbles that could mean any leakage.
- ✓ If large bubbles, pull to surface for maintenance.
- ✓ Wait few minutes, then
- ✓ check leak detector.

- ✓ If everything is OK, begin mission.

ROV Retrieval

- ✓ Pilot calls tether man to pick. up ROV from water.
- ✓ Deck crew calls confirms "ROV on surface!"
- ✓ Operation Technician powers down Surface Control Unit.
- ✓ Operation Technician confirms "Safe to pick up ROV"
- ✓ After securing the ROV on deck, deck crew calls out "ROV secured on deck"

Leak Detection Protocol

- ✓ Surface immediately
- ✓ Power down TCU
- ✓ Inspect (May require removal of housings)

Loss of Communication

- ✓ Operation technician reboots ROV from TCU and checks status again.

If no communication:

- ✓ Power down ROV
- ✓ Retrieve via tether
- ✓ If communication restored
- ✓ Confirm there are no leaks
- ✓ Resume mission

Conclusion

A. Technical challenges

Mechanical

This year's ROV weight and dimensions limitations were the most difficult challenges for our company. We needed to manufacture a high quality ROV, keeping in mind the material used, it's weight, dimensions, and efficiency. Our company members were proposing lots of creative ideas to tackle this challenge, some of these seemed to work fine, and some were not. The electrical aluminum housings we used provided less weight and high strength. ROV frame was designed in a way that keeps it standing well against all stresses while cutting the material usage as much as possible. Mechanical members cooperated with electrical members, stressing on implementing compact electronics to reduce size, hence, reduce weight.

Electrical

Our two main challenges were loss of communication on the I2C bus and the size of the internals of the communication canister. We figured out the cause of the communication loss, which was a result of the increased capacitance on the line, we tackled it by altering the pull up resistance on the data and clock lines and it became stable. For the size, we used Arduino Nano instead of UNO, providing the same processing features and number of I/O, while being way smaller in size. The received thrusters' cables were 24 cables, it made a mess and increased wiring complexity, but our skillful members used a D-25 parallel port connector to handle the huge number of wires. It worked successfully, although it's initial soldering is tedious, but it is only for the installation time.

B. Non-technical challenges

Increasing the harmony and understanding between team members is such a great challenge that needs prior planning and real-time problem solving. Our new members were of less experience, but the seniors and mentors managed to let them engage quickly by providing advices and helping in organizing their schedules. In order to test triton's performance, the team needed a pool near our workshop to operate on. Our University completed the necessary documentations with our workshop director and we managed to get access to the university's pool every day from 8:00 am to 3:00 pm. Funding wise, we faced many difficulties in finding a sponsor to our work. Thanks to our supervisor who helped us to make a deal with a sponsor that could provide us with sufficient fund.

C. Technical lessons learned

How communication protocols work, and learning what to choose according to our needs. Programming skills in C, C++, and C# were enhanced, due to problem solving and extensive debugging. New methods of housing electronics were explored, learned, and tested, providing more experience to our young and senior members. Studying the kinematics of ROV and implementing it in software (Vector algorithm). Gain of experience in creating an intuitive Graphical User Interface (GUI).

D. Interpersonal skills gained

Since all our company members are college enrolled, they have to keep track of their college studies, they managed to separate the time of work and studying, by putting a clear realistic plan to follow, eventually increasing their time management skills. Our sponsorship directors learned to communicate efficiently with company representatives and managed to persuade some of them of our work. Eventually, supporting us financially. This year, our company has a role in community, our members volunteer in teaching robotics to the young people, improving their presentation and communication skills.

E. Reflections

"Working at Torpedo made me acquire the necessary and fundamental skills of problem solving that any engineer would be lucky to have. The rhythm between team members is exceptional, where every member does his best to make his work efficiently. My overall personality did improve for good."

Mohamed Nasser, Research and Development department.

"Torpedo has opened my eyes to a whole new world of ROV design, programming, teamwork, and most importantly: deadline management."

Abdullah Aml, Software Developer.

"This year counts as my second at Torpedo. I met and worked with many remarkable team mates. I enjoy sharing my experiences and learning from theirs in return. Also, my learning gradient is becoming steeper by time, no matter how many years I participate, there is always much to improve. Torpedo is a life style"

Ahmed Hady, Head of mechanical team.

F. Future Improvements

- Automatic buoyancy system that would Adjust ROV buoyancy in just few seconds.
- Improving sealing system for increased working depth (more than 15m).
- Improving reliable waterproof plugs for faster maintenance or replacements.
- Using more advanced communication protocol such as CAN, in order to provide us with more distance, speed, reliability.
- Investing in IP cameras for improved visibility. We also plan to decrease horizontal thrusters number from 4 to 3, reducing cost and power budget, while maintaining speed and maneuverability.

G. Full CAD Design Show

Using this hyperlink, Triton's 3D Design can be viewed in detail. An exploded view is also provided for viewing each part separately.

H. Media and Outreach.

This year, we decided that our passion won't be limited by our company's members, but we will help other students, and show them the entrance to the robotics world. Therefore, we established Torpedo Academy, teaching them engineering essentials, such as programming, CAD design, and scientific principles. More than 35 students completed the academy to the end, holding our passion, and preparing for next year's contest. Also we wanted to reach non-engineering backgrounds, so we gave an attention to social media, and posted our work progress, accompanied with tutorials.

Figure 35. Our Facebook page statistics.

This hyperlink leads to our video, reaching more than 125,000 and achieving 27,500 views on our Facebook page.

I. Budget

Operational Expenses: Item	Amount	Income: Item	Amount
ROV components	$ 3,000.00		
Machining , CNC	$ 200.00		
Welding	$ 50.00		
Printing	$ 300.00	Faculty of Engineering	$ 2,000.00
MATE Entry Fee	$ 100.00	Sponsorship	$ 9,000.00
Workshop tools	$ 500.00	Members dues (200$ each)	$ 3,800.00
Competition travel (950 $ each)	$ 18,050.00	Alexandria University	$ 5,000.00
Competition accommodation	$ 2,100.00	Donation	$ 2,500.00
Total Expences	$ 24,300.00	**Total Income**	$ 22,300.00
Balance			$ 2,000.00

Figure 36. Torpedo budget for 2015/2016.

J. Project Costing

Torpedo 2016 Project Costing

	Type	Category	Expense	Sources/Notes	Qty	Amount	Total
NET COST OF ROV Vehicle – Electrical System	Purchased	Electronics	Joystick	Saitek X52 Flight Control System	1	$ 190.00	$ 190.00
	Purchased	Electronics	USB shield	To interface joystick with uC	2	$ 31.25	$ 62.50
	Purchased	Electronics	DC-DC converter	Meanwell SD500L 48V to 12V	2	$ 169.00	$ 338.00
	Purchased	Electronics	Microcontroller	Arduino Nano	8	$ 9.00	$ 72.00
	Purchased	Electronics	PCB	Fabrication and component		$ 187.50	$ 187.50
	Re-used	Electronics	Camera	CCTV 700TVL	2	$ 40.00	$ 80.00
	Purchased	Electronics	HD camera	Analog HD 720p	2	$ 50.00	$ 100.00
	Purchased	Electronics	Camera ballon	Noise cancellation for long distance	4	$ 4.00	$ 16.00
	Purchased	Electronics	LED lights	3 Watt	4	$ 0.75	$ 3.00
	Purchased	Electronics	Connectors	XT60 and DB-25 conncetors		$ 26.00	$ 26.00
	Purchased	Sensor	Pressure sensor	MS5803 14BA	2	$ 34.50	$ 69.00
	Purchased	Sensor	Current sensor	30A	2	$ 6.75	$ 13.50
	Purchased	Sensor	Temperature sensor		2	$ 4.00	$ 8.00
	Re-used	Sensor	IMU	Adafruit 9 -DOF	1	$ 20.00	$ 20.00
	Purchased	Tether	Power Tether		25meter	$ 0.50	$ 12.50
	Purchased	Tether	Ethernet cable	CAT6 2B	30meter	$ 0.75	$ 22.50
Mechanical System	Purchased	Hardware	Thruster	Blue-Robotics T100 Thruster	6	$ 225.00	$ 1,350.00
	Purchased	Hardware	DC motor	Geared motor 8.8kg.cm	3	$ 12.50	$ 37.50
	Re-used	Hardware	Bilge pump	1100GPH bilge pump	3	$ 51.25	$ 153.75
	Purchased	Hardware	Electric can	Alumnium sheet	1	$ 165.50	$ 165.50
	Purchased	Hardware	Fiber	Material and fabrication		$ 38.75	$ 38.75
	Purchased	Hardware	Pneumatic	Double acting	2	$ 15.00	$ 30.00
	Re-used	Hardware	Solenoid		2	$ 10.00	$ 20.00
	Purchased	Hardware	Regulator		1	$ 9.00	$ 9.00
	Re-used	Hardware	Safety valve and fittings			$ 24.00	$ 24.00
	Purchased	Material	Frame	Polyamide	10kg	$ 6.75	$ 67.50
	Purchased	Material	Gripper	Polyamide	2kg	$ 7.50	$ 15.00
	Purchased	Material	Camera Housing	Polyamide	4KG	$ 7.50	$ 30.00
	Purchased	Material	Bolts and nuts		1	$ 17.50	$ 17.50
Services	Purchased	Fabrication	CNC	Frame, gripper, and fiber mold		$ 132.00	$ 132.00
	Purchased	Fabrication	Machining	Camera casing, and frame		$ 24.00	$ 24.00
	Purchased	Fabrication	Welding	Aluminum electrical can		$ 40.00	$ 40.00
	Total Invested In ROV Vehicle						**$ 3,375.00**
Tether Control Unit	Purchased	Hardware	Control unit	Surface unit frame	1	$ 56.50	$ 56.50
	Re-used	Electronics	Power supply	24V power supply	2	$ 32.50	$ 65.00
	Purchased	Electronics	Power supply	12V power supply	1	$ 10.50	$ 10.50
	Purchased	Electronics	DVR	4-Channel DVR	1	$ 57.50	$ 57.50
	Purchased	Electronics	Usb Hub		1	$ 10.00	$ 10.00
	Purchased	Electronics	Connectors	XT60		$ 12.00	$ 12.00
	Re-used	Hardware	LCD screen	21 inch	1	$ 81.50	$ 81.50
	Total Invested In Tether Control Unit						**$ 293.00**
Extra Expenses	Purchased	Miscellaneous	T-shirts		20	$ 10.00	$ 200.00
	Purchased	Miscellaneous	Printing	Marketing display, pamphlets, etc		$ 35.00	$ 35.00
	Purchased	Miscellaneous	Regonal regsisteration		1	$ 100.00	$ 100.00
	Donated*	Miscellaneous	Transportation	Local and regional transportation		$ 300.00	$ 300.00
	Purchased	Miscellaneous	Invitation fees		19	$ 150.00	$ 2,850.00
	Purchased	Miscellaneous	Transportation	International transportation	19	$ 950.00	$18,050.00
	Purchased	Miscellaneous	Accommodation	International accommodation	6	$ 350.00	$ 2,100.00
	Re-used	Tools	Workshop tools			$ 615.00	$ 615.00
	Total Invested "Purchased, Donated, or Reused"						**$ 27,918.00**
	Total Purchased						**$ 23,997.00**

* Alexandria University Donated

	Item	Note	Qty	Amount	Total
Income	Faculty of Engineering			$ 2,000.00	$ 2,000.00
	Sponsorship	Ezz Steel		$ 8,125.00	$ 8,125.00
	Members dues		19	$ 200.00	$ 3,800.00
	Alexandria University	Travelling and accommodation	5	$ 1,050.00	$ 5,250.00
	Donation	Free travelling ticket	1	$ 1,050.00	$ 1,050.00
	Donation	NTRA		$ 500.00	$ 500.00
	Total Income				$ 20,725.00
	Balance "Income - Purchased"				$ (3,272.00)

Figure 37. Total Project Costing.

K. Acknowledgments

Torpedo company would like to thank the following benefactors:

- **Prof. Dr. Kamel Elshorbagy**, for his technical/non-technical assistance.
- **Ezz Steel**, for providing us with financial support.
- **Eng. Mohammed Mosaad**, for assisting our academy with all care, **Eng. Ahmed Gamal** for evaluating and reviewing our technical report, and **Eng. Ahmed Ismail** for technical consultation.
- **Faculty of Engineering, Alexandria university**, for logistics and transportation.
- **Makers electronics**, for providing reduced electronic parts' rates.
- **AAST**, **HADATH**, **MATE** for organizing the local and regional competitions.
- Our parents, for providing constant support to us.

Figure 38. From left to right, Prof. Dr. Kamel Elshorbagy, Mohamed Mosaad, Ahmed Gamal, Ahmed Ismail.

Figure 39. Acknowledgments.

L. References

- "Build Your Own Underwater Robot and Wet Projects" *By Harry Bohm and Vickie Jensen.*
- "Optimization of thrust allocation in the propulsion system of an underwater vehicle" *by Jerzy Garus*, Int. J. Appl. Math. Comput. Sci., 2004, Vol. 14, No. 4, 461–467.
- Control of Mobile Robots online course *by Georgia Institute of Technology.*
- ROVotron Underwater Robot Control System *<http://www.cathodecorner.com/rovotron/sw-desc.html>*
- "Underwater Robotics Science, Design & Fabrication" *By Harry Bohm, Steven W. Moore and Vickie Jensen.*
- "An Introduction to Computational Fluid Dynamics" *By H K Versteeg and W Malalasekera.*
- "Modelling and control of Robot Manipulators" *By L.sciavicco and B.siciliano.*
- "Arduino Cookbook" *By Michael Margolis.*
- "The C Programming Language" *By Brian Kernighan and Dennis Ritchie.*

Appendices

A. Job assignments

Mohamed Yousry Kamal
CEO
Technical writing, PR

Mohamed Mustafa Abusetta
CFO, Poster Director
Troubleshooting and Maintenance, Media

Karim Emad Genena	Ahmed Hady
Electrical Team Leader	Mechanical Team Leader
Technical writing Director, poster	CAD desinger, Media Director

Ahmed Mohamed Ibrahim Pilot, Camera Specialist	**Mohamed Attia** Fabrication Director, Safety Officer Troubleshooting and Maintenance, Diver
Yehia Ayman Co-pilot, Software developer Troubleshooting and Maintenance	**Mohamed Zghalil** CAD designer, Mission Specialist R&D
Abdullah Aml Software developer, R&D Troubleshooting and Maintenance Director	**Mostafa Zaki** Mission and CFD Specialist
Ahmed Ibrahem Khames Electrical fabrication Director PR	**Sara Yaacoub** Compu. Analysis, Mission Specialist
Mahmoud Samy Software developer	**Ehab AbdulRahman** CAD Designer
Mohamed Nasser GUI developer, R&D	**AbdulRahman Mohamed** R & D
Hossam Fouad GUI Developer, Camera Specialist	**Mahmoud Reda** Tether Man, buoyancy officer
Mohamed Eldemery Camera Specialist	
Sara Abdullah GUI Developer	

Figure 40. Technical and non-technical job assignments of our team.

B. System Interconnection Diagram

Color Code

- I2C Bus (blue)
- USB (green)
- 12V Bus (red)
- Streaming Signal (yellow)
- +48V Power Tether (purple)

Pressure And Temperature Sensor, Leakage Sensor, Adafruit 9-DOF IMU draw power form the Arduino

Power Budget

Element	No. of Elements	Max Power Consumption Per Unit (Watt/Unit)
T100 Thruster	6	130
Manipulator's Solenoids	2	3
Camera	2	1
Light	4	4
Arduino	2	1.4

Total Power = 806.8 Watt

Circuit Breaker Calculations

- Max power Consumption = 806.8 Watt
- Input Voltage = 48V
- Converters Efficiency = 84%
-Overload Factor = 1.5

Current Drawn = (806.8/48)/.84 = 20A
C.B Rating = Current Drawn * 1.5 = 30 A
A 25A C.B is used to protect Triton

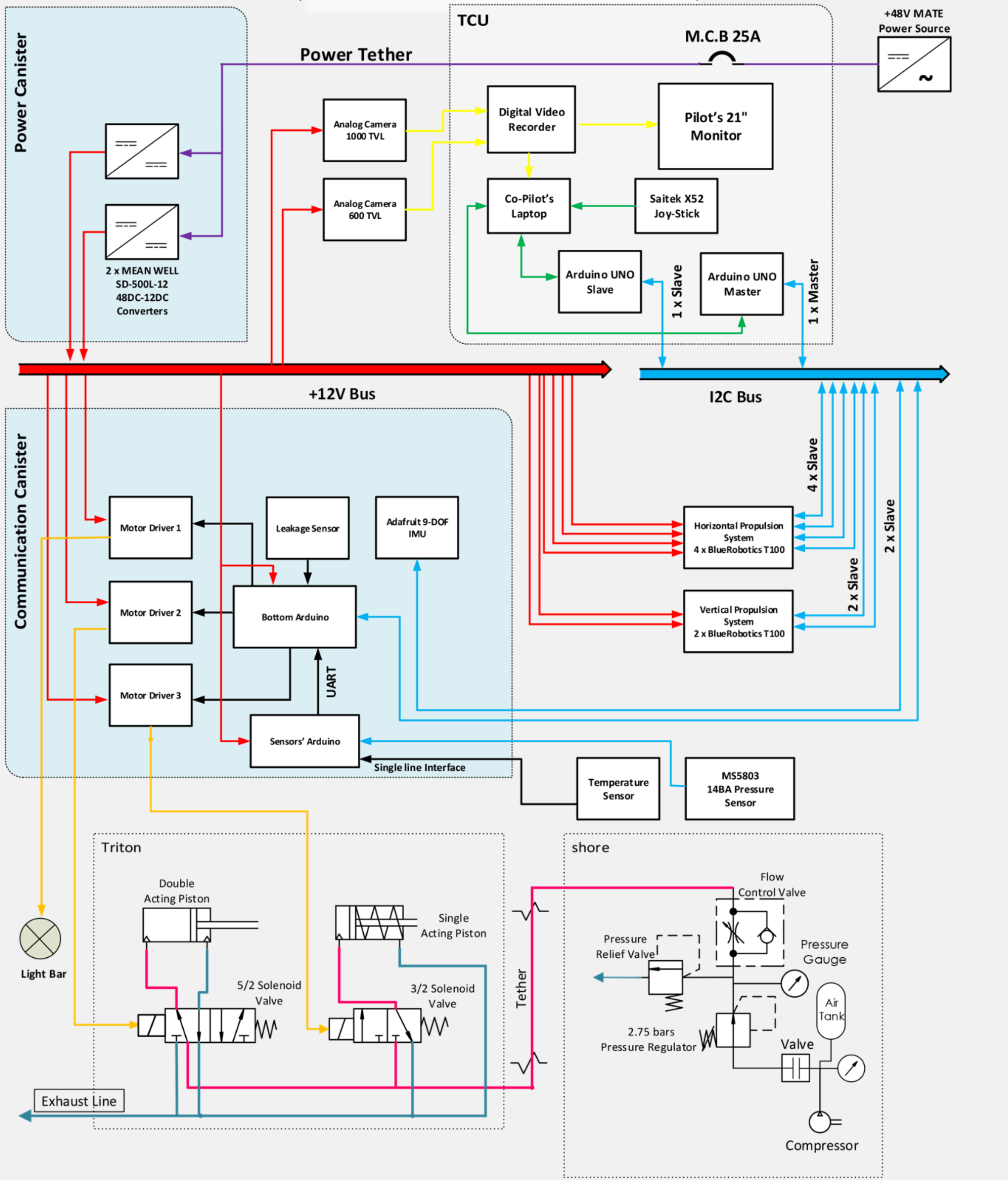

Figure 41. System Interconnection Diagram, including pneumatic and electrical mapping.

C. Software Flowcharts

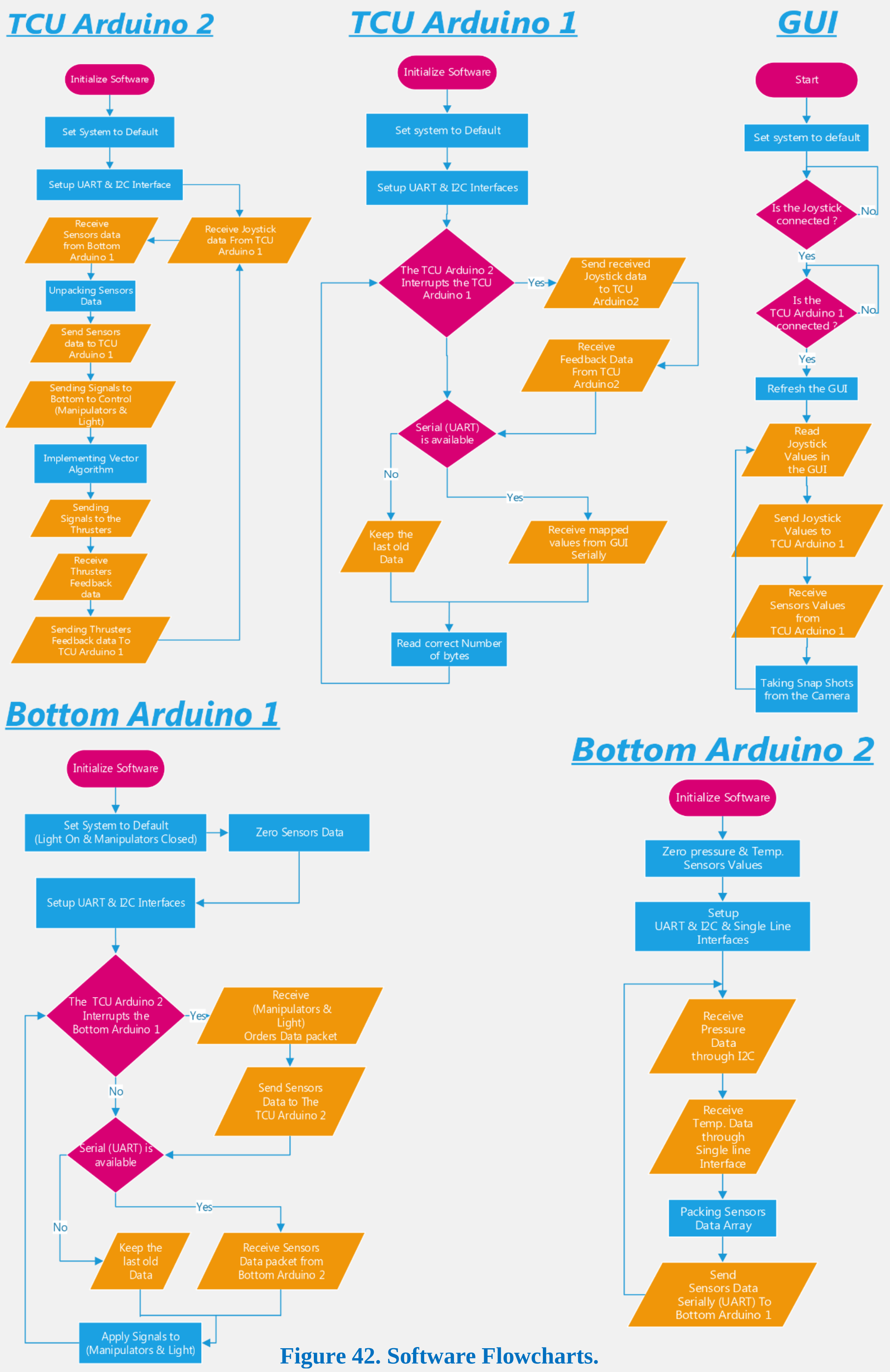

Figure 42. Software Flowcharts.

D. Project Management and Timeline

To complete Triton on time, our company's leadership used a Gantt chart to guide their decisions about scheduling and resources. The chart displayed project deadlines, along with external deadlines set by the competition organizers. The company CEO delegated responsibility to the heads of each department, who in turn led all department members in the development of components and deliverables required by MATE.

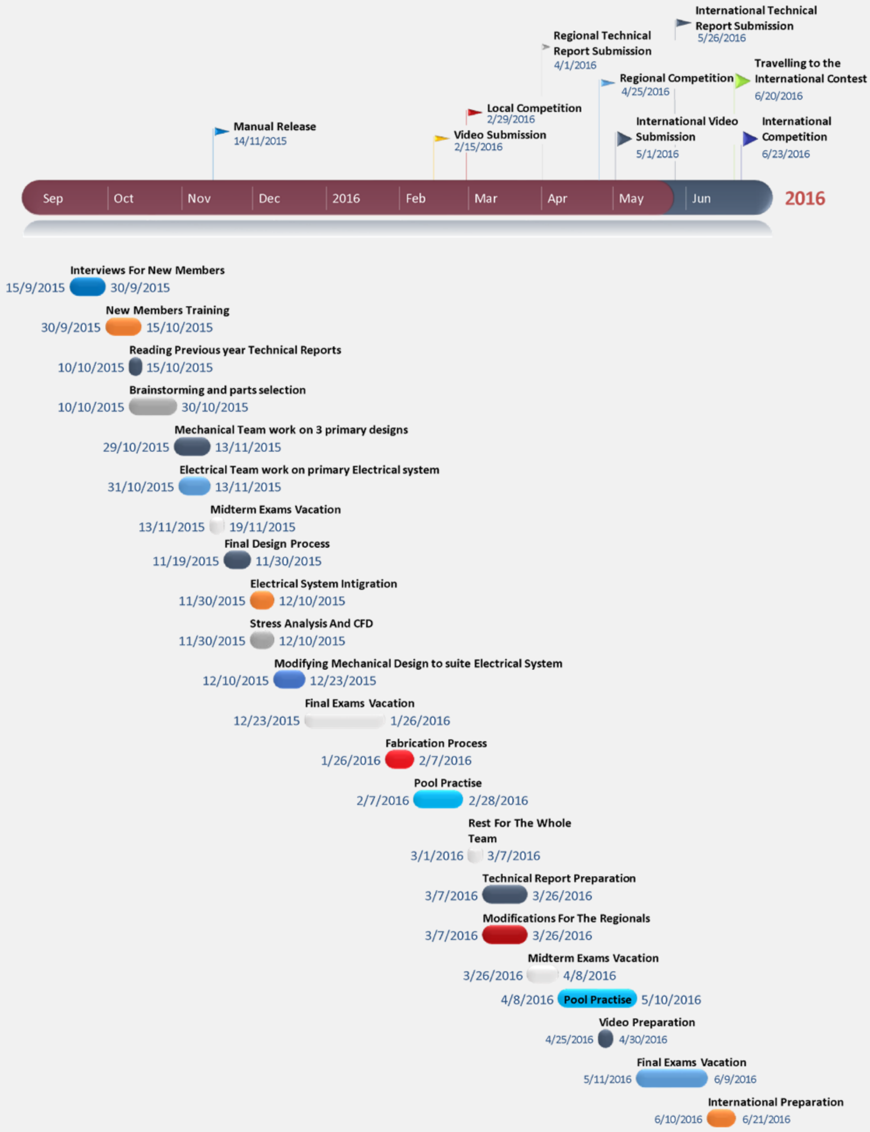

Figure 43. Timeline and Schedule.

The Gantt chart was reviewed daily and the team leaders assigned specific production goals to each sub-team and each sub-team head assigns to each individual. At each workday's closing meeting, the daily production goals and accomplishments were reviewed, and the Gantt chart was updated. Production goals which are not accomplished would be worked on individually by employees between workdays. Members that finished their task on time in as needed and in an enthusiastic and skillful manner were rewarded with more interesting and complex assignments designed to keep them motivated and further develop their skills.

E. Troubleshooting Techniques

During the fabrication and implementation of Triton, our company ensured thorough testing of all mechanical and electrical components. Mechanical components' sealing was tested under 15m depth and electrical system's components were tested solely and then together until all features worked fine. Sometimes, issues happen, resulting from human error or random error, therefore, a clear troubleshooting plan was made to trace and take action on problems faced.

There are several techniques that our company use in troubleshooting problems. When an issue appears, we begin identifying the problem by testing step by step. The affected or malfunctioned components of Triton determine the exact cause. Problems can be caused by loose connections, leakage resulting in electronics damage, firmware not updated, etc.

Tips followed as a standard approach to solving problems:

- Follow the system checklist.
- Analyze symptoms and factors.
- Isolate the source of the problem.
- Define an action plan.
- Reboot and check if everything is working fine.

Figure 45. Team members troubleshooting Triton.

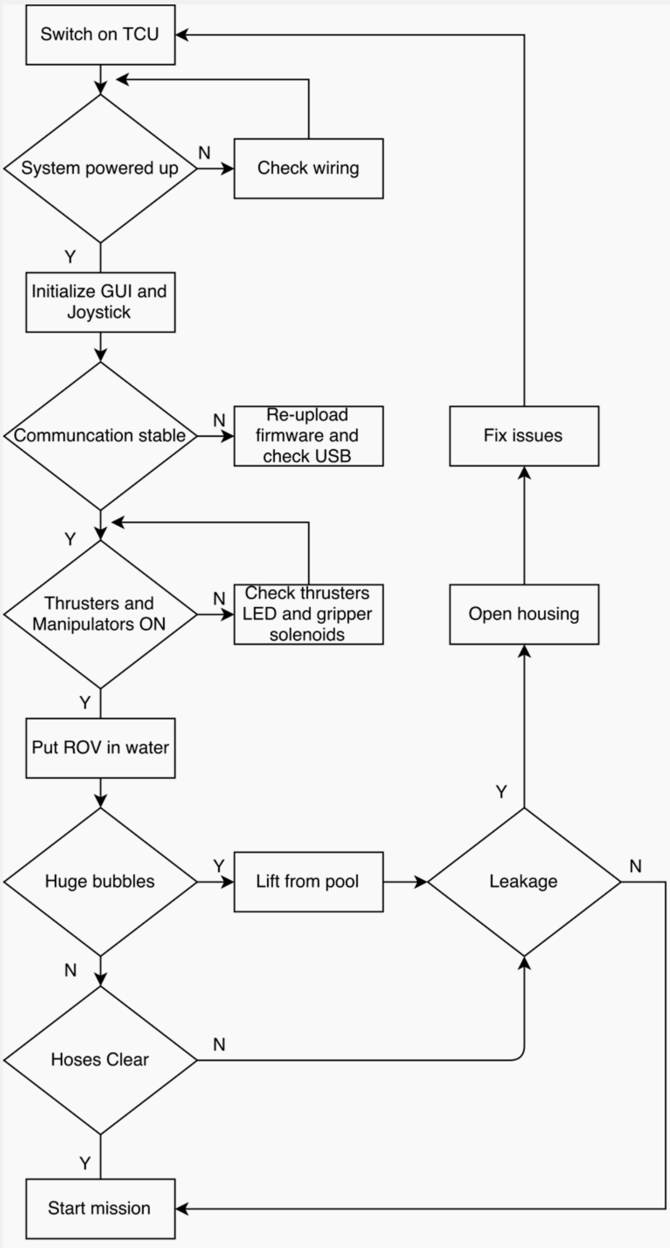

Figure 44. Flow chart of full vehicle troubleshooting.

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