<u>Hammer Heads</u>

Tech Planet (Cairo, Egypt)

Team Members:

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6. Hany Hamed (Chef Software Engineer)
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1.0 Abstract:

This is the first year for Hammer Heads company to participate in the ROV competition which is held this year in the NASA Johnson space center at the neutral buoyancy lab in Texas, organized by MATE corporation. Our product is designed to deal with challenges here on Earth and on Europa to gather more information about both that will help scientists work.

The idea started when our mentor Kamal El Sayed told us about the ROV competition and that it will give us more experience and will teach us lessons, starting from more knowledge about software and hardware, till operating a company.

Then we met at Tech planet and started to divide the tasks to design, software and hardware and decided that the ROV will have:

- 6 degrees of freedom (3 transitional and 3 rotational)
- Aluminum Chassis
- Circular PCB'S that makes good use of the space in the control box
- Arm with 3 degrees of freedom
- Tilting HD cameras that provides full functional seeing
- 30-meter-long tether
- Full power thrusters without using any component
- Cylinder control box that withstands high pressure (5 m under water)

We started on October 2015 to design the ROV based on these features and we had to make a time table to balance between the school and the ROV until we reached our goal to make the design of our product real.

2.0 Design Rationale:

2.1 Chassis:

This year competition is very challenging, as there is a restriction on the ROV Dimensions, moreover this year there is bonus for compact and light weight ROVs. Since some of this year challenges theme are about space and sending gear to space is very expensive and every kilogram counts and of course the dimensions are very critical and the smaller the better. After several brain storming sessions, we concluded that it will be optimal to use six thrusters, two on each axis. One of our biggest challenge was to get our ROV fit in the 48 cm circle. The unique shape of our ROV was inspired by the fact that: the more sides a quadrilateral has, the more area it uses of a circle. Hence, the octagon shape dominates the shape of the ROV from all sides.

The ROV Consists of six Brackets and two main side plates, The Brackets are made of Aluminum as it density is relatively low, not only its weight is light compared to its volume, but also be shaped easily shaped and cut and strong at the same time. Our brackets are laser cut and bent using a cnc bending machine. As for the side plates they were made out of polyethylene, mainly because it is almost neutrally buoyant in water also for its strength and durability.

Since we wanted our ROV to be small in size this presented us with another problem which was that the flow of the vertical thrusters was partially interrupted, the idea of an ROV that grow in size right before the demonstration was the proposed solution. We employed it by putting the brackets that hold the two vertical thrusters on a slider that opens to increase the distance and closes to make the ROV fit inside the circle. The sliders also increase the volume available for use inside the ROV that can be used to install any new actuators.

Our Mechanical Team payed close attention to make the ROV symmetrical so that when the when the pilot wants the ROV to move in a certain direction it moves in it without shifting sideways, because if the ROV is not symmetric it will shift sideways because the drag will be different on the two sides of the ROV.

2.2 Propulsion:

The thrusters are from the main components that determine the speed and maneuverability of the vehicle so we paid close attention to choose the right thrusters without exceeding our budget but also without compromising the performance. BlueRobtics T100 brushless thrusters were the optimal thrusters for our ROV as they were small and they had esc built-in in them and the produce 240 N of torque which makes powerful and capable of maneuvering smoothly.

2.3 Control box:

The control box holds all electronic circuits and modules necessary to control the ROV. It wouldn’t be an exaggeration to say it is the most important component of the ROV system. To lose it would be to lose the whole functionality of the ROV. That’s why it is necessary to be strong and resilient. For a container under water to with stand high pressure the best shape would be a cylinder to disperse the force. The control box is made up of a transparent acrylic cylinder to ease testing and to know if there’s water leakage.

Isolation: we sealed our control box with an end cap with grooves in it with 2 O-rings providing robust and reliable method of isolation.

We made it using polyethylene as it is tough material that can withstand high pressure without deforming.

Cable Glands: After testing several glands on the market and our own custom made glands we decided to choose a certain type of glands as we tested it in a suitable depth and it proved to be successful.

2.4 Buoyancy:

We managed to make the ROV positive neutral buoyant by adding foam so that in case of failure the ROV will move up on its own but also won’t affect the maneuverability of the ROV.

In order to make this we need to calculate the density of the ROV, the density of the foam and make the total density of the ROV almost equals the density of the water using the formula D = M/V.

2.5 Actuators:

Our mechanical team was challenged to create actuators to solve the mission tasks efficiently and effectively but also the actuators need to be simple and light.

2.5.1 Arm:

Our mechanical team designed an arm with three degrees of freedom one rotational, one transitional and the third is the opening and closing of the clamp itself, allowing maximum control and accuracy for the pilot to help him in doing the tasks.

Clamp: To ensure a firm grip on any object in the playground we decided to make a parallel jaw gripper mechanism

The clamp fingers consist of two parts, a wide part and a narrow part that act as funnel to ease on the pilot dealing with objects that need high accuracy and to enable carrying tiny and huge objects.

Also the clamp fingers are covered with rubber to ensure maximum grip.

Bearing are used on every motor shaft to decrease the friction and to carry the weight of the parts instead of the motor shafts so the motors are in maximum effectiveness.

We figured out the motors that we need after tests but the motors we choose caused a problem because they are very large in size because it has a high torque, so we decided to use a normal torque motor and combine it with a used gearbox we bought to increase torque.

After a lot of thinking we figured out that the best way to seal our DC motors is to make acrylic casings, they were as fit as possible to reduce their size and transparent acrylic was used in the casing to make spotting the leaks easy, oil seals were used on the motor shafts exit to prevent water from entering as they work by pressing against the shaft

2.5.2 Funnel:

To help the pilot measure the temperature of the venting fluid coming out of the pipe task, the mechanical team came out with a brilliant idea which is to use a funnel inside it will be the temperature sensor and it will work as follow: the bottom of the funnel is wide from the bottom and tight from the top so when the funnel is brought on the pipe the temperature sensor will be automatically guided to the center of the pipe allowing precise temperature reading. One more advantage of having a modular design for specific tasks is that not tasks relay on a single actuator.

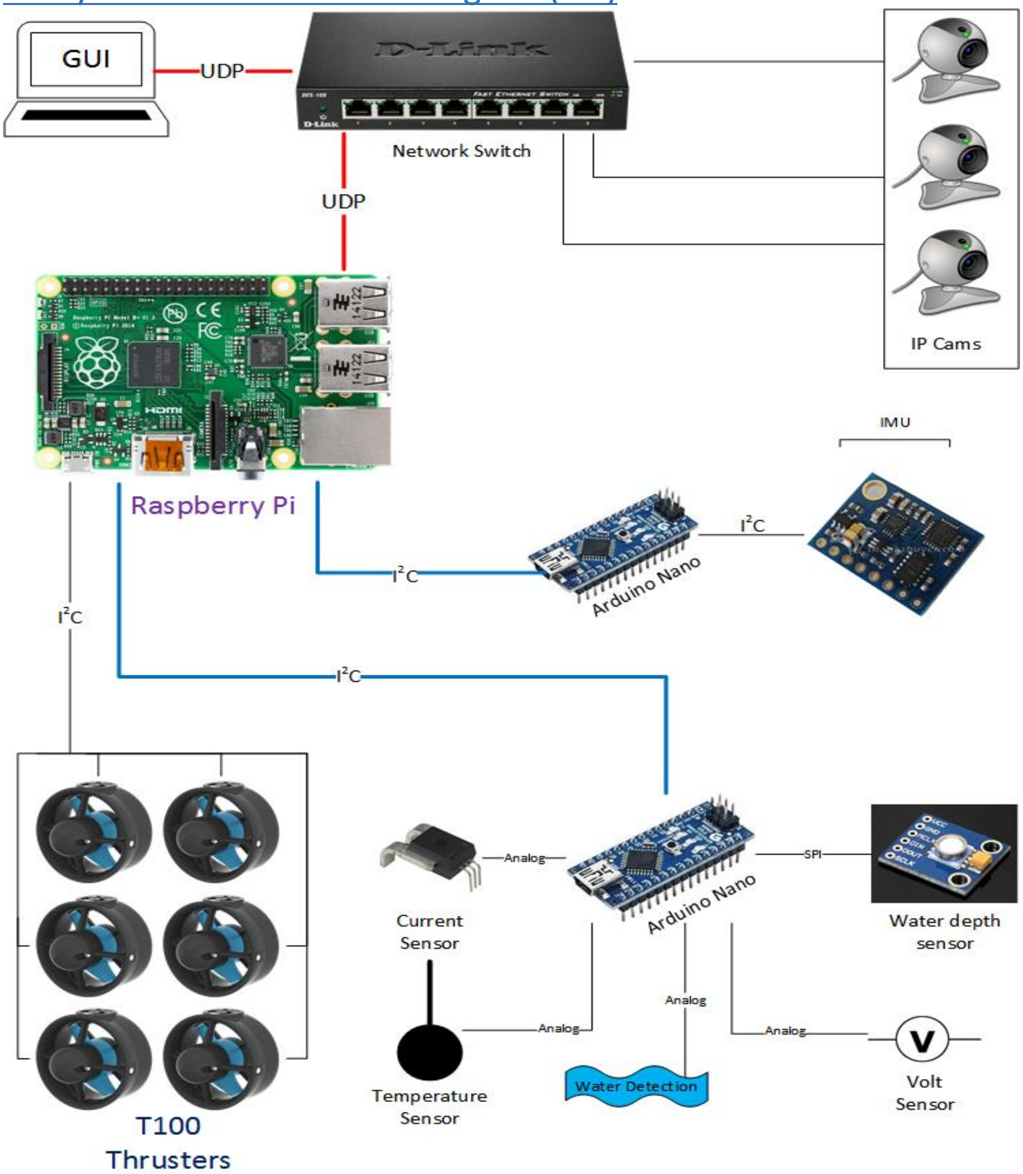
2.6 Camera system:

Without vision it will be literally impossible for the pilot to drive, and the wider the range the camera can see the better the pilot can perform, for this reason the mechanical team have precisely put three IP cameras in three strategic locations, the first one which is the main camera, is located in a dome at the front of the ROV it is attached to servo motor to tilt it, to increase the field of vision for the pilot. The second camera is located on the arm to enable the pilot to have a closer at the objects the arm should hold. The third and last camera is located on the funnel so that the pilot can place it on the pipe to measure the temperature.

2.7 Degrees of freedom:

Our ROV has 6 degrees of freedom and the ability to tilt in all directions because we put two thrusters on each of the 3 axis for translational motion on this axis and rotational motion on the perpendicular axis.

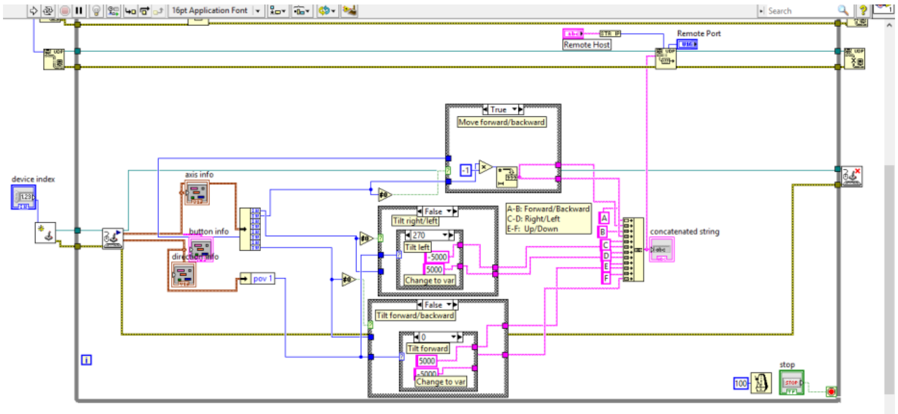
3.0 System Interconnection Diagram (SID)



SID created using Microsoft Visio

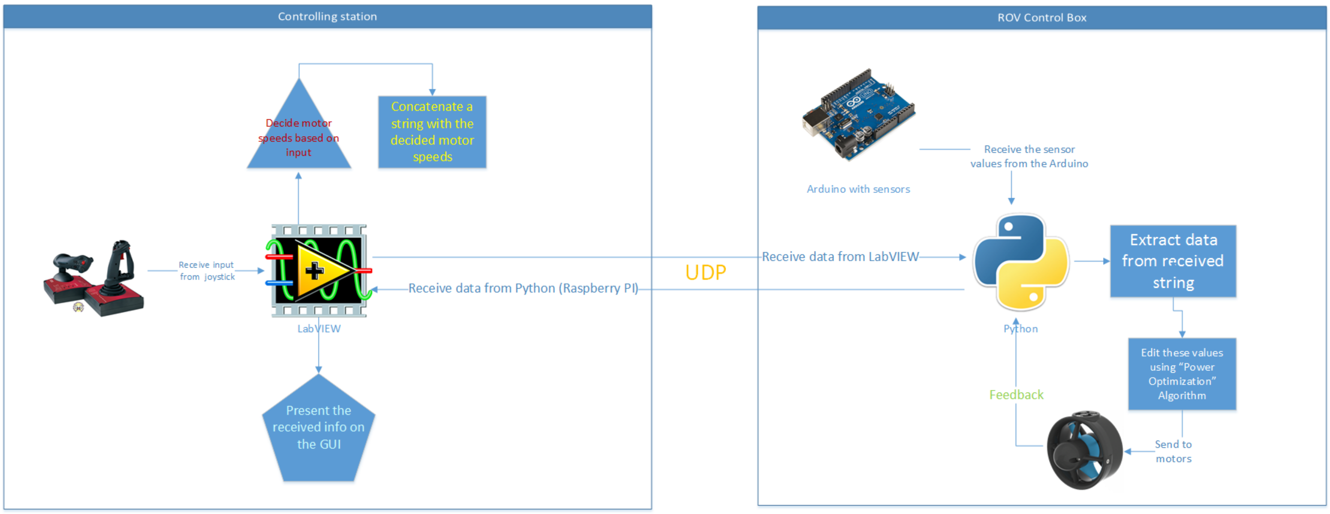
As shown in this SID, our main controller in the ROV is a Raspberry Pi 2, with 2 Arduino Nano's to support it with processing some sensors. The first Arduino has an IMU all by itself as it is very heavy in processing and requires a dedicated microcontroller. The 2nd Nano has the volt, current, temperature, and water depth sensors, along with a small circuit to detect whether or not there is water leaking into the control box. All these sensors are analog, except for the barometer which uses SPI for communication. The communication protocol for the rest of the components is I^2C. The Raspberry Pi will collect the data from these 2 Nano's and from the T100 thrusters and will send it – using UDP – to the computer at the control station which uses LabVIEW – that has a UDP server running – to display the data to the pilot who will react accordingly.

A joystick is used as the controller that the pilot uses. LabVIEW will take input from the joystick and process it to send commands to the Raspberry Pi which will redirect it to the motors. There are also 3 IP cameras placed on the ROV that are connected along with the Pi on a network switch for the computer to be able to connect to whichever device it needs using a single Ethernet cable at the station going through the tether.



4.0 Software Flowchart and overall explanation

The software consists of 2 main parts and 2 small modules. The main parts are the LabVIEW GUI and the Python programs on the Raspberry PI. First, we chose LabVIEW because it has a huge library of functions that makes it very powerful, along with an easy-to-use interface that gives a stress-free experience in creating a GUI that is appealing to the eye, but with a powerful backend that controls the whole system efficiently. Its main purpose is to view all the



The Software Flowchart

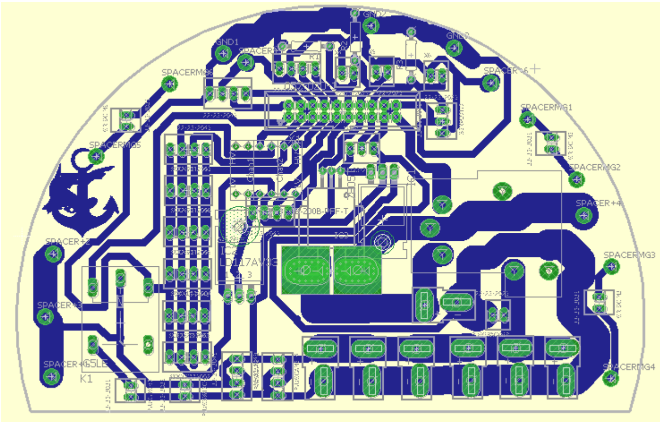
variables and inputs, like the motors' speed, the electric current it is using, its temperature, and joystick values. Then, it will process inputs like joystick and map its values to be sent as motor speed values to the ROV[1], and data sent from the ROV to be displayed properly on the screen. The other main part is the Raspberry Pi inside the ROV, which acts as its main controllers. It has direct

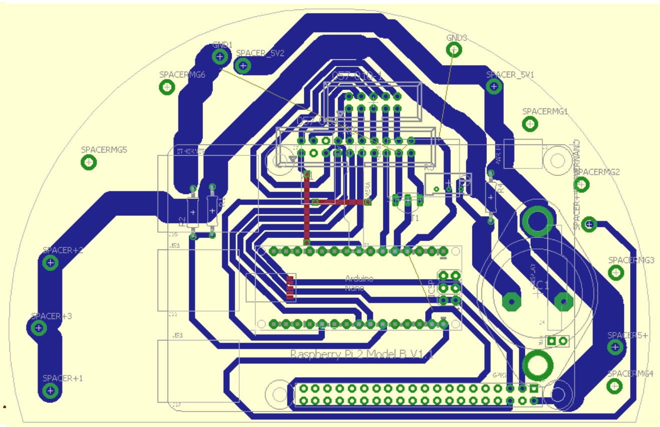
[1] "ROV" refers in this context to the controller inside it, which is the Raspberry Pi 2.

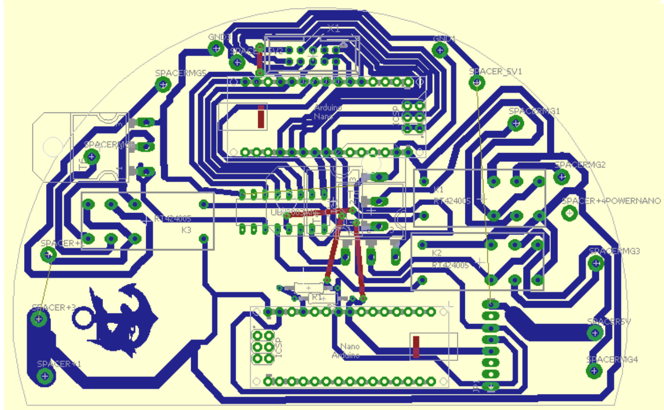
control over the thrusters, and receives data from the 2 modules – the Nanos – to act upon some of it right away, and send the rest to the control station to be viewed by the pilot to know how the ROV is doing. As for these 2 modules, they are the Arduino Nano and the sensors attached to them. The first one has only the IMU as it is heavy in its processing and requires a dedicated Nano or another microcontroller powerful enough to power it with the other sensors, which will be bigger and more expensive, or just directly to the Raspberry Pi, but that defeats the purpose of modularity that makes debugging and repairing easier and gets rid of some of the load off the Pi. The other Nano is connected to 4 sensors: Volt, current, water depth, temperature; and a circuit to detect water inside the control box. The volt sensor is just a voltage divider circuit that uses resistors of values 100 Ω & 1 KΩ, and is read by the analog input of the Arduino to determine the Voltage. The current sensor is the ACS758 (100A) which sends the value to the Arduino using analog. The temperature sensor is the small but famous LM35 with a water-proof casing.

The power optimization in the flowchart refers to the algorithm that will control how much power each motor can consume so that the total current does not exceed the limit. We are going to achieve this by a part of the Python library that we wrote for the motors, as we didn't find any library except for Arduino in C++. So, we made a special library that is customized to our needs in order to have control over the thrusters in the best way.

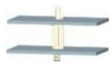
4.1 PCB’s







We have 3 PCBs[2]: Power, Sensors, and Raspberry Pi. They are placed above each other using spacers



that are also used for connecting power or signal. They have this semi-circle shape to fit nicely in out cylindrical control box, with the network switch in front of them. As for the first one, it will receive its power from the tether and then divide it among the other circuits after passing through voltage regulators. For the motors, the T-type connector was the best since it needs the highest current. As for the rest, they receive power using neat jumper wires and special sockets for them that will deliver 12V, 5V, 3V, and ground so that each circuit takes the power it needs. This PCB also has the relay that is located on the main supply flow, so that when the current or voltage increases, the Arduino could turn the power off right away. The data cables of the thrusters will then go through pin headers on this PCB and down to the next one: The Raspberry Pi. The Raspberry Pi will then be able to easily control them directly, and without having a bunch of dangling wires. This board will also have one Arduino that controls the power circuit and uses the sensors placed on it (like current and volt sensors). The last PCB has the Arduino with the IMU, and the other one with the rest of the sensors.

4.2 Tether

The tether we used is a 30m long copper wire with a thickness of 6mm (about 3 AWG) with an Ethernet cable going from the PC to the network switch in the control box. We used this specific thickness as it was the best balance

[2] PCB stands for Printed Circuit Board

between cost and efficiency. We used this formula to calculate the voltage drop:

$\mathrm{V}_{\mathrm{drop(V)}} = \mathrm{I}_{\mathrm{wire\ (A)}} \times (2 \times \mathrm{L}_{\mathrm{(m)}} \times \mathrm{R}_{\mathrm{wire\ (\Omega/m)}}$), derived from the famous equation: $V = IR$, where $\mathrm{R}_{\mathrm{wire}} = \frac{\rho L}{A}$. The natural resistance (ρ) of copper is known to be 1.68×10^{-8} (Ωm) .This ended up being about 0.85V, which is a good value considering the length of the wire. All electrical components have a working range that will definitely accept ~11.15V without any problem.

5.0Troubleshooting Techniques:

- Knowing the problem and making a list with possible errors.
- Making control experiments to test possible error individually.
- Defining the real causes of the problems.
- Brainstorming to get solutions for the errors.
- Designing the solutions.
- Testing possible solution on small prototypes.
- The best working solution is implemented.

7.0 Challenges:

Technical

Our team faces a lot of challenges … and this is ordinary in any work or in any project , and the most important thing is “to keep moving forward” and to cross the barriers.

The first technical problem we faced is the size of the rov …especially this year with the new size restrictions. we wanted to expand the rov maneuvering with the least number of motors , and that was a problem in the assembly with the other things in the rov as the control box , cameras , arm... and there is another problem depending on the size, which is the distance between the thrusters of the rov , at first we wanted to make 45 vector motor arrangement

But the thrusters were to close from each other , and that will affect the flow of motors ,also this arrangement doesn’t allow degrees of freedom knowing that we only have six thrusters , so after a lot of brain storming sessions of our team , we reached our recent motor arrangement and we added sliders to it for expanding and shrinking the rov that we wrote about it in the chassis article.

Non-Technical:

As a team, we faced a lot of challenges. Some were big some small, but all of them left their mark on us. These are some of the challenges we faced:

For most of us, being in a big team was a new thing. We didn’t notice at first that it needed special management and organization until we reached a point of extreme disorganization. Stuff were lost and damaged, deadlines weren’t met, tasks were left unfinished, and not everyone was involved. After we recognized the problem, we gathered together to address it. We put together a leadership hierarchy, rules to govern how the team works, regulations for equipment use, and got everyone motivated to get involved again.

As the costs of constructing the ROV are demanding, we are constantly faced with a problem of how to provide for these costs. We tried to find a sponsor but our efforts didn't pay off because we are a new team and nothing was in production yet. A fundraiser was proposed, we proceeded with the idea. We also accepted donations for the team.

Planning for the design and construction of the ROV wasn't an easy task. Unexpected thing always popped up and ruined plan progress. We solved this by making our plan more flexible, planning for those unexpected things, researching what we'll do before we have to do it, and setting forth procedures on how to deal with the unexpected.

Communication is always a crucial part of any successful team. At first communication amongst ourselves wasn't good which caused a lot of problems and delays. To solve this, we made a chatting group for all team members and put updates on it periodically. Also, we always have to inform other team members with updates in work or anything unexpected to keep everyone.

8.0 Project Costings

8.1List of items and Costs

This is the table we made to list everything we bought. All prices are in Egyptian Pounds. All of these items are bought new, except for very few things that we already had, and therefore didn't include in the list.

8.2 Budget

The budget we set for the project was 25000 Egyptian Pounds.

9.0 Safety:

Safety of team members and anyone dealing with some aspect of our work is our top priorities. When working, we make sure that we do it in a clean, safe environment, that the people working with any tools are well trained to use it, that they wear the appropriate safety gear like safety goggles and gloves, and that there's nobody around that could get hurt from flying fragments or hot soldering irons. We constructed our workshop in such a way that ensures all tools are safely stored and workspace is organized.

Safety is also considered when dealing with the ROV. All sharp edges are either polished or covered. All wires are well insulated. Electrical equipment is put in casings. Thrusters are shielded. And proper warning stickers are placed on the ROV.

To protect our equipment, we always measure the power supply's voltage before operating the ROV. There's a current sensor in our circuits to always monitor and regulate the power consumption. We have a 25A fuse to protect our electronics against power overload. The pilot always has the ability to shut down the system in case any issues arise. There's a water detector inside the control box to inform the pilot of any leakage if it might happen so that he can take appropriate measures.

10.0 Reflections:

“It's a new experience, and I learned new skills in robotics under water” - Youssef

“Working on the ROV gave me new experiences and taught me new things about software, especially the practical part of it” - AbdelRahman

“Taught me the real meaning of teamwork and I learned more about sealing” - Abdelrahman

“There's a bigger challenge than solving a problem, which is actually knowing what is the problem!” – Marwan

“ROV taught me perseverance, how to get out of my comfort zone to explore other areas in my country to get components and make components.” – Ahmed

"It wasn't just a normal competition with normal preparations it was completely a new level, it taught me time management to balance between school and the competition.” - Farouk

“Managing a team is not as easy as it sounds it needs work and organization. Teams need a strong communication network” - Hajar

"I learned new things about Python and Raspberry Pi, such as how to create a custom library and use I2C communication, in addition to learning more about the protocol itself. I also improved my PCB designing skills significantly." – Hany

"ROV simply craved in us uncountable skills and experiences that's incomparable with any other professional competition and how easily we could turn mind block into building block that ends problems way faster also it didn't make me get out of my comfort zone it became my number one comfort zone! " - Mohammad

11.0 Future improvements:

There were many problems and errors that faced us during the competition and

We learned from this problem and we would like to add some features in the ROV

To help in making the mission smoother, faster, and more simple to the pilot

12.0 References:

- **Arduino**: https://www.arduino.cc/en/Reference/HomePage
- **Python**: https://www.jetbrains.com/pycharm/documentation/
- **NI LabVIEW**:http://www.ni.com/en-lb/community.html
- **BlueRobotics:** https://www.bluerobotics.com/forums/

- Eagle: http://www.cadsoftusa.com/training-service/tutorials/

- raspberry Pi: https://www.raspberrypi.org/forums/

To achieve our goal more efficiently and more effectively without facing any other problems in the ROV

13.0 Acknowledgements:

We would like to thank the following:

- Tech Planet, for providing us with a workspace and tools for the whole team to meet and work.
- Engineers Kamal Sayed and Aly Magdy for their continuous help and for the lessons they gave us about everything related to the ROV.
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- Hadath corporation for organizing the regional competition.
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