TEKNOFEST ISTANBUL

AEROSPACE AND TECHNOLOGY FESTIVAL

UNMANNED UNDERWATER SYSTEM

COMPETITION

CRITICAL DESIGN REPORT

NAME OF TEAM: EMU AQUABOTICS

MEMBERS OF TEAM:

Name	Surn**ame**
AHMED	ELSAYED
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ABDEL RAHMAN	BEKAWI
MOSSAB	HAMDI
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SHEHABELDIN	HOUSEIN
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Table 0-1 List of Abbreviations

1	AHRS	Attitude Heading and Reference System
2	AoI	Area of Interest
3	AUV	Autonomous Underwater Vehicle
4	ROV	Remotely Operated underwater Vehicle
5	UUV	Unmanned Underwater vehicle
6	Al 6063	6063 Aluminum Alloy
7	HDPE	High-Density Polyethylene
8	PA6	Polyamide 6
9	CG	Center of mass
10	CB	Center of buoyancy
11	CV	Computer Vision
12	ESC	Electronic Speed Controller
13	FMEA	Failure Mode and Effects Analysis
14	I/O	Input Output
15	IMU	Inertial Measurement Unit
16	PDB	Power Distribution Board
17	RGB	Red Green and Blue
18	ROS	Robots Operating System

Chapter 1 REPORT SUMMARY

Unmanned Underwater Vehicles (UUVs) have a wide range of applications in marine geoscience, and are increasingly being used in the scientific, military and commercial sectors. (ScienceDirect, 2014)

In this project we propose a UUV with the capability of diving to a desired depth, navigating through narrow channels, manipulating, sorting and collecting small objects as well as identifying targets.

The proposed design configuration is modular, compact and light weight to perform the mission efficiently and effectively. The body is made entirely of HDPE and fitted together using readily made, locally available aluminum links to ease connecting the supports to the main frame. A stereo camera is placed facing forwards, which is used for navigation in both the controlled and autonomous parts of the mission. Our custom-made main hull features both mechanical and chemical isolation to ensure the safety of the electrical components enclosed. The topology of the proposed design is optimized to meet the performance requirement.

The design configuration is proposed to meet the challenges and mission objectives of the Teknofest Unmanned Underwater Systems Competition.

The proposed design has eight BlueRobotics thrusters, providing approximately 50 N of thrust each. The modular mechanical and electrical platforms enable the vehicle to switch between AUV and ROV systems efficiently.

The design is proposed in order to meet the design for cost (DFC), design for manufacturing and assembly (DFMA) and availability constraints.

Chapter 2 SCHEMA OF TEAM

2.1. Team Members

The team members' information is listed in table 2-1.

Table 2-1 Aquabotics team members

Name	Department	Class	School
Abdel Rahman Bekawi	Electrical Engineering	7th Semester	Eastern Mediterranean University
Ahmed Elsayed	Mechatronics Engineering	8th Semester	Eastern Mediterranean University
Hazem Mohamed	Mechatronics Engineering	8th Semester	Eastern Mediterranean University
Ahmad Kutada Aljabali	Mechatronics Engineering	8th semester	Eastern Mediterranean University
Shehabeldin Housein	Mechatronics Engineering	8th Semester	Eastern Mediterranean University
Al-Khattab Al-Qaseem	Electrical Engineering	6th semester	Eastern Mediterranean University
Amina Ait Ben Ouissaden	Computer Engineering	4th semester	Eastern Mediterranean University
Alhassan Khalil	Mechatronics Engineering	5th semester	Eastern Mediterranean University
Abdulrahman Al Salkhadi	Industrial Engineering	6th Semester	Eastern Mediterranean University
Mossab Hamdi	Industrial Engineering	7th Semester	Eastern Mediterranean University

2.2. Organization Schema and The Distribution of Tasks

We realized that a proper team organization method would benefit the team most. So, we established a heirarchy and an appropriate task distribution schemes, as shown in table 2-2.

Table 2-2 Positions and distribution of tasks

Title	Name
Team Leader/Electrical Design	Abdel Rahman Bekawi
Mechanical Design Leader	Ahmed Elsayed
Mechanical Design	Hazem Mohamed
Software Development Leader	Ahmad Kutada Aljabali
Software Development	Shehabeldin Housein
Software Development	Al-Khattab Al-Qaseem
Software Development	Amina Ait Ben Ouissaden
Software Development	Alhassan Khalil
Media & Outreach	Abdulrahman Al Salkhadi
Marketing	Mossab Hamdi

Chapter 3 PROJECT CURRENT SITUATION EVALUATION

Currently the project initial design phase is complete, and Manufacturing of the vehicle's frame, isolation hull and manipulator mechanism has commenced. Furthermore, procurement of electrical components and boards is running smoothly with multiple parts already arriving.

With some parts already manufactured and other ready of the shelf components bought and delivered, design verification has begun such as assembling manufactured parts to insure fit and functionality, testing of available boards and electrical components to verify safety, intercommunication and features, and finally using software simulations to test the completed software modules.

Based on the early tests performed most of the vehicle functionality was confirmed, proving the accuracy of design calculations and assumptions guiding the design process, by performing the tests and observing the results it was decided to add some minor modifications and improvements to the vehicle design.

Chapter 4 **VEHICLE DESIGN**

3.1. System design

Fig 3.1 shows the system break down structure with the part codes.

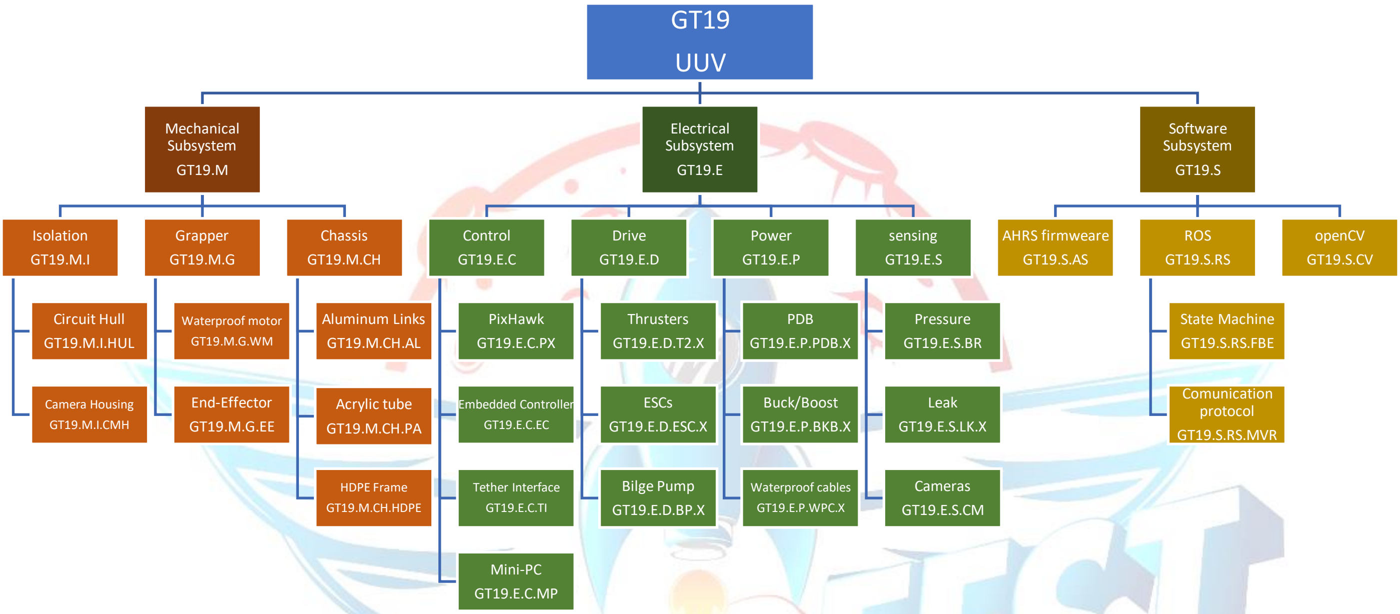


Figure 4-1 System Breakdown Structure

3.2. Mechanical Design of Vehicle

3.2.1. Process of Mechanical Design

To reach the optimum design, we went through different phases and ideas. We began by studying other previous designs which participated in other competition, we also spent a lot of time studying how commercial ROVs are built and manufactured. We settled for the commonly used box shaped open-frame design for its stability and ability to house most components needed. The ROV is being designed to give maximum serviceability allowing easy assembly and disassembly of parts to make any repairs as quickly as possible.

Next, we started sketching the agreed upon design using the Computer Aided Design (CAD) program SolidWorks, which was then - taking all efficiency and safety factors into consideration - finalized. All the CAD files were prepared to be machined by a Computer Numeric Control (CNC) mill ‘s Computer Aided Manufacturing (CAM) package, after converting them into Drawing Exchange Format (DXF) files. However, we were limited by the material availability and the manufacturing techniques available. Our main objective is to design a vehicle using the minimum number of components. This eases the assembly procedure while also reduces the ordering and manufacturing costs.

While designing the AUV, our aim was to:

a. Reduce the AUV’s dimensions as much as possible.

b. Ensure that the AUV is adequately rigid.

c. Reduce the vehicle’s weight.

d. Ensure that the center of mass (CG) is directly below the center of buoyancy (CB).

e. Achieve a suitable separation between the CG and CB to obtain optimal stability.

f. Design for ease of assembly and maintenance.

3.2.1.1. Design configuration 1

In our first phase of design, we agreed on the main overall shape of the vehicle, two main side frames connected by supports, which in turn are used to mount other components. Next, we tried to make the vehicle as hydrodynamic as possible by designing a 3D shell that covers it. The design is entirely made of HDPE, fastened together using the finger-joint technique, where the supports are connected to the main side frame by interference. The gripper is mounted at the front to be facing forwards, where a camera is mounted above it, to have it in its field of view. The overall dimensions are 834mm x 550mm x 450mm, the overall weight is 16.5 kg and the CG is below the CB by 70mm.

Figure 4-2 Design Configuration 1

3.2.1.2. Design configuration 2

During this phase, we used the same overall shaped agreed on, but a different more optimized side frame. We also modified the hydrodynamic shell to match the new dimensions and configurations. The chassis is also made entirely of HDPE and fitted together using the finger-joint technique. The gripper and camera placements were also unchanged. The overall dimensions are 750mm x 450mm x 479mm, the overall weight is 11.2 kg and the CG is below the CB by 64.9mm.

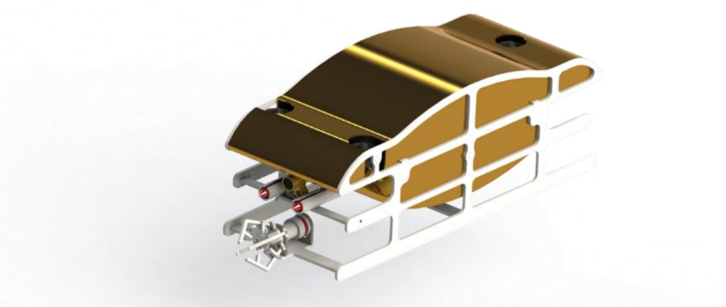


Figure 4-3 Design Configuration 2

3.2.1.3. Proposed design configuration

In the final design, we redesigned the side frame to be as topology optimized as possible, we also removed all the protruding parts. The body is made entirely of HDPE and fitted together using readily made, widely available Aluminum links to connect the supports to the main frame more efficiently. All the components are brought as close as possible to each other, which made the vehicle as compact as possible.. Next, the fixed camera is placed facing forwards, having the gripper and the mission probes in its field of view. The overall dimensions are 580mm x 450mm x 450mm, the overall weight is 9.5kg and the CG is below the CB by 40.3mm.

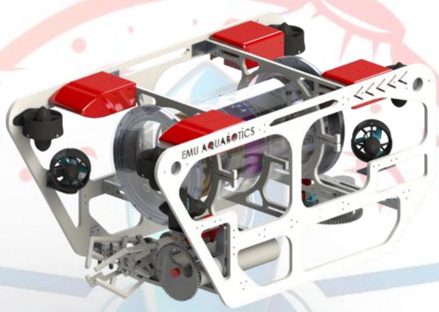


Figure 4-4 Proposed Design Configuration

Table 3-1 compares the main design evolutions through the design process:

Table 4-1 Design Configuration Comparison

	Parameter	**Design config. 1**	**Design config. 2**	**Proposed Design config.**
1	Material	HDPE	HDPE+ABS Plastic	HDPE
2	Fastening method	Finger joint technique	Finger joint technique	Aluminum Links
3	Dimensions (LxWxH) (mm)	834x550x450	750x450x435	580x450x450
4	Mass (Kg)	15.5	14.2	13.8
5	Buoyancy force (N)	150	134	122

3.2.2. Manipulator

We chose a modified bilge motor to power the arm as it is already isolated. This motor is placed inside a PA6 housing to ease its mounting on the ROV (as shown in figure 3-5). Next, this motor opens and closes the end-effector using a ball screw.

We chose the ball screw for its useful functions, such as its low friction and zero backlash. In addition, it transfers the rotational motion to linear smoothly, which is perfect for a reliable operation. The end effector is designed as shown to be able to grab objects with various shapes and dimensions.

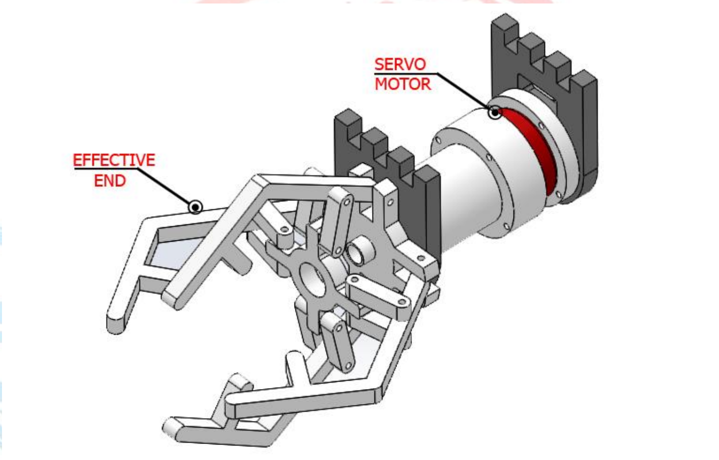


Figure 4-5 Gripper Mechanism

3.2.3. Materials

After careful research, we concluded that HDPE and Al 6063 are the most convenient materials to use as demonstrated in the following Pugh's criteria matrix.

Table 4-2 Material Selection Pugh's matrix

	Cost	Weight (according to different thicknesses)	Availability	Durability	Manufacturability	Score
Priority	4	2	5	2	3	
Titanium	5 (20)	10 (20)	5 (25)	10 (20)	5 (15)	100
Al 6063	7 (28)	9 (18)	10 (50)	8 (16)	8 (24)	136
HDPE	10 (40)	8 (16)	8 (40)	7 (14)	10 (30)	140
ABS Plastic	8 (32)	7 (14)	7 (35)	5 (10)	6 (18)	109

Chosen for its lightness and rigidity, our mechanical team chose HDPE as the material of fabrication. It provided the stiffness needed while it can also be easily cut on the CNC machine. It is also widely used in the commercial ROVs and its easily attained. The density of the Polypropylene is approximately 952 kg/m3 which is close to that of water (about 1000kg/m3), this makes it easier to adjust the buoyancy of our ROV. (Steels, n.d.) (Polypropylene, n.d.)

Main Features:

a) Ease of manual shaping, CNC cutting and drilling
b) Lightness
c) Rigidity
d) Good vibration properties
e) Cheap

Table 4-3 HDPE properties

Property	Value	Unit
Elastic Modulus	$107x10^7$	N/m^2
Poisson's Ration	0.4101	N/A
Shear Modulus	$377.2x10^5$	N/m^2
Mass Density	952	Kg/m^3
Tensile Strength	$221x10^5$	N/m^2

3.2.4. Isolation

Our main hull's design is crucial as it houses the electrical and controlling components. The hull is divided into three main parts, as shown in tabel 3-4:

Table 4-4 Hull main parts

Part	Feature
Al 6063 Cap	Fitted with 2 O-rings, made of Al for its good heat transfer capability
PA6 Cap	Fitted with 2 O-ring, made of PA6 to ease drilling in it to pass the cables into the tube.
PA6 Tube	Electrical components housing. 600mm long 200mm in diameter

Other than O-rings, we used isolating chemicals to ensure that no water passes through. These chemicals are described below in table 3-5:

Table 4-5 Chemical Isolation Compounds

Chemical	Use
Marine Silicon	Applied to the edges between the caps and the tube and to the penetrators
Silicon grease	Applied between the outer diameter of the caps and the inner diameter of the tube

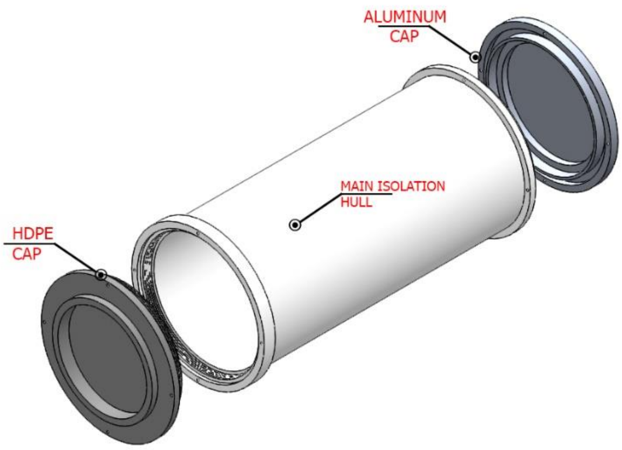


Figure 4-6 Main Hull

3.2.5. Design Calculations

3.2.5.1. Buoyancy

To calculate the vehicles weight in water, we must subtract the buoyant force acting on the AUV from its mass. First, we obtained the overall volume of the vehicle from SolidWorks, then, using Archimedes principle, multiply it by the water density and gravity, which gives us the buoyant force. Next, we subtract this value by the mass, which is also obtained from SolidWorks, to get the vehicles weight in water.

Table 4-6 Buoyancy Calculation

Parameter	Method of calculation	Value
Weight on-shore	Obtained from SolidWorks	13.8 kg = 138 N
Total AUV Volume	Obtained from SolidWorks	About 0.0128 m^3
Density of water	-	1000 kg/m^3
Buoyancy Force	ρ x g x volume submerged	128 N
CG and CB separation	$CB - CG$	100.3 mm
Weight while fully submerged in water	Weight on shore – Buoyant force	138 – 128 = 10 N = 1.0 kg

3.2.5.2. Thrust

The following table describes the thrust value for each DoF:

Table 4-7 Thrust Calculation

Degree of freedom	Thrust x number of motors in the corresponding direction (N)	Maximum Thrust (N)
Surge forwards	2 x 51	102
Surge backwards	2 x 41	82
Heave upward	3 x 51	153
Heave downwards	3 x 41	123
Sway right	51	51
Sway left	41	41
Yaw	51 + 41	92
Positive Pitch	2 x 41 + 51	133
Negative Pitch	2 x 51 + 41	143
Roll	51 + 41	92

3.2.6. Production Methods

Table 3.1-4 discusses the process of manufacturing each part. It also includes the suppliers and their locations.

Table 4-8 Manufacturing Plan

No.	Part number	Part name	Vendor	Machine	Process
1	GT19.M.CH.HDPE	Frame	Local suppliers (Egypt)	a) CNC	a) Main frame will be cut on CNC machine b) Assembly is done by screws and nuts
2	GT19.M.G	Gripper		b) N.A	c) Assembling custom made parts to obtain the desired function
4	GT19.M.I.HUL	Isolation tube	Local suppliers (Egypt)	c) Lathe	d) It will have 3 main parts e) Al 6063 cap made on lathe machine f) The end cap requires a lathe machine in shaping and drilling 16 holes inside this cap to connect cables g) For the main part, they will be fabricated on lathe machine according to the given design
5	N.A	Isolation technique	Local suppliers (Cyprus)	d) N.A	h) Using O-rings for the plastic end cap i) Using marine silicon around the caps j) Using grease around the end caps k) Using 3M compound those techniques will be applied consequently to achieve maximum isolation

Table 4-9 Assembling Plan

No.	Part number	Part name	Assembling
1	GT19.M.CH.HDPE	Frame	a. Screws will be used to mate between side Al 6063 supports and the main frame b. The hull will be mounted after assembling it c. Motors will be fixed in their places using bolts and nuts only d. The gripper will be fixed.
2	GT19.M.I.HUL	Hull	a. The hull will be assembled by closing the end caps and adding isolating material
4	GT19.M.G	Gripper	-

3.2.6.1. Procurement and Shipping

After selection of material, approving the design, writing down most of the part list and decided the manufacturing way we decided to order our parts from Egypt since we have a lot of options there and we will send the designs to the workshops there so we can have our parts ready there, we have an advantage by procurement from Egypt since it's much cheaper than Cyprus. So, the rest is just assembling parts here and testing.

All the components will be prepared in Egypt to be shipped through cargo, this will add to the cost but still cheaper than local suppliers and this was the best option the team agreed on.

3.2.6.2. Detailed Process

Our AUV is going to be built using a wide variety of manufacturing techniques, we are going to use a wide range of measuring devices to ensure compliance with our rigid model, including calipers, rulers, squares, level and measuring tape. Using lathe machine to make our custom designed isolation tube with two caps at the ends, one cap is made from Al 6063 acting as a heat sink and the other cap Is made from plastic which will have 16 hole where we are going to use penetrators to connect cables without water leakage , using O-rings around the end caps is the first stage of isolation followed by 3 other stages which are as follows

a) Marine silicon and silicon grease to the end caps will help providing maximum safety from leakage
b) 3M compound which is the final stage where we add it on the edge between the end caps and the main isolation tube
c) Isolation tube material is mainly BA6 plastic which will be manufactured using lathe machine according to the design and by the help of workshop technician.
d) 3D printing the external shell to benefit maximum from the aerodynamics without adding much weight in addition to covering to the main parts and giving a good shape to the AUV.
e) CNC machine will be used to cut our main frame according to the provided design, the frame is made from polypropylene with some side supports made from Al 6063 and this Al 6063 is cut by normal saw.
f) Loaded spring provided at local suppliers will be used to assemble the torpedo launcher with a bilge motor to remove the latch allowing the torpedo to be fired to the target.
g) Since we are using CNC and 3D printing techniques in building our AUV most of our manufacturing will be assembling parts with screws and screwdrivers, and it will not take a lot of time according to the Project Timeline given in Appendix E.

We will start manufacturing process by assembling the main frame that we have cut on CNC and mounting the main hull on the frame and putting some weights inside (dummies) and start testing the isolation technique and the dynamics of the AUV, next step is mounting the thrusters, gripper and torpedoes on the chassis without removing dummies and start testing the motors stability and control. Last step is to mount all parts inside the isolation tube and make sure every part is working perfectly then we can proceed to the next step which is the most important one (Testing), before moving to testing we will make sure every single point is working perfectly without any interactions with other systems.

3.2.7. Physical Features

Our aim is to build a UUV capable of completing both the manual and the autonomous missions seamlessly and in the most efficient and time saving strategy, without any compromises in the mechanical, electrical or software designs. Figure () illustrates the vehicles capabilities.

Main Features:

- Semi-Autonomous
- Depth rating: 15m
- Thrust Force: 6.5 kg.f
- On shore weight: 13.8 kg
- 6 DOF maneuverability

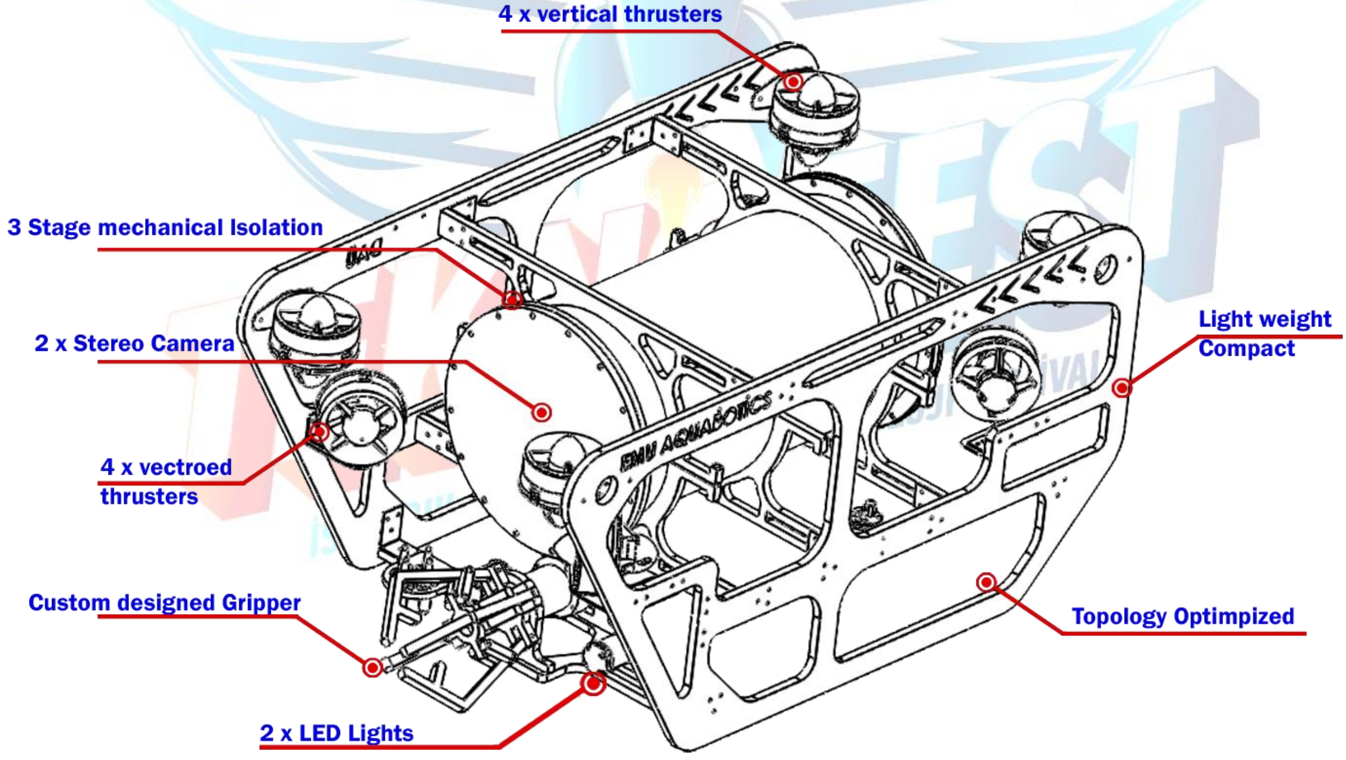


Figure 4-7 Labeled Illustration

3.3. Electronic, Algorithm and Software Design

3.3.1. Process of Electronic Design

3.3.1.1 Main Control unit:

As a lot of processing power is required for computer vision and managing the main software which will be developed using ROS.

There are many alternatives to be used in such case but the need of various USB ports as well as an Ethernet connection is essential, so our options can be limited to the following boards shown in table 3.1-6 below.

Table 4-10 Alternatives for mini PCs

Vendor	Model	Pros	Cons
Intel	NUC board	Assembled with intel processor Easy to install Linux operating system 4 USB ports (2 USB 2.0 and 2 USB 3.0) Easy shipping and customer support	-
Axiomtek	MANO882	2 DDR3-1333/1600 SO-DIMM, up to 16GB 4-IN & 4-OUT Digitak I/O 2 Ethernet ports	Processor to be purchased separately Expensive without processor
GigaByte	GB-BRi3H-8130	Cheap 4 USB ports (2 USB 2.0 and 2 USB 3.0)	-

3.3.1.2 Cameras:

The available options for cameras to be installed on the UUV can be divided based on three criteria:

a. Connection method: USB, Wi-Fi or HDMI
b. Isolation: Pre-isolated, or Added-isolation during manufacturing
c. Stereo Vision Availability: Stereo camera, or Mono camera

Although many connection methods are available the most commonly used is USB connection due to its wide availability, reliability, and ease of use, unlike for example Wi-Fi connection which cause many problems due to poor connection quality underwater and difficulty using multiple cameras at once which is necessary for the intended purpose of the UUV (MONTANA STATE UNIVERSITY, 2013), another option is HDMI although it's as reliable and easy to use as USB it still has a significant disadvantage in cost compared to USB.

The second criteria is stereo vision which is a very useful feature since stereo cameras can give "Depth Map" information alongside the RGB footage, but this feature comes at a significant cost of at least 449$ per camera (StereoLabs, 2018), while a good quality mono camera although lacking depth maps it will cost around 50-100$, but it will require a software method to obtain depth information.

As to the final criteria isolation (waterproofing), the two options are either pre-isolated cameras or added-isolation during manufacturing, which boils down to a tradeoff between cost and manufacturing time and effort, pre-isolated cameras will cost more while adding isolation will take extra manufacturing effort.

3.3.1.3 Power System

In this system, the main concern is the amount of voltage and current delivered to each device and try to control them by using some specific boards that perform the voltage regulating and current limiting processes. These terms can be done using a voltage regulator or a converter that steps up or down the voltage and the current. The specifications of each device must be considered so that no over current or voltage will be applied.

After we have done the research on this topic, we found that we have 3 different types of converters and they are more convenient for us because it provides an adjustable voltage or current feature.

a) **The buck converter (Figure 3-5):** is used for stepping down the input voltage to a minimum value but not being higher than the input and it uses a constant current. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

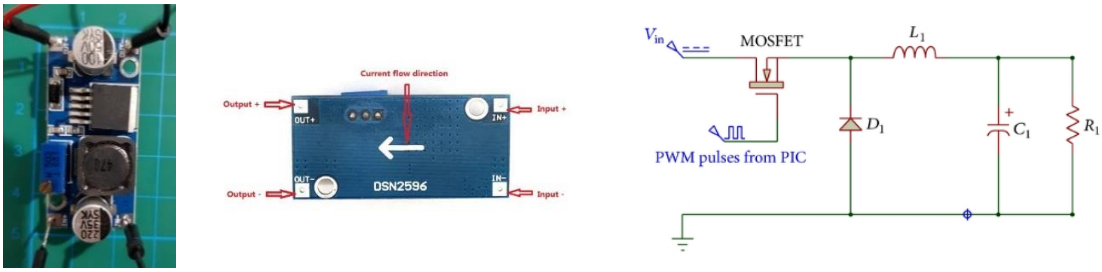


Figure 4-8 Buck Converter and its circuit diagram (Mohod, 2014)

b) **The boost converter** (Figure 3-6**):** which does the opposite that the buck converter does which is stepping up the input voltage to a maximum value and again at a constant current. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

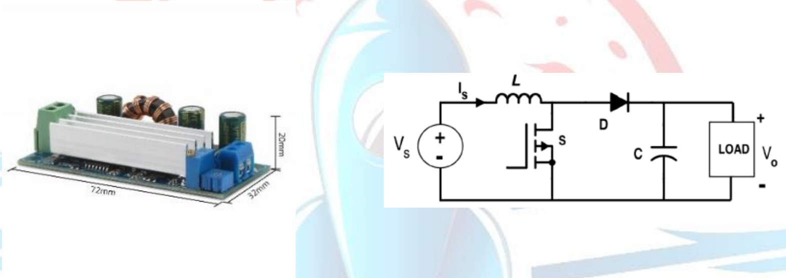


Figure 4-9 Boost Converter and its circuit diagram (Team, 2015)

c) **The buck/boost converter** (Figure 3-7**):** It combines the functionality of both the buck and the boost converters as it steps up or down the voltage, some of these converters are with a constant current and some with an adjustable current feature which is the thing we want. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

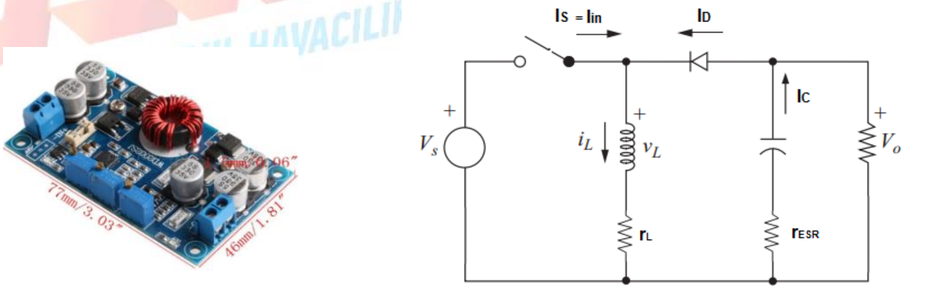


Figure 4-10 Buck/Boost Converter and its circuit diagram (Hussein, 2014)

d) **Programmable converters** (Figure 3-8)**:** so, it makes the regulation precise to have that exact output voltage and most probably we will be using the programmable one because it is better for us to have a precise value not to damage our devices.

Figure 4-11 Intelligent Programmable Converter (DCDC-USB-200 Converter, 2016)

3.3.1.4 Motors

The Electronic Speed Controller (ESC): Should be used to give a Pulse Width Modulation (PWM) signal to control the speed of the motor, deliver the desired power to the motor whenever needed (asked for by the control unit) and to provide a safety for the over current applied to it.

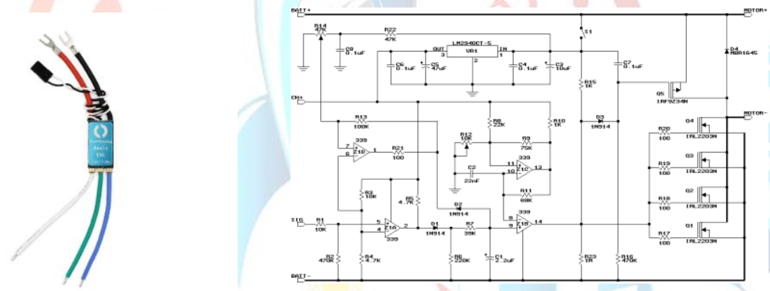


Figure 4-12 Basic ESC BlueRobotics and its Circuit Diagram (Magazine, 1999)

3.3.1.5 Monitoring

- **The leak detection sensor: SOS BlueRobotics** (Figure 3-10) will interrupt the system and sends an alarm to the controller whenever the water touches the probes connected to it.

  We need such a sensor since we are going to use an isolated tube that has an opening from one side to have all the connections coming out and going to the devices outside that tube and whenever the water goes in then the whole system will be damaged.

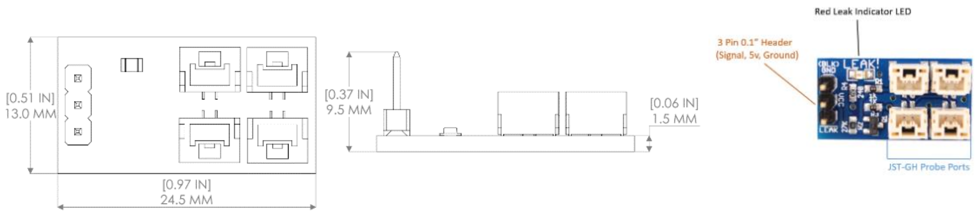


Figure 4-13 SOS Leak Sensor BlueRobotics

- **Weather sensor** (Figure 3-11)**: DHT11** sensor will allow the team to check the temperature and the relative humidity of the enclosure to try to control them not to affect the efficiency of the devices.

Figure 4-14 Temperature Sensor Module (DHT11 DHT-11 Digital Temperature and Humidity Temperature sensor for Arduino, n.d.)

3.3.1.6 AHRS and embedded controller

We are using the PixHawk board as an Attitude heading and reference system (AHRS) for various reasons as following:

a. PixHawk MPU6000 as main accel and gyro, ST Micro 16-bit gyroscope and ST Micro 14-bit accelerometer/compass (magnetometer) all integrated as an AHRS
b. PixHawk can be connected to a pressure sensor directly
c. Have a pre-built kill switch for safety concerns
d. Supports the ArduSub firmware intended to be used as we are going to discuss in the software subsystem
e. Can be connected directly to the electronic speed controller (ESC) to precisely control the motors
f. I2C, SPI, 2x CAN, USB interfaces which can be integrated with various sensors
g. Built especially for vehicles
h. Open source

So, the PixHawk can save a lot of time and effort that can be exploits in other complex systems to be designed. We will use the PixHawk 1 since it’s the which is fully tested and supported by the developers of ArduSub the control firmware.

Figure 4-15 PixHawk 1 [29]

3.3.2. Process of Algorithm Design

3.3.2.1 Overview

For developing the top software layer that is responsible about any part of the software system we found that the Robot Operating System is the best choice. First ROS has a wide community around the world which will allow us to find support for problems we would face.

ROS has a very powerful and flexible packaging system which make it way easier to build complex software systems on top of it. Finding the appropriate packages that can be used for a system to reduce time required to develop such system.

The architecture of ROS is what makes it very powerful for robotics projects, the need in any robotic system for real-time values from the sensors is essential so, ROS is providing the Publisher/Subscriber feature where communication occurs trough "Topics" which is the communication channel with a pre-defined message architecture. Also, each package can contain Publishers and Subscribers it's always better to separate packages depending on the functionality. with the existence of these features and tools ROS is optimal for robotics projects development.

Vehicle controls is one of the essential elements in any vehicle software system. Our vehicle has six degree of freedom as shown in the figure.

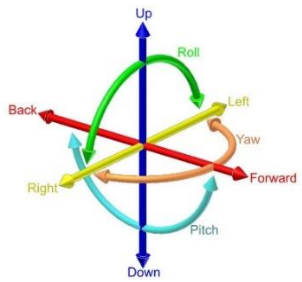


Figure 4-16 Degrees of Freedom in 3D space (Ionescu, 2010)

ArduSub is a firmware equipped with 3 diving modes and controllers for each degree of freedom it’s designed primarily to be used in ROVs system, but it has extended capability to be used for developing AUV functionality easily.

We can summarize the main power features in ArduSub as following: (ArduSub, n.d.)

a. Feedback control and stability: Based on a multicopter autopilot system, the ArduSub controller has accurate feedback control to actively maintain orientation.
b. Depth hold: Using pressure-based depth sensors, the ArduSub controller can maintain depth within a few centimeters.
c. Heading hold: By default, the ArduSub automatically maintains its heading.

3.3.2.2 Computer Vision

The options for computer vision are very limited with OpenCV being practically the only realistic option for image processing, but within OpenCV there are plenty of options that can be used to achieve the same intended goals (Joshi, Escrivá, & Godoy, 2016) (Laganière, 2014), based on the intended use for the UUV there are two major goals:

a. Object detection and tracking based on known colors and shapes. Object detection can be done by thresholding, Haar cascades (deep learning trained AI module), or rule-based AI, while tracking can be done using multiple methods including but not limited to centroid tracking, Deep learning algorithms (CSRT, KCF, MIL etc.) (Prince, 2012).
b. Detecting paths which is a very common task with many implementations available that achieve it, these implementations all follow the same basic process (Prince, 2012):

1. Area of interest detection (AoI)
2. Edge detection
3. Detection of parallel lines
4. Determining most likely paths

Although the used process is the same but the way each step is achieved differ slightly from one implementation to the other.

Finally, in case a stereo camera was not chosen a third major goal will need to be implemented in software

c. Depth detection, there are three possible software options one of which isn't computer vision dependent, but it'll still be discussed here for clarity and ease of comparison for the reader:

1. Reference dimensions: This method gives very accurate measurements for predefined target using the basic trigonometric concept of similar triangles. (Szeliski, 2012)
2. Estimated FOV thresholds: This method uses an estimated threshold for the area in the camera FOV covered by the object which will give an estimated distance range, if the object is too close it will cover an area larger than the upper FOV threshold, if it's too far it will cover an area smaller than the lower FOV threshold. (Szeliski, 2012)
3. State machine process: Using mission plan steps to move the UUV to the required distance, for example: move to touch the target -> move back at X speed for Y seconds

Image processing algorithm

This algorithm was designed to be simple, modular where every step can be modified without the need to modify the steps before and after it (Joshi, Escrivá, & Godoy, 2016) (Laganière, 2014) :

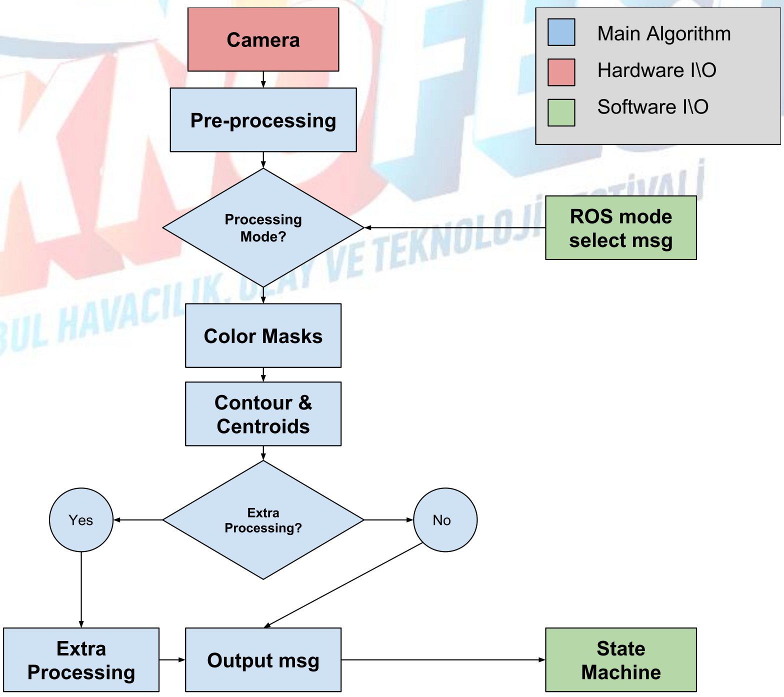


Figure 4-17 Computer Vision Algorithm

The software system consists of different layers to control the vehicle in a very efficient way to accomplish the mission. We will build our own custom meta-package on top of ROS each package will be responsible of a certain subsystem in the vehicle. Each package will consist of the required and the necessary ROS nodes.

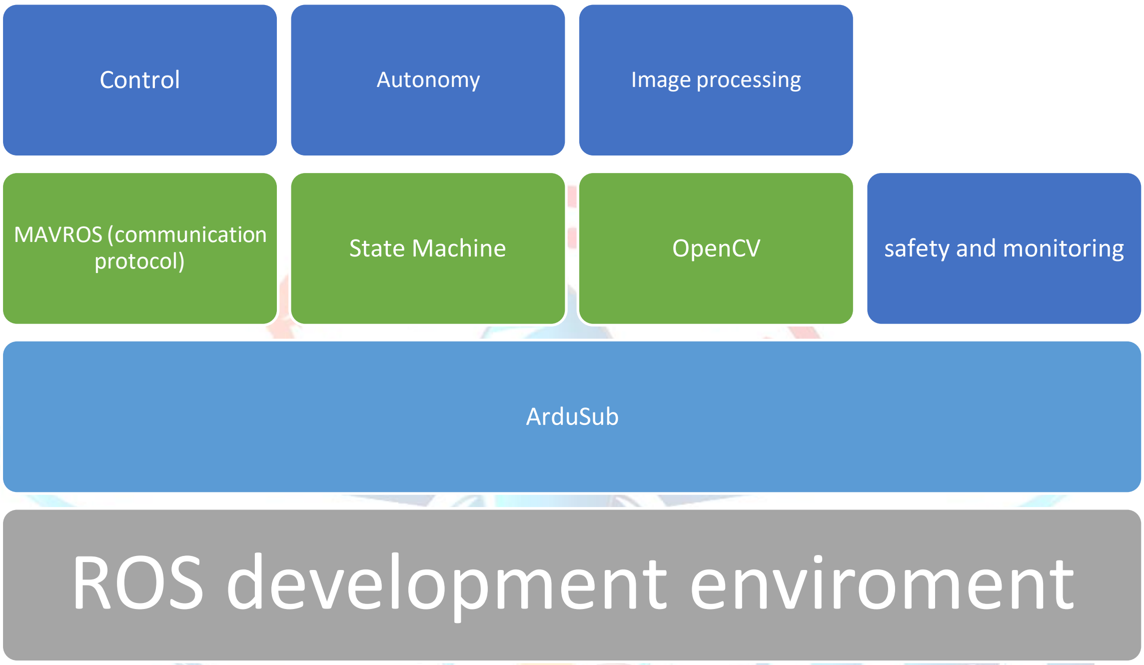


Figure 4-18 Layers Break down of the software system

3.3.3. Process of Software Design

Our software design is mainly a meta package consist of packages categorized depending on functionality so each package is responsible for only one function in the ROV our software design can be as described in the following table.

Table 4-11 List of designed packages and their functionality

Package Name	Package functionality
Image processing	Path following to guide the vehicle Navigate through a color-coded gate
Autonomy	Taking decision for using the state machine to perform a pre-defined mission
Control	Responsible to stabilize the vehicle Provide services to move the vehicle in any direction (Heading_to, Save_heading, Heading_to_saved, Move_forward, Move_backward, Move_right, Move_left, Pitch, Dive_to, Save_depth, Dive_to_saved, Gripper_hold and Gripper_release) Precision grapping system to control the manipulator
Safety and monitoring	Monitor the vehicle and take actions before serious damage could happens

More explanation about how our main two packages working is described below which they are the autonomy package and the control package.

a) Autonomy

This package is the decision maker. For autonomy we will exploit the power of state machines since the mission is well described and somehow, we can predict the actions needed. SMACH is a ROS package which allow us to build a state machine as visualizing it in the figure is an initial state machine for our proposed design and all the functionalities there is tested on the SITL simulator.

b) Control

The ArduSub firmware which we are considering it as our main control program has three diving modes.

a. Manual mode: passes the pilot inputs directly to the motors, with no stabilization. ArduSub always boots in Manual mode.
b. Stabilize mode: is like Manual mode, with heading and attitude stabilization.
c. Depth Hold: is like Stabilize mode with the addition of depth stabilization when the pilot throttle input is zero. A depth sensor is required to use depth hold mode.

We are exploiting the MAVROS package to communicate with the PixHawk since the PixHawk is using the MavLink protocol for communication and receiving commands and give feedback to the system, so a ROS driver is a must and that what we found in MAVROS. Also, the control package is responsible for the and gripper system by communicating with the Arduino Mega using the ROSSerial package.

The control package will have various ROS services to control the AUV in any direction required the initial services written and tested on the SITL simulator is as following.

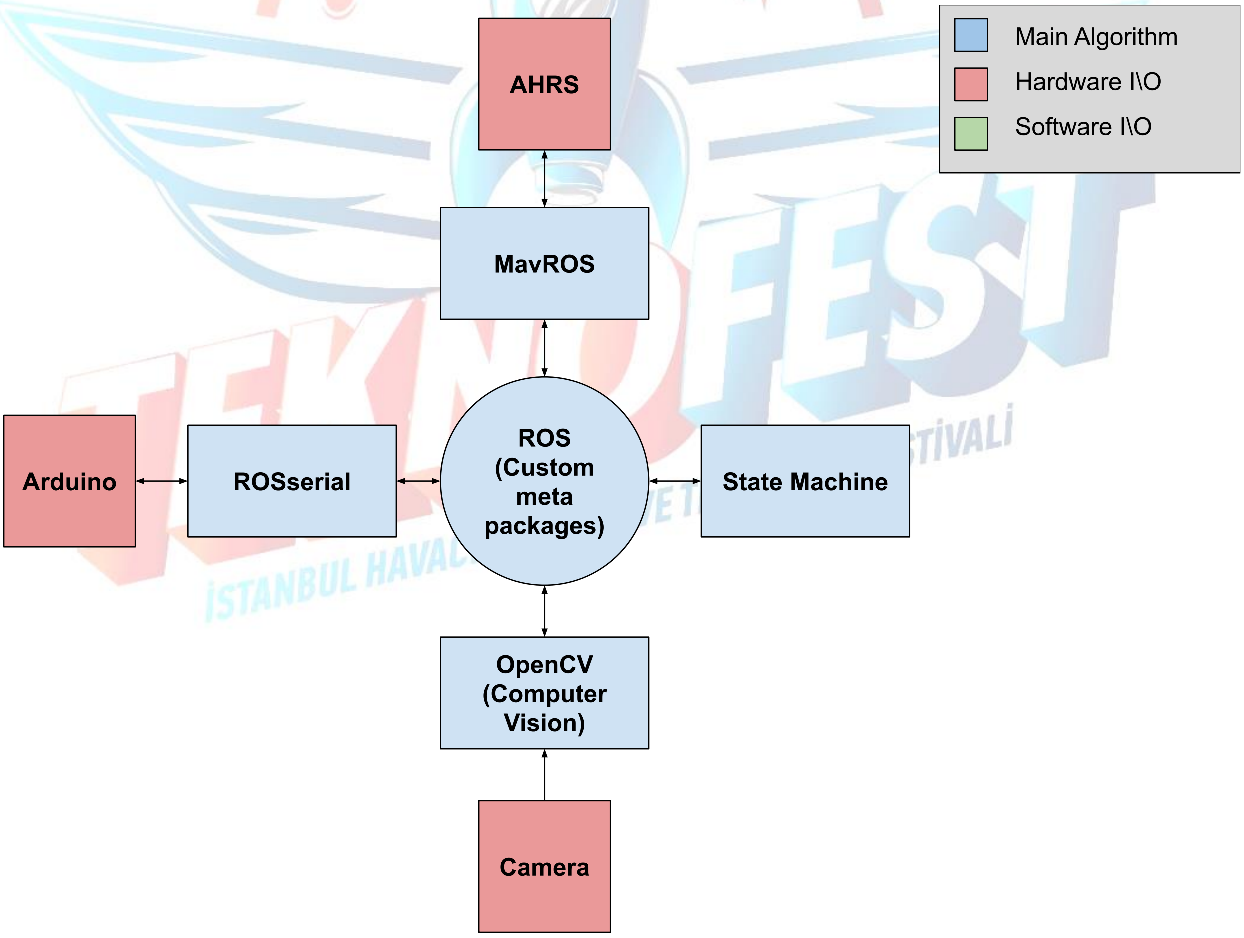


Figure 4-19 Overview of the software subsystem

3.4. External Interface

The on-board Mini-PC that directly controls the UUV, will be connected to a surface computer in the control station, using an Ethernet cable tethered to the vehicle on one end and connected to a the surface computer on the other.

The connection between the two computers will be established as a TCP port opened over SSH, once a connection is established each computer will be running its own node of Robot Operating System (ROS) and all exchange of information and instructions will be done using ROS topics and messages, enabling us to develop a modular system that can be easily expanded.

The surface computer will have a graphical user interface, built using Qt library which is a Python library used to develop graphical interfaces, this interface will allow the user to change some vehicle parameters and options on the fly such as thruster speed, the interface will show a live video stream from the the cameras installed on the vehicle, it will also provide information about the state of the vehicle including current depth, heading and temperature inside the isolation hull, finally the interface will give a warning to the operator in case of an emergency

such as leak detection.

Finally, the vehicle will be controlled by the pilot using a PlayStation4 Controller, the controller was chosen for its ease of use and intuitiveness making the task of navigating the UUV easier for the pilot.

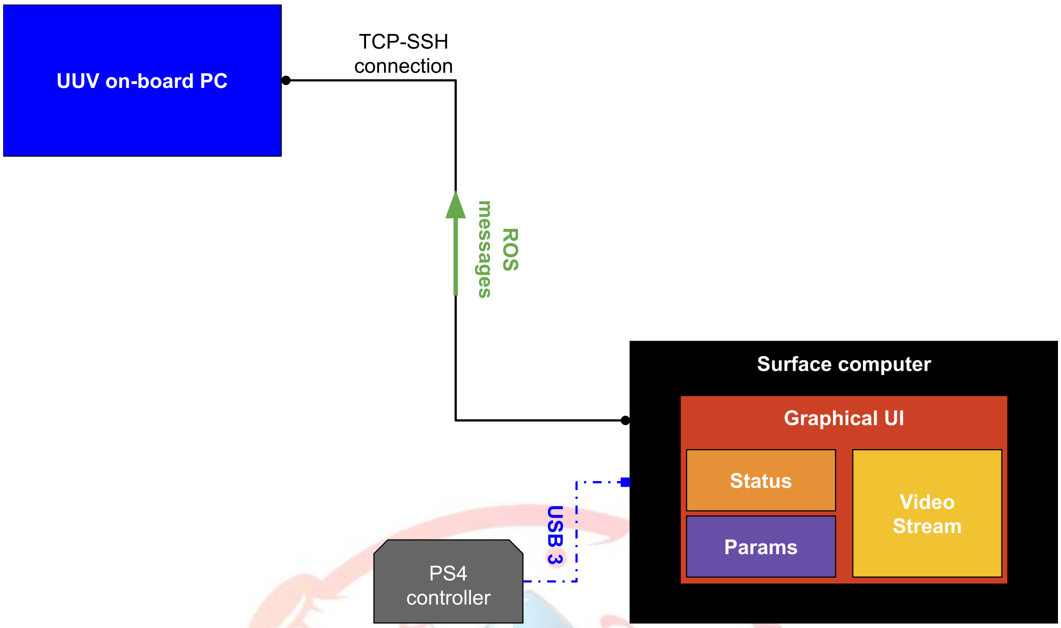


Figure 4-20 External Interface Diagram

Chapter 5 SECURITY

4.1. Main Aspects

We followed the safety requirements and precautions described in the competition terms and conditions. After careful consideration, strict guidelines and appropriate solutions have been agreed on, as described in the following table.

Table 5-1 Main safety concerns and solutions

No	Safety aspect	Description and Solution
1	Emergency stop botton	A kill switch has been placed on the hull's endcap which can be easily rotated in case of any emergenc. It is controlled using a microcontroller and an SSR relay.
2	Fully isolated power cables	High quality, waterproof power and control cables are purchased. In addition, the cables will be housed in a cable shield for further protection.
3	Presence of a fuse	A 25A DC fuse is placed at a distance of 30 cm from the power source.
4	Water Sealing test	Our sealing test consisted of 3 steps. First, we submerge the isolation tube with a closed endcap to test the main isolation techniques. Secondly, the cables are inserted using cable glands but with no components inside. The last step is fully testing the ROV's isolation.
5	Sealing of Electrical motors	We purchased commercial Bluerobotics T200 Brushless motors, tested to a depth of up to 130 m.

6	Sharp edges on motors	The motors are protected with a kortz nozzle around the propeller, which acts as a protection for both the propellers and the vehicle's operators.
7	Sharp edges on chassis	All sharp edges are already filleted in the design. The screws have been carfully selected according to the length required.
8	Loose connection between the vehicle and the control station	It has been taken into consideration that an extra length of the tether will be left between the pool's surface and the control station.
9	Separation from the AC supply	Connectors have been added at both terminals of the power cable, which makes it fool proof and cannot be connected to the AC supply.
10	Presence of hydraulic systems	No hydraulic systems are used in the vehicle.
11	Presence of loose components	All components have been properly fastened and we made sure that there is no wobble in any component or support.

4.2. Safety Checklist

To ensure the safety of both the vehicle and the operators, we created a safety checklist which we follow during manufacturing and testing.

Table 5-2 Safety Checklist

Electrical	
	NO wires near motors
	25A fuse present
	NO exposed wires
	Circuit board isolated
	Wires properly attached to tether

Mechanical	
	NO exposed motors
	NO loose screws
	Caution signs present
	NO sharp edges
	Gripper securely held
	NO cracks in tube
	3 O-rings present in the polypropylene stopper

	Camera fixed properly

Drilling and cutting	
	Wearing eye goggles
	Keeping sharp and drilling tools in the tool box
	Wearing safety gloves

Chapter 6 TESTING

Results of tests performed so far are shown in the table provided below

Table 6-1 Vehicle, components and algorithms test results

#No.	Part Number	Test Name	Feature\Part	Equipment	Standards	Test Description	Results
				Mechanical Subsystem			
1	CC01.M	Inherent Stability	UUV Cg\Cb	Pool	N.A	The UUV is placed in the water, to see if it will remain stable.	The vehicle was inherently stable without external forces
2	CC01.M.CH	Chassis	HDPE	Pool		The main challenge is the on-shore structure integrity, as the forces acting underwater are diminished.	The frame was rigid during transportation and handling
3	CC01.M	Restoration Forces	UUV cg\cb	Pool	N.A	A force is applied to the UUV to test its restoration capability and time	The restoration force was slightly more than calculated, it is planned that prototype 2 shall has smaller separation between the Cg and Cb
4	CC01.M.I.HUL	Isolation	Hull	Leak Sensor	IP6X	The UUV is left in the water for an extended period with a leak sensor placed inside the main Hull to detect any water isolation defects	After various tests, our isolation method was validated. Our future plan was to increase 1 more isolation stage on the caps
				Electrical Subsystem			
5	CC01.E.D.T2	Thrusters off-board	Thrusters	Multimeter	N.A	Thruster are tested to confirm they function	At first, each thruster was tested alone and the

						properly before they're installed on the UUV	current measured for each to be at max 3A DC (Note: it was tested using Arduino and Pixhawk to provide the motors with PWM signals)
6	N.A	Power Supply	Power Supply	PC Power Supplies	N.A	Main Power Supply tested to certify it delivers the required voltage and power the vehicle needs	Connecting five PC power supplies allowed us to have 1.5 kW of power at 12VDC and they were connected in parallel to give full power. In addition, after the vehicle was completed the power supply was tested by pulling the max current the vehicle needed which was about 25A DC
7	CC01.E	Electrical circuitry of Components	Electrical System	All Components	N.A	All of the available components connected together to justify the functionality of each component	This kind of test has been done off-board and, and was successful
8	N.A	Circuit Connectivity	Electrical Sub-system	Connection tester circuit	NFPA 496,NFPA 70	Verifying that all electronic components are connected properly	This was done by using a Multimeter to check all connections and make sure no short-circuit is present
				Software Subsystem			
9	CC01.S.C	Communication	Communication between	Vehicle Ethernet		Establishing an SSH connection and receiving	The connection was stable and uninterrupted,

			Vehicle and surface station	Power supply		vehicle diagnostic and video stream of vehicle cameras.	but the bandwidth was limited causing some lag in the video stream.
10	CC01.E.S	Sensor Readings	Sensors	Intel NUC	NISTH B 157	Verifying All sensors readings are reaching the main computer	Sensors provided reliable readings.
11	CC01.S.RS	Thrusters direction (Dry)	Thrusters	Thrusters Surface computer	N.A	Ensuring all Thrusters are mounted in the correct orientation and thrust in the proper direction.	thrusters 1, 2, 5 needed a reversed polarity.
12	CC01.S.RS	Thrusters speed control (Dry)	Thrusters	Thrusters Surface computer	N.A	Testing the electronic speed controllers (ESCs) for each Thruster individually by giving arbitrary speed values.	All thrusters operated as expected.

Chapter 7 **EXPERINCES**

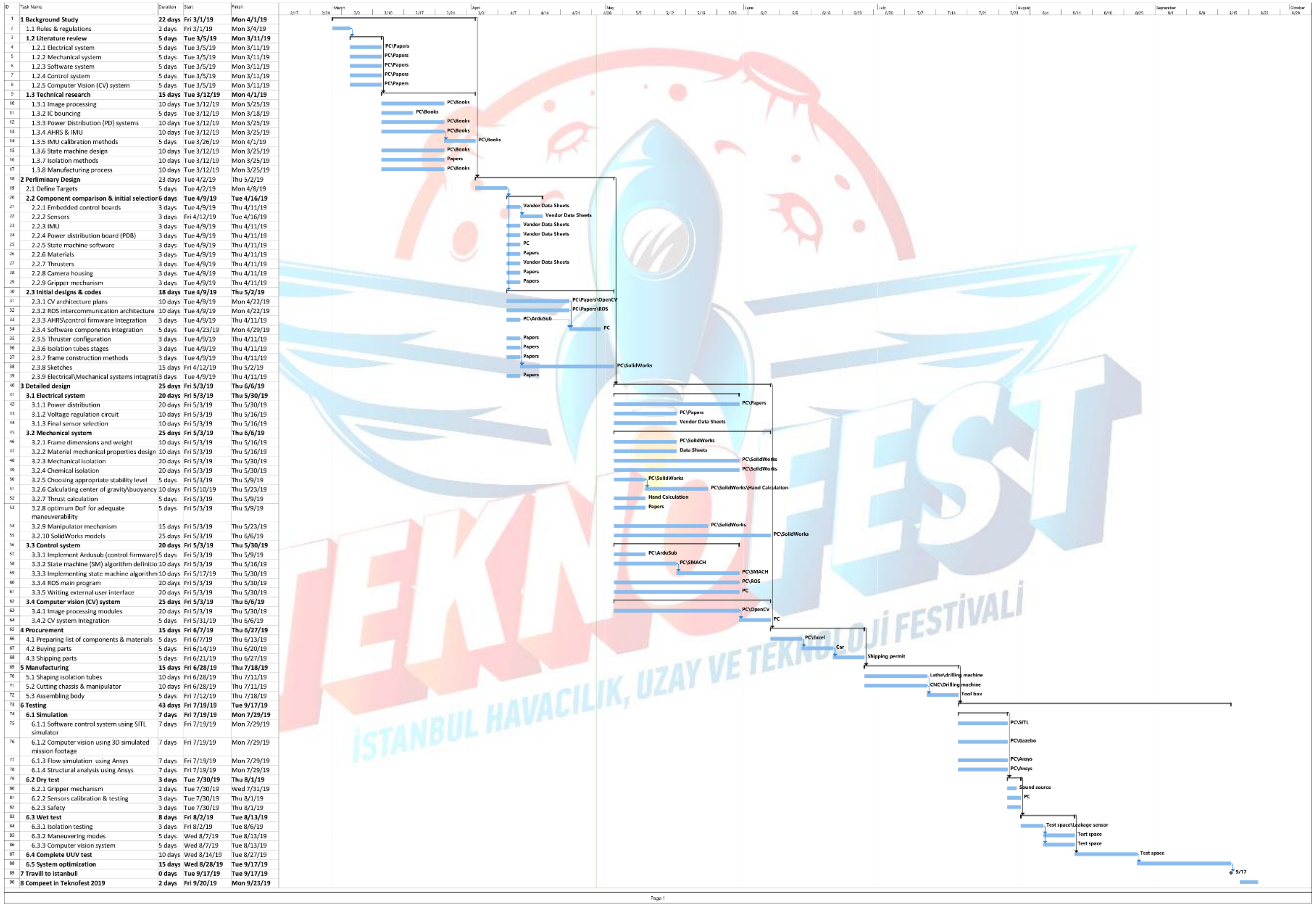
Naturally some mistakes will be made during design, manufacturing and handeling of the vehicle and its components.

From these mistakes valuble leasones were learned, some of these lesones and mistakes are as follows, the first and most important lesone is to cheack electrical connections for shorts and to add fuses that will cutoff power incase of any unexpected short circuit or power surge, second lesone is to handle components and parts carefully during transportation and assembling, further more it was learned that during the design and development process there are many parameters other then ideal preformence that ought to be considered such as cumputation and processing cost for software algorithims, financial cost of components and shipping and manufacturing time delays.

The learned lesones will not only help in the remainder of this project, but they are aplicable for all future work and projects, that our team members will work on in the future during their careers as engineers.

Chapter 8 TIME, BUGDGET AND RİSK PLANNING

5.1. Project Timeline



ID	Task Name	Duration	Start	Finish
1	**1 Background Study**	**22 days**	**Fri 3/1/19**	**Mon 4/1/19**
2	1.1 Rules & regulations	2 days	Fri 3/1/19	Mon 3/4/19
3	**1.2 Literature review**	**5 days**	**Tue 3/5/19**	**Mon 3/11/19**
4	1.2.1 Electrical system	5 days	Tue 3/5/19	Mon 3/11/19
5	1.2.2 Mechanical system	5 days	Tue 3/5/19	Mon 3/11/19
6	1.2.3 Software system	5 days	Tue 3/5/19	Mon 3/11/19
7	1.2.4 Control system	5 days	Tue 3/5/19	Mon 3/11/19
8	1.2.5 Computer Vision (CV) system	5 days	Tue 3/5/19	Mon 3/11/19
9	**1.3 Technical research**	**15 days**	**Tue 3/12/19**	**Mon 4/1/19**
10	1.3.1 Image processing	10 days	Tue 3/12/19	Mon 3/25/19
11	1.3.2 IC bouncing	5 days	Tue 3/12/19	Mon 3/18/19
12	1.3.3 Power Distribution (PD) systems	10 days	Tue 3/12/19	Mon 3/25/19
13	1.3.4 AHRS & IMU	10 days	Tue 3/12/19	Mon 3/25/19
14	1.3.5 IMU calibration methods	5 days	Tue 3/26/19	Mon 4/1/19
15	1.3.6 State machine design	10 days	Tue 3/12/19	Mon 3/25/19
16	1.3.7 Isolation methods	10 days	Tue 3/12/19	Mon 3/25/19
17	1.3.8 Manufacturing process	10 days	Tue 3/12/19	Mon 3/25/19
18	**2 Perliminary Design**	23 days	Tue 4/2/19	Thu 5/2/19
19	2.1 Define Targets	5 days	Tue 4/2/19	Mon 4/8/19
20	**2.2 Component comparison & initial selectior**	**6 days**	**Tue 4/9/19**	**Tue 4/16/19**
21	2.2.1 Embedded control boards	3 days	Tue 4/9/19	Thu 4/11/19
22	2.2.2 Sensors	3 days	Fri 4/12/19	Tue 4/16/19
23	2.2.3 IMU	3 days	Tue 4/9/19	Thu 4/11/19
24	2.2.4 Power distribution board (PDB)	3 days	Tue 4/9/19	Thu 4/11/19
25	2.2.5 State machine software	3 days	Tue 4/9/19	Thu 4/11/19
26	2.2.6 Materials	3 days	Tue 4/9/19	Thu 4/11/19
27	2.2.7 Thrusters	3 days	Tue 4/9/19	Thu 4/11/19
28	2.2.8 Camera housing	3 days	Tue 4/9/19	Thu 4/11/19
29	2.2.9 Gripper mechanism	3 days	Tue 4/9/19	Thu 4/11/19
30	**2.3 Initial designs & codes**	**18 days**	**Tue 4/9/19**	**Thu 5/2/19**
31	2.3.1 CV architecture plans	10 days	Tue 4/9/19	Mon 4/22/19
32	2.3.2 ROS intercommunication architecture	10 days	Tue 4/9/19	Mon 4/22/19
33	2.3.3 AHRS\control firmware Integration	3 days	Tue 4/9/19	Thu 4/11/19
34	2.3.4 Software components integration	5 days	Tue 4/23/19	Mon 4/29/19
35	2.3.5 Thruster configuration	3 days	Tue 4/9/19	Thu 4/11/19
36	2.3.6 Isolation tubes stages	3 days	Tue 4/9/19	Thu 4/11/19
37	2.3.7 frame construction methods	3 days	Tue 4/9/19	Thu 4/11/19
38	2.3.8 Sketches	15 days	Fri 4/12/19	Thu 5/2/19
39	2.3.9 Electrical\Mechanical systems integrati	3 days	Tue 4/9/19	Thu 4/11/19
40	**3 Detailed design**	**25 days**	**Fri 5/3/19**	**Thu 6/6/19**
41	**3.1 Electrical system**	**20 days**	**Fri 5/3/19**	**Thu 5/30/19**
42	3.1.1 Power distribution	20 days	Fri 5/3/19	Thu 5/30/19
43	3.1.2 Voltage regulation circuit	10 days	Fri 5/3/19	Thu 5/16/19
44	3.1.3 Final sensor selection	10 days	Fri 5/3/19	Thu 5/16/19
45	**3.2 Mechanical system**	**25 days**	**Fri 5/3/19**	**Thu 6/6/19**
46	3.2.1 Frame dimensions and weight	10 days	Fri 5/3/19	Thu 5/16/19
47	3.2.2 Material mechanical properties design	10 days	Fri 5/3/19	Thu 5/16/19
48	3.2.3 Mechanical isolation	20 days	Fri 5/3/19	Thu 5/30/19
49	3.2.4 Chemical isolation	20 days	Fri 5/3/19	Thu 5/30/19
50	3.2.5 Choosing appropriate stability level	5 days	Fri 5/3/19	Thu 5/9/19
51	3.2.6 Calculating center of gravity\buoyancy	10 days	Fri 5/10/19	Thu 5/23/19
52	3.2.7 Thrust calculation	5 days	Fri 5/3/19	Thu 5/9/19
53	3.2.8 optimum DoF for adequate maneuverability	5 days	Fri 5/3/19	Thu 5/9/19
54	3.2.9 Manipulator mechanism	15 days	Fri 5/3/19	Thu 5/23/19
55	3.2.10 SolidWorks models	25 days	Fri 5/3/19	Thu 6/6/19
56	**3.3 Control system**	**20 days**	**Fri 5/3/19**	**Thu 5/30/19**
57	3.3.1 Implement Ardusub (control firmware)	5 days	Fri 5/3/19	Thu 5/9/19
58	3.3.2 State machine (SM) algorithm definitio	10 days	Fri 5/3/19	Thu 5/16/19
59	3.3.3 Implementing state machine algorithm	10 days	Fri 5/17/19	Thu 5/30/19
60	3.3.4 ROS main program	20 days	Fri 5/3/19	Thu 5/30/19
61	3.3.5 Writing external user interface	20 days	Fri 5/3/19	Thu 5/30/19
62	**3.4 Computer vision (CV) system**	**25 days**	**Fri 5/3/19**	**Thu 6/6/19**
63	3.4.1 Image processing modules	20 days	Fri 5/3/19	Thu 5/30/19
64	3.4.2 CV system Integration	5 days	Fri 5/31/19	Thu 6/6/19
65	**4 Procurement**	**15 days**	**Fri 6/7/19**	**Thu 6/27/19**
66	4.1 Preparing list of components & materials	5 days	Fri 6/7/19	Thu 6/13/19
67	4.2 Buying parts	5 days	Fri 6/14/19	Thu 6/20/19
68	4.3 Shipping parts	5 days	Fri 6/21/19	Thu 6/27/19
69	**5 Manufacturing**	**15 days**	**Fri 6/28/19**	**Thu 7/18/19**
70	5.1 Shaping isolation tubes	10 days	Fri 6/28/19	Thu 7/11/19
71	5.2 Cutting chassis & manipulator	10 days	Fri 6/28/19	Thu 7/11/19
72	5.3 Assembling body	5 days	Fri 7/12/19	Thu 7/18/19
73	**6 Testing**	**43 days**	**Fri 7/19/19**	**Tue 9/17/19**
74	**6.1 Simulation**	**7 days**	**Fri 7/19/19**	**Mon 7/29/19**
75	6.1.1 Software control system using SITL simulator	7 days	Fri 7/19/19	Mon 7/29/19
76	6.1.2 Computer vision using 3D simulated mission footage	7 days	Fri 7/19/19	Mon 7/29/19
77	6.1.3 Flow simulation using Ansys	7 days	Fri 7/19/19	Mon 7/29/19
78	6.1.4 Structural analysis using Ansys	7 days	Fri 7/19/19	Mon 7/29/19
79	**6.2 Dry test**	**3 days**	**Tue 7/30/19**	**Thu 8/1/19**
80	6.2.1 Gripper mechanism	2 days	Tue 7/30/19	Wed 7/31/19
81	6.2.2 Sensors calibration & testing	3 days	Tue 7/30/19	Thu 8/1/19
82	6.2.3 Safety	3 days	Tue 7/30/19	Thu 8/1/19
83	**6.3 Wet test**	**8 days**	**Fri 8/2/19**	**Tue 8/13/19**
84	6.3.1 Isolation testing	3 days	Fri 8/2/19	Tue 8/6/19
85	6.3.2 Maneuvering modes	5 days	Wed 8/7/19	Tue 8/13/19
86	6.3.3 Computer vision system	5 days	Wed 8/7/19	Tue 8/13/19
87	**6.4 Complete UUV test**	10 days	Wed 8/14/19	Tue 8/27/19
88	**6.5 System optimization**	**15 days**	**Wed 8/28/19**	**Tue 9/17/19**
89	**7 Travill to istanbull**	**0 days**	**Tue 9/17/19**	**Tue 9/17/19**
90	**8 Compeet in Teknofest 2019**	**2 days**	**Fri 9/20/19**	**Mon 9/23/19**

5.2. Cost Analysis

Table 8-1 Cost Analysis

Total Cost without available parts and components									
#	Part Number	Name	Source	Model	Qty.	Cost ($)	Total cost	Shipping method	Shipping Cost
1	GT19.M.D.T2.X	Thrusters	Blue Robotics	T200 Thrusters	8	195	1560	Cargo	-
2	GT19.E.S.BR	Pressure sensor	Blue Robotics	Bar30	2	70	140	T.B.D	-
3	GT19.E.S.LK	Leak sensor	Blue Robotics	SOS sensor	3	20	60	T.B.D	-
4	GT19.E.C.PX	AHRS	ArduPilot	PixHawk 1	1	220	220	T.B.D	-
6	GT19.E.C.NC	Main Control Unit	Intel	NUC	1	429	429	T.B.D	-
10	GT19.E.P.BKB.X	Buck/Boost	Bangood supplier	XL6009	10	20	20	T.B.D	-
11	GT19.E.P.WPC.X	Waterproof cables	Local Supplier	-	40 m	116	116	-	-
17	GT19.E.P.VTU	VGA to USB converter	Local Supplier	N.A	2	20	40	T.B.D	-
19	GT19.M.I.AHC	Al 6063 Hull cap	Egyptian Supplier	AL 6063	1	203	203	Cargo from Egypt	-
20	GT19.M.I.PHC	Plastic Hull cap	Egyptian Supplier	PA6	1	30	30	Cargo from Egypt	-
21	GT19.M.I.HUL	Circuit Hull	Egyptian Supplier	Acrylic	2	232	464	Cargo from Egypt	-
24	GT19.M.CH.CHS	Chassis	Egyptian Supplier	Custom Design	1	400	400	Cargo from Egypt	-

26	GT19.E.C.ETH	High-speed Ethernet cable	Ultra-Spec Cables	40 m Cable waterproof	1	20	20	T.B.D	-
27	N.A	Multi-meter	-	-	-	-	-	-	-
28	N.A	Soldering station	-	-	-	-	-	-	-
31	N.A	Bread Boards	-	-	-	-	-	-	-
32	N.A	Screwdriver	-	-	-	-	-	-	-
33	N.A	Screws	-	-	-	-	-	-	-
34	N.A	Chemical Isolation Material	-	-	4	28	112	-	-
35	GT19.E.P.HTS .X	Heat shrinks	-	-	-	-	-	-	-
37	N.A	Transportation	T.B.D	-	-	-	-	-	-
38	N.A	Cargo from egypt		-	-	650	650	-	-
39	N.A	Printing	Deniz Shop	-	-	50	50	-	-
Total Cost							4514		

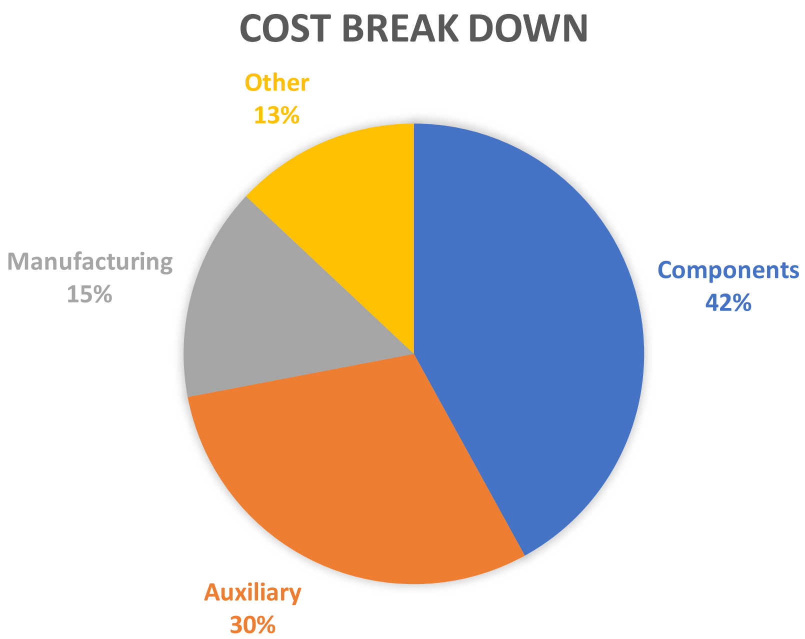


Figure 8-1 Cost Break Down

Since the components are the most expensive part according to the bill of materials (BOM), then it took almost half of the budget planned to this project.

Secondly, we have the auxiliary materials which is costly due to limited resources in Cyprus and VAT added to every product, so it was planned to take 30% of the budget.

Then, we have the manufacturing which will mostly be done in Egypt, since there are three Egyptian students in the team. It will cost almost 15% of the budget since we are using expensive material such as Aluminum 6063, etc.

Then for the rest 13% we have included other expenses like shipment and transportation inside Cyprus.

5.3. Failure Mode and Effects Analysis (FMEA)

The final design should be tested after manufacturing to ensure its safety and quality, also all parts should be tested to ensure that they function as intended, after that all sub-systems will be tested, and finally the complete vehicle will be tested to verify its ability to perform the intended objectives, the test are performed to ensure that none of the elements has failed and they have achieved their intended functionality, table 5-2 provides a Failure Mode and Effects Analysis (FMEA), it also includes the Risk Priority Number calculations.

Table 8-2 Failure Mode and Effects Analysis

#	Part number	Function Effected	Potential Failure Modes	Potential Failure Effects	Potential Causes of Failure	RPN = Severity*Occurrence*Detection	Recommended Action
1	GT19.M.I	Isolation	Water Leakage	Electric power circuit Short, Breaking internal components	Impact to the hull, Improper end cap installation, penetrator breakage	10*2*3=60	Detect failure using leak sensor and cutoff power.
2	GT19.E.D.T2	Thrust	Thrusters not working	Vehicle unable to move, Vehicle unable to stabilize	Disconnected power cable, ESC not working, Control computer disconnected	8*2*1=16	Check power levels and connections proper installation
3	GT19.E.C.PX	Control	Uncontrollable behavior	Unable to return to stable position, Moving in the wrong direction	Bad IMU readings, Broken thruster, Broken ESC	7*2*1=14	Kill switch then remove the vehicle from water and check all thrusters and sensors.
4	GT19.E.C.PX	Control	Extreme overshoot	Unable to reach and stop at destination	Poorly calibrated Controller and sensors, High latency in communication	5*2*2=20	Check Controller and sensor calibration.

5	GT19.E.S.BR	Depth control	Wrong depth	Unable to hit expected depth	Broken depth sensor	6*2*3=36	Add redundant depth sensor, test and calibrate depth sensors
6	GT19.E.S.BR		Fluctuating depth	Unable hold depth	Poorly calibrated Controller and depth sensors, High latency in communication	5*2*2=20	Check Controller and depth sensor calibration.
7	GT19.M.G	Gripper	Not actuating	Unable to hold or release object	Power disconnect, Disconnected controller, Broken actuator	7*2*1=14	Check actuator, check power, and check connection to controller
12	GT19.E.P.PDB	Power distribution	Power cutoff	Data loss, vehicle sink	Broken PDB, Disconnected power	8*3*2=48	Check PDB, Check Connection wires
13	N.A		Power surge	Burning electrical components	Miss designed power distribution system, Broken PDB.	9*2*3=54	Test and verify power distribution system, check PDB.
14	GT19.S.AS	ROV control	Control loss	Vehicle sink	Broken control pad, Disconnected tether	7*2*1=14	Check tether, Check control pad
15	GT19.S.AS	AUV control	Unstable navigation	Missing mission targets and objectives	Bad sensor and camera data, software bug or crash	7*4*2=56	Extensively test and review software layer, check all sensor connection and functionality
17	GT19.S.CV	Vision	Loss of Vision	Loosing direction, unable to identify mission objectives	Disconnected Camera, Software crash, processing pc crash	8*2*1=16	Check cameras connection and functionality, check computer and software layer.
20	GT19.S.RS	Data Logging	Data Loss	Losing some or all sensor data during testing and operation	Code error, hard drive failure, computer crash, disconnected sensor.	2*2*1=4	Check hard drive and computer, test and review software layer

Chapter 9 **ORIGINALITY**

During designing the various ROV systems, we were faced with many ‘make or buy’ decisions. While some components were cheaper to manufacture and better to be custom made to suit our needs, others were much easier and cheaper to procure, which gave us more time to focus on other systems. The original components and designs are listed below.

Table 9-1 Description of original designs

No	Component	Description
1	Chassis	a) Design based on the mission specifications b) Topology optimized c) Designed to be within the bonus points requirements
2	Isolation Hull	a) Designed based on the the chosen components. b) Modular mounting mechanisim c) 2 Stage chemical isolation d) Aluminum IP6X cable glands as penetrators
3	Gripper	a) Designed to grab and manipulate,different shapes and sizes. b) Reliable mechanisim with zero backlash
4	Power circuit	Custom designed to meet saftey and power requierments
5	Kill switch	Safety kill switch circuit for energancy situations.
6	Image processing	a) Custome algorithims to detect and track targets b) Guiding the vehicle during atonumus operations
7	Autonmy State Machine	Custome state machines to control autonmus behaviour of the vehicle
8	Control station UI	a) Graphical user interface, for the control station designed to give the UUV pilot all the nessesary information to complete the mission. b) Configuration panel for the vehicle control parameters.

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