Computer Aided Engineering Design
MENG303

Name of Project: *TURTLE ROBOT*

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ABSTRACT

Most robots operate exclusively on either land or water. In this project, an amphibious robot will be modelled. Amphibious robots are robots that are capable of moving on land and in water. The land turtle will be mimicked in this project to achieve this set objective. The report is divided into six chapters. The first includes the projects significance and objective as well as some product evaluation measures (DFX). The second chapter includes concurrent solutions of past related works with comparisons between these works to understand the proof of process. Design and analysis are done in chapter three. This includes design criteria for the project, selected designs and some calculations based on our design. The most suitable material for the product is chosen based on a decision matrix. The fourth chapter explains the manufacturing plan in detail, the selection matrix for the manufacturing process of our design and bill of materials (BOM). Chapter five includes the testing plans for our project and how the project objective is achieved under constraints. A proof of concept was made and tested in a real environment and the interaction of the prototype with the environment is observed. In the last chapter, some recommendations are provided for future references and how improvements can be made to achieve better results.

The proposed design in this project is promising and will serve as a foundation for future robots that can adapt to unstructured environments.

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LIST OF SYMBOLS AND ABBREVIATION

3D: Three dimensional

ABS: Acrylonitrile Butadiene Styrene

DOF: Degree of Freedom

IPMC: Ionic Polymer Metal Composite

QFD: Quality Function Deployment

SoC: System on A Chip

TCP: Transmission Control Protocol

IP: Internet Protocol

AT: Attention

USB: Universal Serial Bus

ICSP: In-Circuit Serial Programming

UART: Universal Asynchronous Receiver and Transmitter

PWM: Pulse-Width Modulation

SLA: Stereolithography

FDM: Fused Deposition Modelling

BOM: Bill of Materials

CHAPTER 1: INTRODUCTION

1.1. Detailed definition of the project

This project aims at designing a turtle project. The project in this report is a selection design with a semantic, graphical, physical, and an analytical design language. In this report, we will present the turtle robot in proof of product which means it can be sent by the bank of the supplier to the bank of the buyer to evidence that the product (commodity) does really exists. The turtle in this project has the capability to float on the water and swim as well as moving on the land. More details about the movement are in the body of the report. In this project, the best material suitable for the turtle robot has been chosen based on the best toughness, cost, strength, density and machineability. Detailed design and drawing of each part of the robotic turtle is provided in this report. Also, a detailed comparison between the results of the other articles on this topic is provided. Moreover, everything in this project is based on standards.

1.2. Significance of the project

The significance of this project is to increase the knowledge of the technology and the robot's world by increasing the electromechanical knowledge as well as programming skills to develop the technology needed for present and future applications, improving the standard of living. If intended to be used in water, our product could help in deep water exploration, pollution detection and other areas. Future prototypes can be made based on our projects to create Human Occupied Vehicles (HOVs) that can travel more than 10000m for an extended time beneath the ocean to study the ocean and gather data, specimens and pictures. The material used would need to be able withstand the extreme pressures as the robots goes deeper into the ocean. Our product is remotely controlled and falls under Remotely Operated Vehicles (ROVs) but can be upgraded to Autonomous Underwater Vehicles (AUVs) or even a hybrid with combined features of both systems. Environmental scientists are also looking for solutions to the challenges brought about by industrial processes which affects the ecosystem around the world. Successive prototypes of our product can be equipped with sensors that helps detect chemicals in the ocean. The prototypes could be equipped with claws and used to investigate plastic wastes in oceans and beaches, mitigating the effects of pollution thereby restoring ecosystems and reducing the environmental damage caused by human activity.

1.3. Detailed project objectives

The objective of this project is to apply the knowledge gotten from fluid mechanics, vibration, strength of materials, and other relevant courses in building a robotic turtle that is capable of swimming and walking on land. The commands/actions the robot is to take will be transmitted through a wireless transmitter. The project will give us a broad understanding of the mechanics & electronic configuration of machines and how they are designed. Working on this project will help us in building our technical skills and applying the knowledge gotten from past courses.

By June 2022, our project team will have used about 70 hours, between 4 to 6 hours per week to design, model, and build a proof-of-concept model. Some of the materials required for building the robot will be ordered online and some others will be gotten from a junkyard. The team will estimate the process, track the budget daily and communicate budget concerns in our weekly meeting in other to finish the project at the allocated time.

1.3.1. Design for Cost

The main objective of this project and the main constrain is to design the robot with low cost. The design of this robot provides a freedom of choosing the material and the manufacturing way since you can use any plastic material which gives the ability to do injection moulding or 3d-printing. Therefore, it is easy to manufacture it with a very low cost. Moreover, the design has a very low number of parts which means less energy required, less labours, less waste and tooling which leads to less cost.

1.3.2. Design for Assembly

The parts required for the design should be easy to assemble. In this robot, the parts are easy to be assembled. There are 10 manual assembly processes which don’t require a professional person. Moreover, there are 40 screws for holding the motors to be done also manually and easily.

1.3.3. Design for Manufacturability

This involves making a plan on how to manufacture the parts of the robot. The manufacturing processes that need to be carried out for making the design should not be complicated and expensive. The parts needed for the design should have low manufacturing cost and low waste. In this robot, the design provides the capability to be manufactured easily with no machining after the manufacturing and with almost no waste since injection moulding and 3d-printing can be used. Due to the simplicity of the parts and the small number of the parts, the manufacturing process is simple and short.

1.3.4. Design for Safety

The design should be safe and should not have a potential of causing harm to the user. This includes making sure that there are no sharp edges that can inflict harm to the user and properly insulating all electrical wires.

1.3.5. Design fo Environment

One of the most important constrains and objectives of this project is to design for environment. In this project, the manufacturing way is suitable for the environment since it does not waste lots of energy. And the design supports the manufacturing process to be done with almost zero waste.

1.3.6. Design for End of Life

This involves measures taken after the product fulfils its functions and how its components can be recycled to make more products. This involves dismantling the system into individual components to recover the materials used. Designing for end of life also includes designing for disassembly, designing products with a longer life span, using fewer different types of material, & labelling components for easy material identification. In this robot, the parts can be reused in many other projects after disassembly. Moreover, recycling process is available for the material used for manufacturing the robot.

1.3.7. Design for Sustainability

Ensuring the final product has no adverse effect on the natural world is another important design factor. One sustainable consideration is designing a project with a long-life span and reducing waste at the same time. The design should be based on the Hannover principles. Figure 1 shows the model for design for sustainability.

Figure 1: Design for sustainability

1.4. Detailed project constraints

This involves limitations that are already present in the design phase or future constraints that will arise as the design reaches its final stages which are unavoidable. These factors are:

- Time: This includes active time available to work on the design and make the physical model, & the deadline for completing the project.
- Cost: This is the most important factor/constraint in the project as all work is carried out on a limited budget. The make or buy decision is also influenced by this. The essential materials needed for accurate performance of our prototype are expensive so cheaper alternatives were used while also accomplishing the project objectives. As progress is made in the design phase, the cost also varies from the initial estimate.
- Availability of resources & materials: Some important materials needed for our prototype were hard to find in the country so we had to request for them to be delivered, which increases the already limited time.
- Environment/material selection: The final product needs to be able to be disassembled and the materials used needs to be recyclable so other products can be manufactured from them. Different materials are used in the project and the selection of which materials to use is very important as the expense is increased if one material contaminates the other.
- Manufacturability: This includes how the shape of each part/component of the product can be accurately manufactured. Specifying the most suitable manufacturing process for the parts was also a difficult part as the manufacturing process has an effect on cost and other evaluation measures.

1.5. Report Organization

There are six chapters in this report. In the first chapter, the project is well defined, and the significance, objectives and constraints of the project are discussed.

In the second chapter, various research papers concerning amphibious robots were reviewed. Then, solutions for achieving movement, communication, etc were outlined from the research papers that were reviewed. Decision matrices were drawn to ascertain the best type of solution for the project The engineering standards for the concurrent solutions were also explained.

In the third chapter, the project design and analysis are done. This includes design criteria for the project, selected designs and some calculations based on our design. Alternate designs made by the team are also included here.

In the fourth chapter, the manufacturing plan is explained in detail as well as the selection matrix for the manufacturing process of our design. A Bill of Materials (BOM) tables is also included showing all components of the design, costs and the quantity needed.

In the fifth chapter, testing plans for the project and how the project objective is achieved under set constraints is illustrated. Failure Modes and Effect Analysis (FMEA) is included in this chapter as possible modes of failure and parts likely to fail are shown.

In the sixth chapter, recommendations are provided for future references and how improvements can be made to achieve better results are explained.

CHAPTER 2: LITERATURE REVIEW

2.1. Background Information

It is very clear that autonomous robots play an important role in today's technological advancements. The need for a more adaptive and multi-ability machinery pushes the drive to do more research into improved and more advanced robots. One of the main concerns in robotic development is developing an autonomous robot that can operate effortlessly both on land and water regardless of the environment.

A turtle being the best representation of this ability to live, survive and function on both land and deep waters bestows ideas and inspiration for many designs and solutions that are used to develop better robots. Some of the mechanisms it uses to survive on are applicable to many situations thus the need for extensive research into the behaviour of these creatures. Many proposed concepts and developed prototypes based on a turtle design mainly involve performing a desired task or navigating a single environment that is either land or water. Developing an autonomous robot that can perform tasks on any environment is the main goal for extensive research.

2.2. Concurrent Solutions

Vogel et al., (2014) achieves splash free locomotion on land and in water by switching gaits of their quadrupedal amphibious robot called RoboTerp to manoeuvre terrain. Figure 2 shows the 3D model of the amphibious robot called RoboTerp. To eliminate extra weight and avoid the switching the limbs for locomotion, a ball is placed under the limbs of the robot so as to it move on land and rough terrain by increasing friction. Splash free swimming is achieved by the help of passive compliant mechanism that makes the limb of the robot behave like a valve. The design works in such a way that rhythmic leg oscillations generate a forward thrust to propel the robot and open to allow the legs move back to initial position and begin the process once more. With this design, the energy needed to create movement is reduced and the need for complex and costly designs are eliminated.

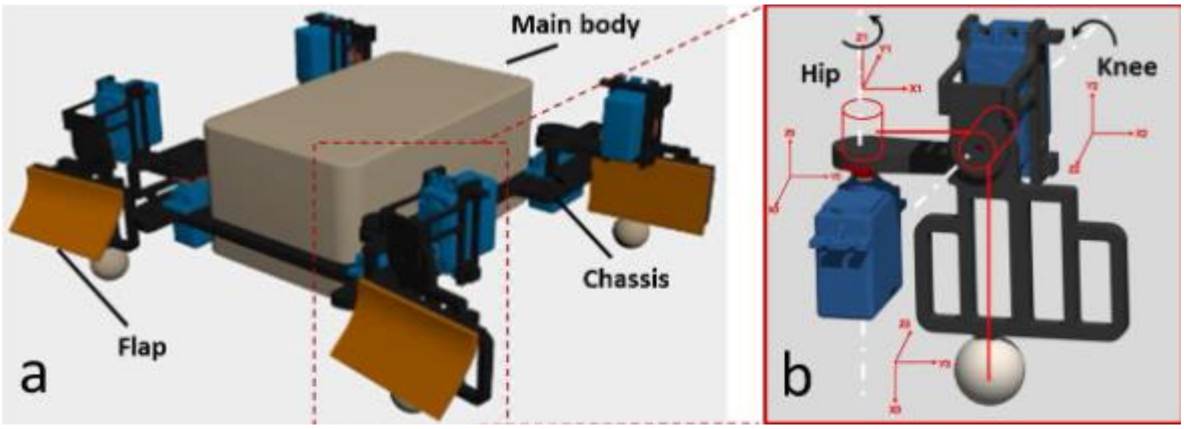


Figure 2: 3D Model of Roboterp

Domazetovska et al., (2020) designed an environmentally friendly bio-inspired low budget turtle robot designed to operate only on natural terrain. The robot body was 3D printed making it easy to accurately build the body with the right dimensions. The body also contains solar panels that power an Arduino Mega controller which works in turn with stepper motors. This thereby makes it self-sustainable and self-reliant. An android application custom made is used to control the motion of the robot by the help of an HC-05 Bluetooth module that has a signal span of 10m. The main programming for the application is based on JAVA language. Arduino C++ programming language is also used for the operation of the Arduino mega controllers. The results show that the robot fits the boundaries of the real turtle's movement.

A small-scale turtle-inspired amphibious robot was designed to walk on amphibious areas and narrow underwater caves to solve issues on navigating on underwater terrain. Xing et al., (2019) achieves motion by employing a multi-vectored water-jet composite propulsion mechanism (LMVWCPM) that achieves movement in a specified direction by following a coordinate system at the geometric centre of its body. Basing on the analysis of the force and proposed locomotion in submarines, yaw control and depth control experiments conducted showed the robot can keep the desired angle and the desired depth with the mean error of 1.7 degrees and 1.47 cm respectively making the performance of this robot is superior than the previous designed robots that use similar mechanisms. This study thereby gives valuable ideas for the design of small-sized amphibious robots with the aim of walking rugged underwater terrain.

Fu et al., (2019) developed another amphibious robot that has two movement modes: car-like movement on the land and boat-like movement on the water. This amphibious robot is composed of mechanical sub-system, electrical sub-system and sensor sub system. The control system is composed of the host computer and embedded controller. After repeated experiments, the measured maximum speed of the robot in water was about 1 m/s, and the maximum speed on the ground was more than 1.8m/s. Wireless remote control was also achieved by the use of radio signals. This research work shows that the wireless control function of the amphibious robot is feasible. Moreover, the parts of the prototype were manufactured with ABS material. The main performance parameters of this prototype were listed as follows a) The size (length × width × height) of the structure in the normal configuration is: 162mm ×60mm×40mm; b) The overall mass of the system is less than 0.3kg; c) The highest route speed is about 1m/s; d) The highest running speed is larger than 1.8m/s; e) The continuous working time is longer than 20 minutes; e) It has a maximum load of 0.2kg.

Low et al., (2007) worked on improving the design and performance of amphibian vehicles which will have reasonable speed and stable swimming ability like turtles. Studies have shown the high effectiveness of the turtle's underwater locomotion whose thrust is generated by the flapping foil-like flippers. The flippers of the robot were designed for both lift-based swimming and land crawling. This was achieved by a two DOFs mechanism. A ball made of rubber was placed with the flipper to prevent surface destruction when walking on land. Figure 3 shows the schematic design of the flipper with appendage attached.

Figure 3: Flipper with rubber appendage

A study was carried out on the mechanism of flipper-based terrestrial locomotion by sea turtles. To achieve this aim, a robot called FlipperBot was designed for quasi-static movement on granular media. Flat-plate flippers that were either fixed wrist joints or freely rotating were designed to be used as the front limbs of the robot. It was observed from the research that the biological inspired free wrist was better than the fixed wrist because it was less prone to failure. Another key finding from this research is that the performance of the robot significantly reduced when it moved on the ground that was already disturbed during its previous steps. Flipperbot serves as a proof that flippered locomotion is not effective for granular media (Mazouchova et al., 2013).

In the quest of designing an amphibious robot that is efficient, a morphing limb that changes its structure depending on the medium of locomotion was developed. The limb shapes of two animals that have the same morphology was observed: Sea turtles (Chelonioidea) and tortoise (Testudinidea). A limb that changes from the shape of a sea turtle flipper to a tortoise leg was created as shown in Figure 4 . This morphing limb helps to attain lift-based swimming and legged walking of a robot. This is achieved by changing the stiffness of the limb. In this design, there is no use of rigid metal parts. The morphing limb consists of soft fluidic actuators in an antagonist configuration and a thermoset epoxy, which is a variable stiffness material bonded to the strain limiting layer between the actuators to aid in morphing between the flipper and leg states of the limb. The thermoset is embedded with a thin-foil copper heater that helps to heat the thermoset. Several tests were conducted on the limb and it had good performance in leg and flipper states. Automation of the changes of the morphing limb (flipper and leg states) is a challenge in this design. The morphing limb can be used in unstructured and dynamically changing environments since it is resistant to corrosion and vibrations (R. Baines et al., 2020; R. L. Baines et al., 2019).

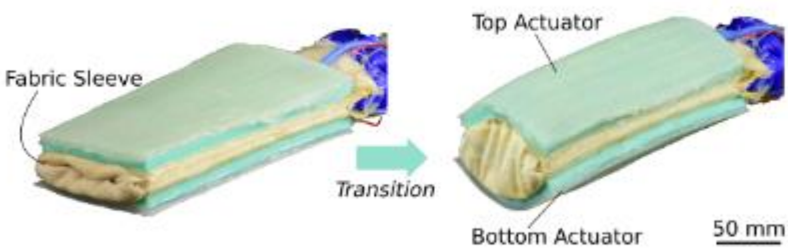


Figure 4: Variable Stiffness Morphing Limb

Taking inspiration from amphibious turtles, Shi et al., (2013) proposed an idea of using a "mother-son" system which comprises of several microbots as "sons" and a bigger spherical body as the "mother". Although these microbots had some desired features like a compact structure, flexibility and multi-functionality, it had some drawbacks such as unstable high speed and low endurance needed for real-life applications. The mother robot is designed to overcome these disadvantages. It possesses a spherical body (which can rotate and change direction than a streamlined design & a large interior space for the microbots) and four legs (actuated by four water-jet propellers and eight servomotors making it possible to walk on land and also three-directional cruising in water). The researchers also provided feasibility results for previously developed microbots, mechanisms involved in the mother robot and develops a prototype after carrying out a series of experiments to achieve motion on land and underwater.

In order to achieve versatile locomotion and high mobility in complex underwater terrains, Sun & Ma, (2011) presented an eccentric paddle mechanism (e-paddle) capable of achieving different gaits and gait sequences. Figure 5 shows the schematic, image and 3D drawing of the gait design used. Three terrestrial and two aquatic gaits are used to produce motion. Similar patterns were observed in the walking and paddling gaits but there were different interactions between the legs and the environment. Gait simulations were carried out and a prototype was developed to verify the forward and inverse kinematic models of the observed motion behaviour. The motion behaviours are paddle-tip-orientated (PTO) behaviour and wheel-centre-orientated (WCO) behaviour which were used in more than one gait and in which the kinetic models were built upon. One challenge faced was the integration of three active actuated joints into a small shell. This was solved by using an inversed timing belt reducer folded into the inner gear to couple with an actuator pulley.

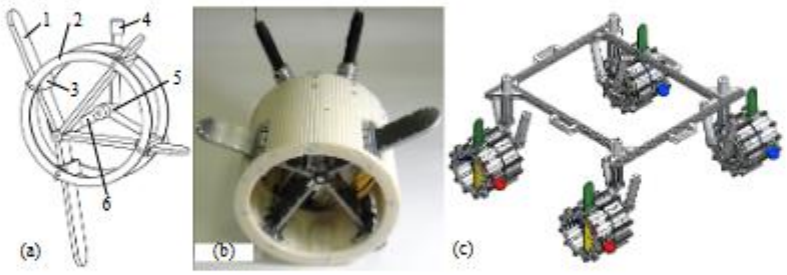


Figure 5: ePaddle design for amphibious locomotion

A major setback of autonomous micro-robotic turtles is power restriction which minimizes their deployment time. Q. Sun et al., (2020) designed a robotic turtle with self-charging capabilities. The robotic turtle is employed with a power supply battery, microcontroller unit (MCU), five H-bridge driving circuits, five IPCMs, two ultrasonic receivers and a wireless charging receiver module. The fins driven by five IPCMs achieve the desired movements through different instruction combinations. The microcontroller unit adjust the output waveform after receiving ultrasonic signals placed at the underwater charging station. The first coil is placed directly in front of the ultrasonic transmitter as the charging target and the second coil is placed at the bottom of the miniature robotic turtle. The robotic turtle will self-charge when the two coils come close to each other and produce an induction. Figure 6 shows the schematic robotic build of the turtle robot with the different components as shown.

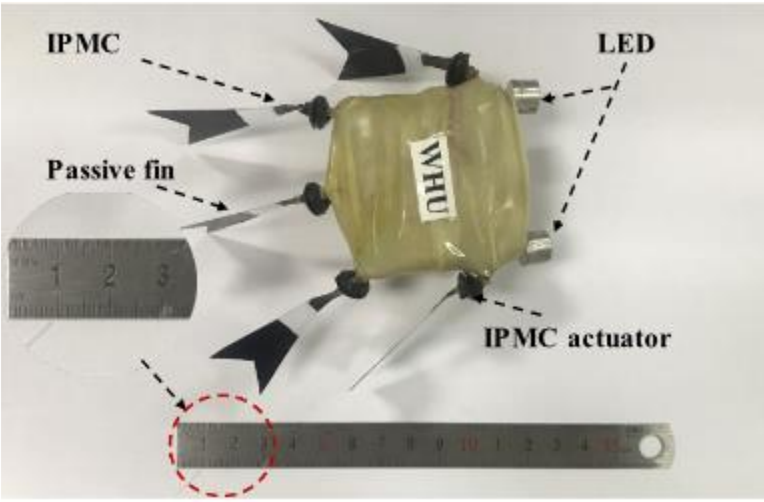


Figure 6: Prototype of the miniature robotic turtle that uses IPMC

Single or multiple soft actuators are used in swimming robots to simulate the dynamic movement of a fish. The development of effective soft actuators is critical to the success of designing a robot. Majority of these actuators have drawbacks such as slow response time, blocking force etc. A way to overcome the water drag, provide stability and limit other drawbacks which reduces the efficiency of the actuators was devised. To achieve this, a hybrid propulsion mechanism by using double soft legs as caudal fins and side paddles as pectoral fins is implemented as shown in Figure 7. To ensure that the swimming robot floats under actuation, two floatation housing are attached to the underside of the complaint paddle housing. Complex swimming motion of the robot was accomplished by using servo motors (Garcia et al., 2022).

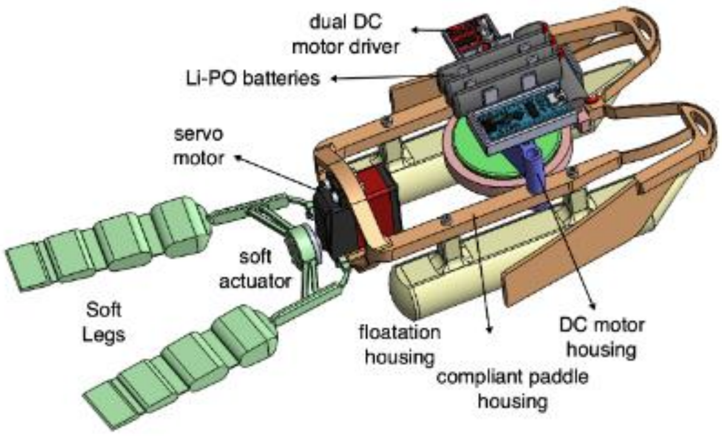


Figure 7: Robot using soft electromagnetic actuation

Zhong et al., (2018) designed an amphibious hexapod robot with variable stiffness legs capable of adapting to various complex environment. This design enables the amphibious robot to achieve locomotion with only one set of propulsion mechanism. The legs are constructed with rigid fan shaped frames which operate as a walking leg and also protect the flexible flippers used for aquatic motion. During the design, the leg strength, the material of the leg frame and its weight were considered so that the leg structure will have enough strength to support the weight of the robot including the batteries used to power the robot. The legs were also designed to be slender so that the drag profile in the direction of the water flow is low.

Zhang et al., (2013) worked on an amphibious robot called AmphiHex-I. AmphiHex-I uses a transformable fin-leg propulsion mechanism which makes it able to walk on rough and soft terrains and swim in water. Figure 8 shows the schematic design of the AmphiHex-I flipper in both modes of locomotion.

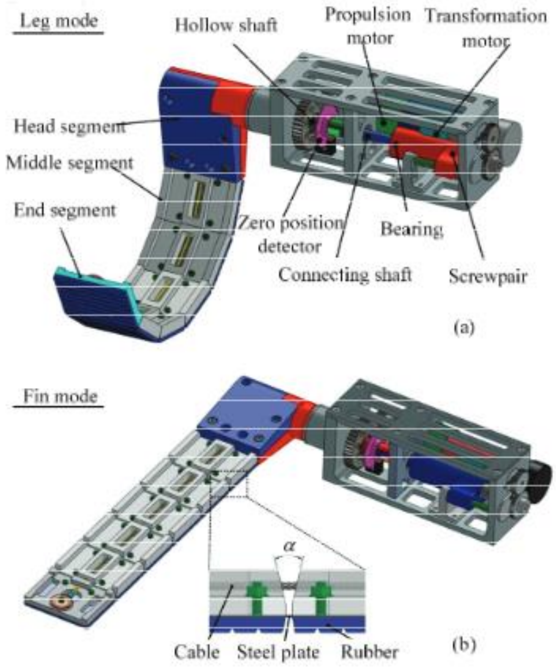


Figure 8: Transformable Fin-Leg Mechanism of AmphiHex-I

2.3. Comparisons of the concurrent solutions

Most of the literatures reviewed in this project are about amphibious robots. Few research papers were found on modelling a turtle robot. R. Baines et al., (2020) stated that "The paucity of literature concerning amphibious robots is due in part to the fundamental challenges of designing and integrating together propulsive mechanisms for effective water and land-based locomotion". Due to this reason, modelling of the robot to move like a turtle is removed from the objective. The objective is redefined to make a robot to move on land and water.

The following are the solutions found for the movement mechanism of the turtle:

i. Variable Stiffness Morphing Limb
ii. Transformable Fin-Leg Composite Mechanism
iii. Smart Soft Composite (SSC) Structure
iv. Flipper and ball
v. Soft Pneumatic Actuators (SPA)
vi. Eccentric Paddle Mechanism (ePaddle)

vii. Ball and a passive complaint flap

Table 1: Decision matrix for movement mechanism

Criteria	Weights	Ball and a passive complaint flap	Flipper and ball	Transformable Fin Leg Composite Mechanism	Variable Stiffness Morphing Limb
Simplicity	5	9	4	2	2
Durability	5	8	6	5	7
Manufacturability	4	8	6	3	2
Cost	5	7	5	2	2
Total		152	99	57	63

Four solutions were picked from the solutions for movement mechanism. This is because we are not knowledgeable enough to achieve the other two movement mechanisms. From the decision matrix, the ball and complaint flap has the highest score. This means that it is going to be used for the movement mechanism.

The following are the solutions used for achieving communication with the turtle:

i. Bluetooth module

ii. Wireless Fidelity (Wi-Fi)

iii. Wired connection

The following are the solutions for interfacing the inputs and outputs:

i. Arduino Mega controller 2650

ii. Robot Operating System (ROS)

The following are the solutions for powering the robot

i. Solar powered

ii. Battery powered

Due to limited funding of the project, the robot will be powered using batteries.

2.4. Engineering standards of the concurrent solutions

According to The American Society of Mechanical Engineers (ASME), “A standard can be defined as a set of technical definitions and guidelines, “how to” instructions for designers, manufacturers, and users. Standards promote safety, reliability, productivity, and efficiency in almost every industry that relies on engineering components or equipment” (*Standards & Certification - FAQ | ASME - ASME*, n.d.).

The standards used for the solutions of the movement mechanism are ANSI Z400, OSHA 29 CFR 1910.1200, ASME B1.1, and IEC 60034 (American National Standards Institute, 2010; International Electrotechnical Commission, 2022b; OccupationalSafety and Health Administration, 2012; The American Society of Mechanical Engineers, 2004).

The standards used for the solutions for communication are RED, ETSI EN 300 328 (European Telecommunications Standards Institute, 2019; European Union, 2014).

The standards of the solutions for the controller are EU RoHS, EU REACH 211 (European Union, 2006, 2011)

The standards for the options for powering the robot are IEC 60086, and IEC 61215 (International Electrotechnical Commission, 2021, 2022a).

The standards for the robots are ISO 8373:2012, and ISO 10218-1:2011 (International Organization for Standardization, 2012a, 2012b).

Table 2: Standards for concurrent solutions

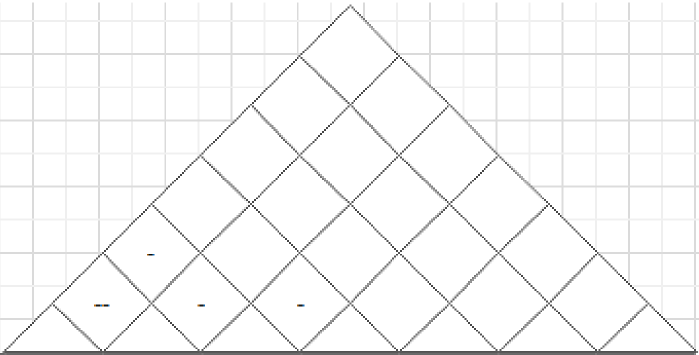
Standards	Description
ANSI Z400	This Standard applies to the preparation of MSDSs for chemicals and materials1 used under occupational conditions. It presents basic information on how to develop and write MSDSs that are complete, clear and consistent.
OSHA 29 CFR 1910.1200	This standard is about occupational safety and health concerning toxic and hazardous substances.
ASME B1.1	This standard specifies the thread form, series, class, allowance, tolerance, and designation for unified screw threads.
IEC 60034	This standard is applicable to all rotating electrical machines, except rotating electrical machines for rail and road vehicles
RED	This is Radio Equipment Directive. It is a regulatory framework for placing radio equipment on the market in the EU.
ETSI EN 300 328	This is a standard for wideband transmission systems
EU RoHS	This is a directive of the EU that restricts the use of hazardous substances in electrical and electronic equipment to protect the environment and public health.

EU REACH 211	This regulation aims to improve the protection of human health and the environment from the risks that can be posed by chemicals.
IEC 60086	This standard is intended to standardize primary batteries with respect to dimensions, nomenclature, terminal configurations, markings, test methods, typical performance, safety and environmental aspects.
IEC 61215	This International Standard lays down IEC requirements for the design qualification and type approval of terrestrial photovoltaic modules suitable for long-term operation in general open-airclimates.
ISO 8373:2012	This standard defines terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments.
ISO 10218-1:2011	This standard specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots.

CHAPTER 3: DESIGN AND ANALYSIS

3.1. Quality Function Deployment (QFD)

In order to generate the engineering specifications, a QFD was drawn (David G. Ullman, 2009). Quality function deployment helps to establish and achieve the needs and the requirements of the customers. The weights for customer's requirements are from 1-5. The QFD is shown in Figure 9.



	Importance	Relative Weights	Low density	High yield strength	Low cost of production	Efficient motors	Use of temporary fasteners	Waterproof materials	Use of radio waves for communication
WHATs									
Cheap	4	13.3		○	◉	◉	○	○	○
Low power consumption	4	13.3	◉	○	△	◉			○
Able to carry small loads	5	16.7	△	◉			◉		
Durable	4	13.3		○	◉	○		◉	
Move on land and water	5	16.7	◉	◉		○	△	◉	
Ease of maintenance	3	10					◉		
Controllable	5	16.7							◉
Important Weights	30		286.7	420.3	252.7	329.4	296.9	309.9	230.1
Relative Importance Weights			13.5	19.8	11.9	15.5	14	14.6	10.8

Figure 9: Quality Function Deployment of the project

From Figure 9, the highest weight for engineering specifications is high yield strength of the material used. This means that we are to focus more in designing a product using a high yield strength material. Low density is equally important in choosing the material because without it, the robot will not be able to move in water.

3.2. Design Criteria

The design objectives and constraints will be discussed in this section.

3.2.1. Design Objectives

The design objectives of the turtle robot are:

i. Land and water movement: The main design objective is to design a model that can efficiently move on land and water.

ii. Low cost: Another design objective is for the design to have low cost in manufacturing. This enables the manufacturer to avoid spending huge sums of money; thereby making the manufacturing process affordable.

iii. Great quality: Great quality is also important because it enables the turtle robot to function in any terrain effortlessly thereby reducing the need for servicing.

iv. Waterproof: The turtle robot should also be waterproof. This is to avoid damage of the interior components of the robot when placed in water.

v. Lightweight: In order for the turtle robot to swim in water, the material used for the robot must have low density.

vi. Controllable: One of the design objectives is that the turtle robot should be controllable either wirelessly or wired.

3.2.2. Design Constraints

The following are the constraints in the design of the robotic turtle:

i. Cost: The availability of funding for the project plays a huge role in the design process. If there are no much funds for the project, cheaper and low-quality materials will be used for the design. This limits the type of design that can be carried out.

ii. Standards: Since specific standards have to be followed for the manufacturing of the robot, it makes the design process laborious and more expensive.

iii. Manufacturing process: If the machine and the parts of the desired manufacturing process are not available, it reduces the quality of the design and also increases the cost of production.

iv. Availability of resources: When resources needed for the design are not available in the vicinity, it increases the cost of the project and makes the design process slower since more time will be spent on getting the parts.

3.3. Proposed/Selected Design

The selected design for the turtle robot is to use a ball and passive complaint flap as shown in Figure 10 below. The decision matrix for this selection can be seen in CHAPTER 2: LITERATURE REVIEW. The design will be divided into two subsystems; mechanical and electrical subsystems. The design and reason for selection of each part will be illustrated in the following sections.

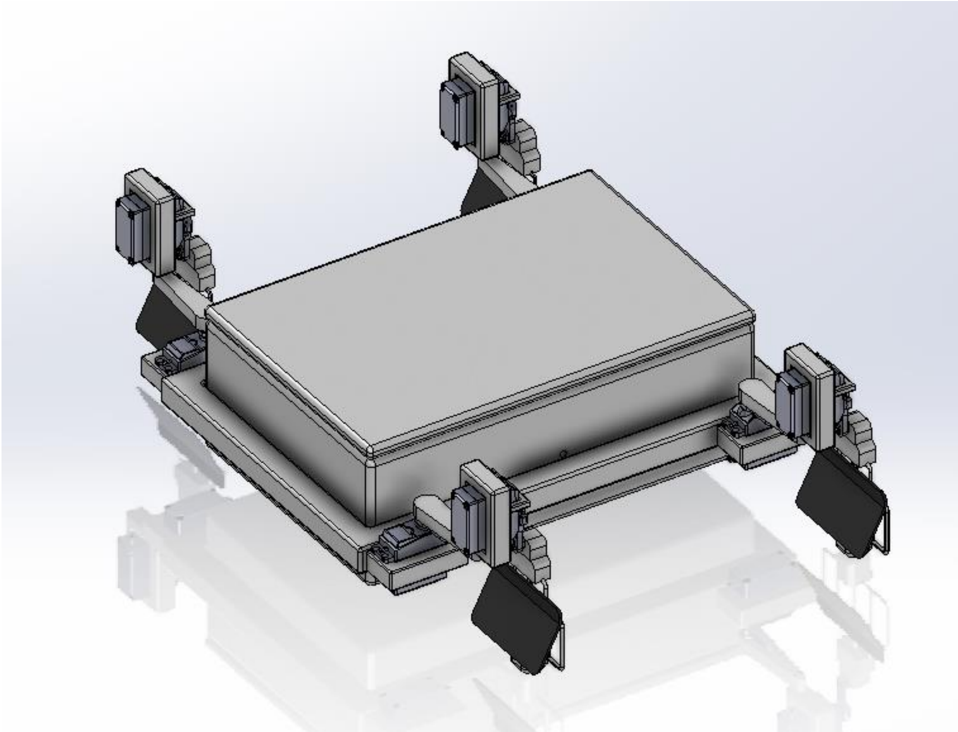


Figure 10: Selected Design

3.3.1. Mechanical Subsystem

All the mechanical parts will be discussed in this section.

3.3.1.1. Box

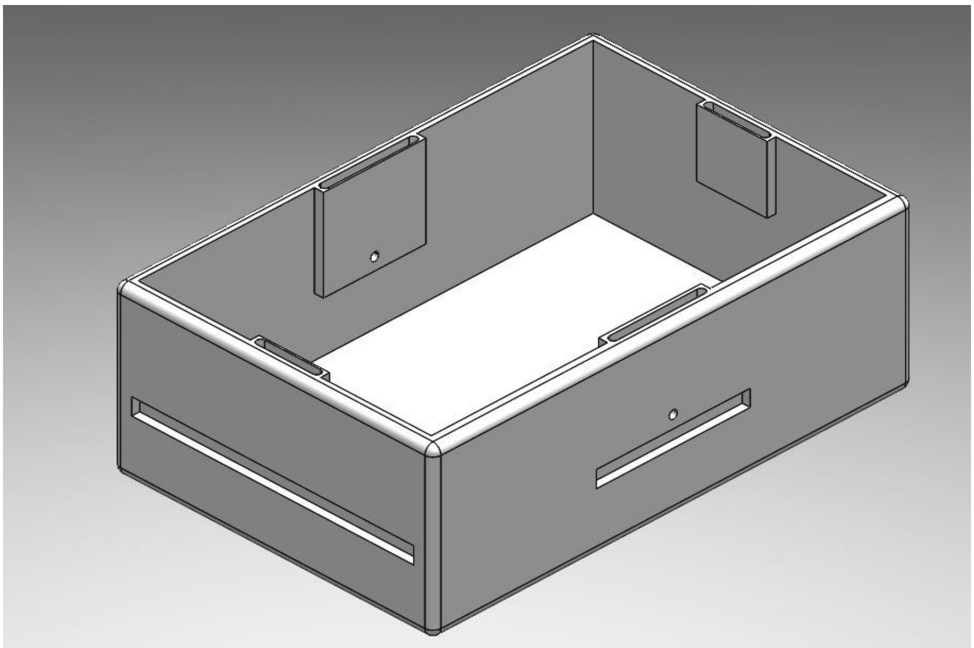


Figure 11: Box

Figure 11 shows the main box design that will serve as the main body of the robot. Since the turtle should be able to carry small loads, space was provided for this function. The holes seen on the top of the box will serve as the placement for the lid. The reason why this method was chosen is to avoid extra cost for screws and machining.

The box will also serve as a space for placing the components needed for the electrical subsystem of the robot such as battery, controller and Wi-Fi module.

3.3.1.2. Lid

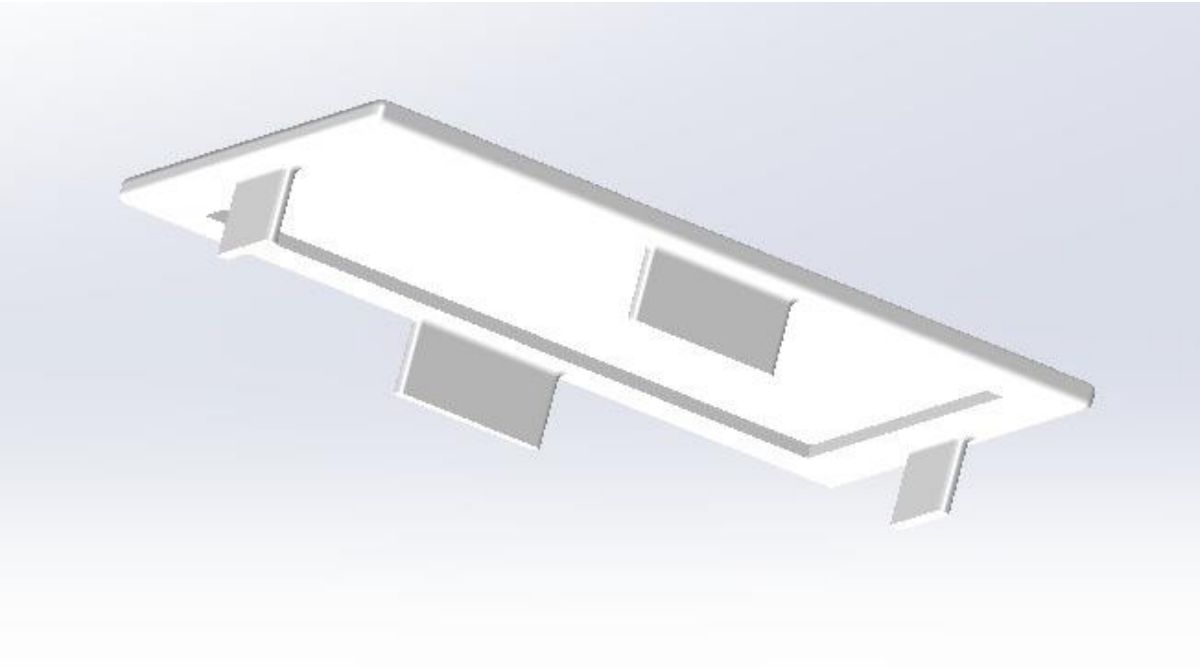


Figure 12: Lid

The lid as shown in Figure 12 will help with the covering the lower box. One of the design objectives is to make the robot waterproof. This method for insertion for the box and the lid helps to prevent water from entering the box which can cause damage to the electrical components in the box.

3.3.1.3. Frame

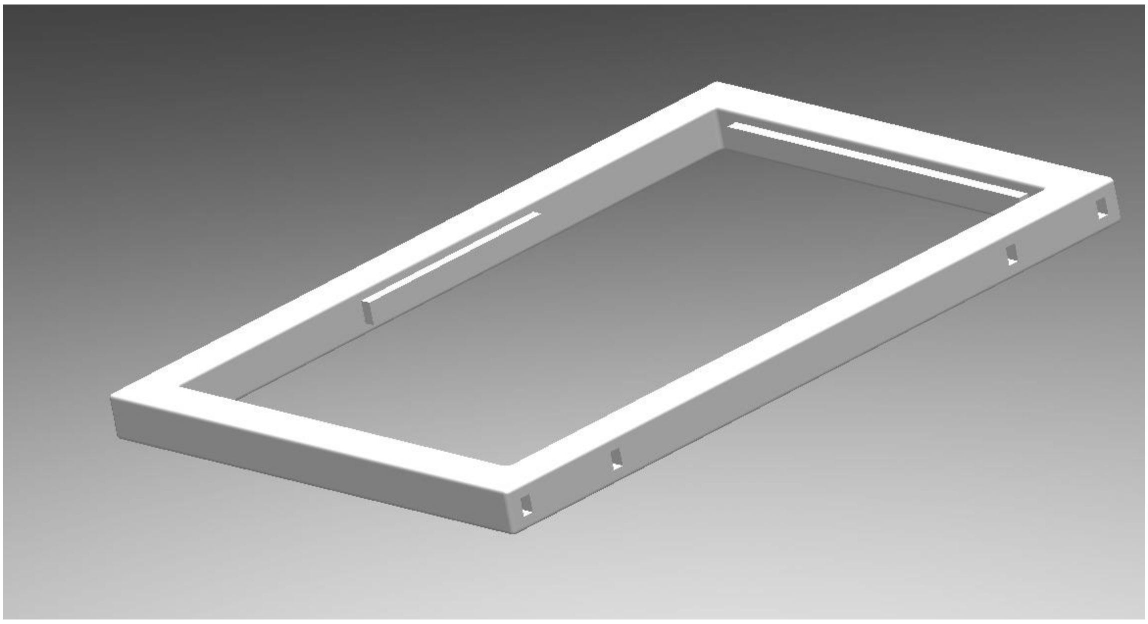


Figure 13: Frame

Figure 13 Shows the rectangular frame placed around the box that is to aid with the attachment the turtle flippers to the turtle box. Holes are created as shown that help in the screwing of the motors to the frame.

3.3.1.4. Motor holder

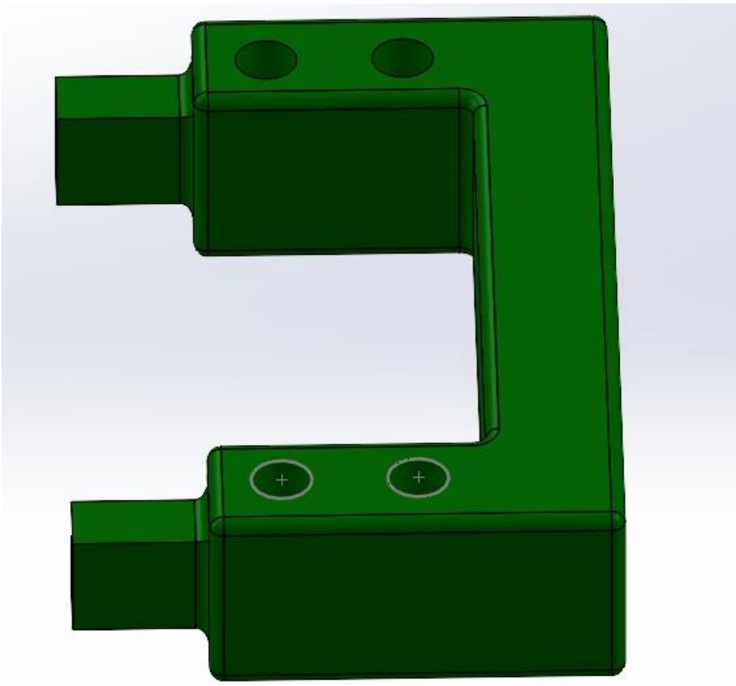


Figure 14: Motor holder

Figure 14 shows the motor holder. The motor holder is used to keep the motor in place. Counter sink holes are created on the motor holder so as to be able to fasten the motor onto the motor holder. Provisions were also made to be able to place the motor holder on the frame.

3.3.1.5. Motor arm

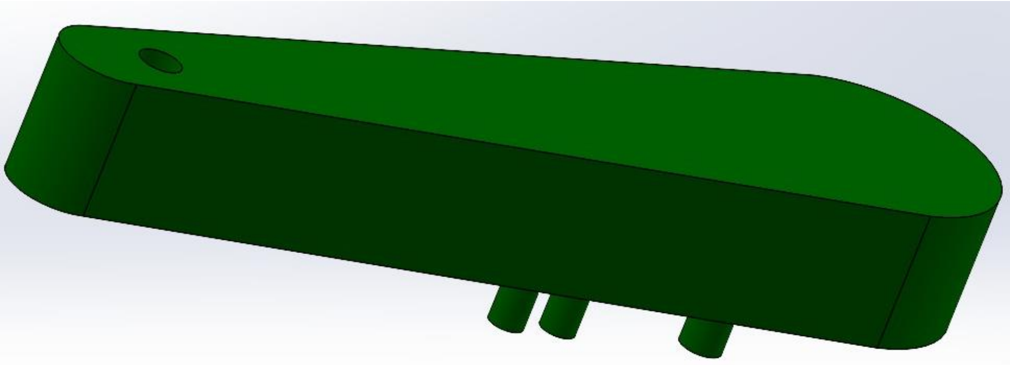


Figure 15: Motor arm

The standard motor arm provided by the servomotor cannot be used for the design because of its length. To overcome this problem, a newly designed motor arm as shown in Figure 15 was designed to provide the needed torque for the turtle movement.

3.3.1.6. Second motor holder

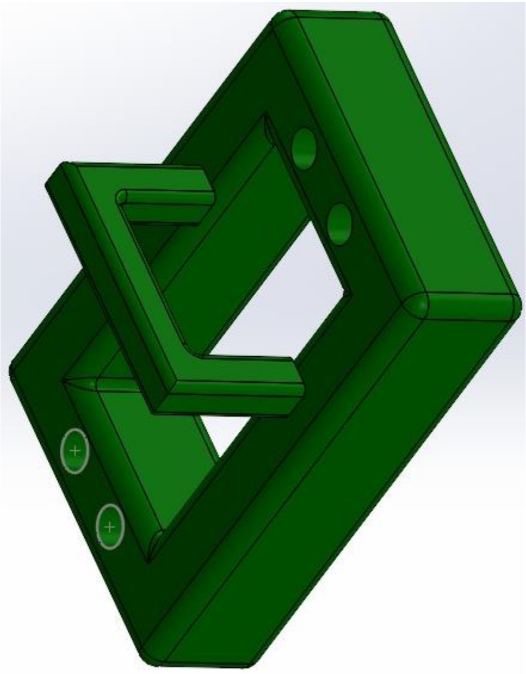


Figure 16: Second motor holder

The second motor holder as shown in Figure 16 aids in keeping the second motor in lock. The second motor is used to achieve two DOF motion. This motor holder will be fastened on the motor arm using standard screws. Counter-sink holes are also made to keep the motor in place using screws.

3.3.1.7. Flipper Holder

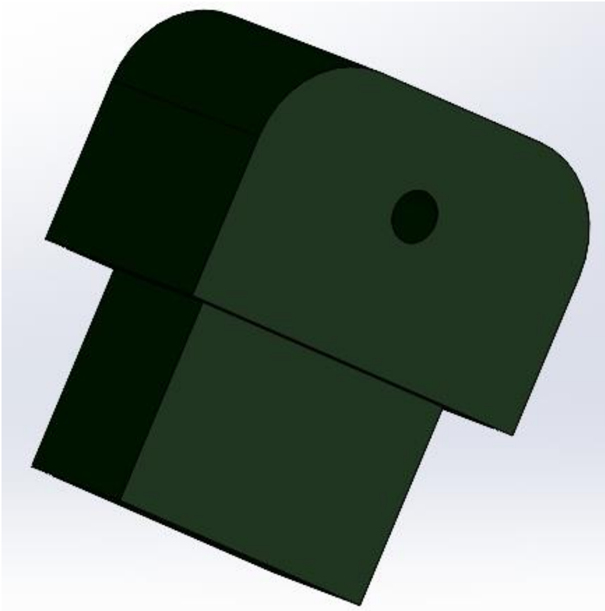


Figure 17: Flipper Holder

Figure 17 shows the flipper holder will help to hold the knee of the robot. It will be fastened on the motor arm of the servomotor. Also, in order to achieve easy disassembly of the knee from the flipper holder, a type of connector-receptacle joint was made.

3.3.1.8. Knee

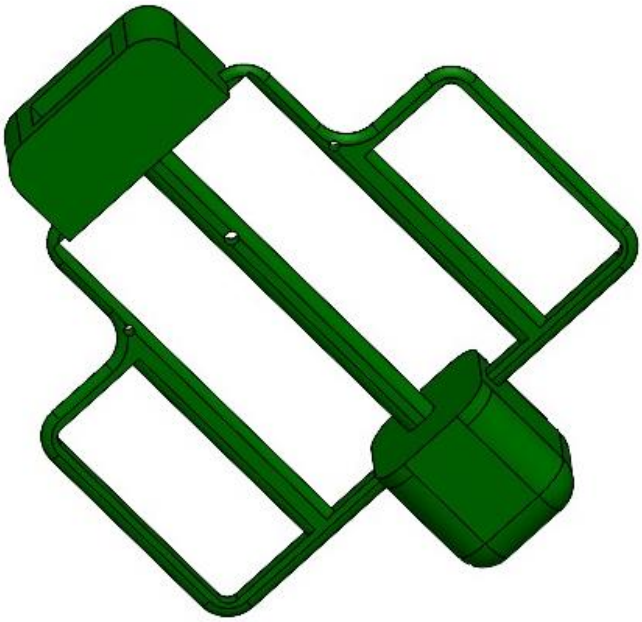


Figure 18: Knee

Figure 18 shows the knee which is the main component used in the turtle movement. The selection matrix for this mode of movement can be seen in Table 1. The design works in such a way that rhythmic leg oscillations generate a forward thrust to propel the robot for swimming. The space provided allows the leg to move back to initial position without generating much drag. It also has a block which allows land movement of the robot.

3.3.1.9. Flap

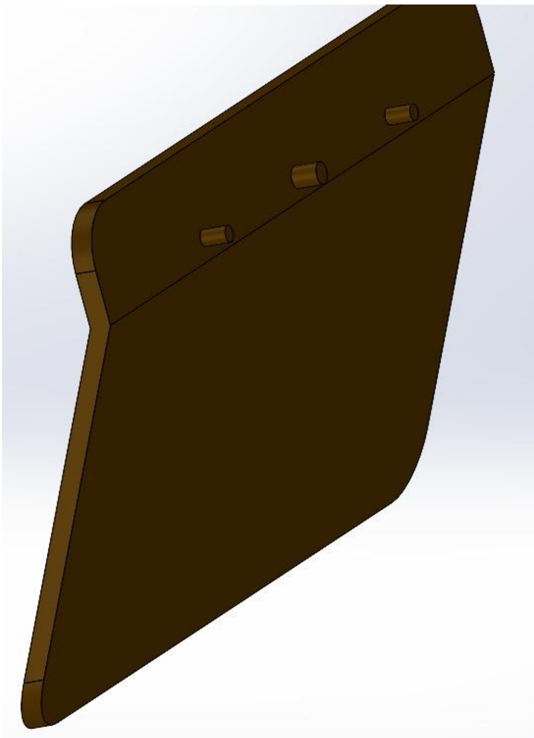


Figure 19: Flap

Figure 19 shows the flipper flap component. This passive complaint mechanism helps a lot in achieving swimming. In the forward thrust of the robot, it stays at the frame of the knee; helping to prevent water flow in the spaces of the knee. This results in a reaction force which propels the robot forward. However, as the knee performs a recovery stroke, the flap moves away from the knee. This allows water to flow through the interior of the knee which in turn, removes drag during the recovery stroke.

3.3.2. Electrical Subsystem

The electrical subsystem is made up of servomotors, battery, Wi-Fi module, and controller.

3.3.2.1. Servomotors

Servomotors were chosen for this project because of the following reasons.

i. High efficiency: One of the consumer's requirements in the QFD is low power consumption. In order to achieve this requirement, a servomotor will be used.

ii. Closed loop control: A servomotor provides the necessary feedback control of the rotation angle. This is necessary for the movement of the flippers.

iii. Cheap: Since a servomotor does not necessarily need a motor driver for operation, it reduces the cost of using a servomotor.

iv. Precision: Using a servomotor allows for precise control of angular position, velocity and acceleration.

v. Ease of programming

The criteria that will be used to choose the right servomotor are:

i. Weight

ii. Cost

iii. Power requirement

iv. Size

v. Waterproof

vi. Torque

vii. Speed

Table 3: Decision matrix for servomotors

Criteria	Weights	SG90	MG90S	MG995	MG996R	DS3225	DS3230MG	DS04-NFC
Cost	5	10	9	7	7	4	3	5
Weight	3	10	10	5	5	4	4	6
Torque	3	3	3	5	5	8	8	4
Speed	2	10	10	8	9	9	9	8
Size	1	10	10	5	5	5	5	5
Waterproof	5	0	0	0	0	10	10	0
Total	119	114	86	88	129	124	76	119

According to the decision matrix, the best servomotor to select is MG996R. This servomotor cannot be picked because it is not waterproof. The motor that will be selected is DS3225 which is the second highest scoring motor.

3.3.2.2. Wi-Fi Module

The decision matrix for picking Wi-Fi Module for communication can be seen in .

Table 4: Decision matrix for communication

Criteria	Weights	Bluetooth	WiFi
Range	5	-1	+1
Ease of programming	4	+1	-1
Cost	5	-1	+1
Total		-6	6

The Wi-Fi module that was selected for this project is ESP8266 WiFi Module as shown in Figure 20 below. This is a self-contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to your Wi-Fi network. The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor. Each ESP8266 module comes pre-programmed with an AT command set firmware i.e., it can be simply hooked to an Arduino device and get about as much Wi-Fi-ability as a Wi-Fi Shield offers. The ESP8266 module is also extremely cost effective (*Espressif ESP8266 | Wia*, n.d.).

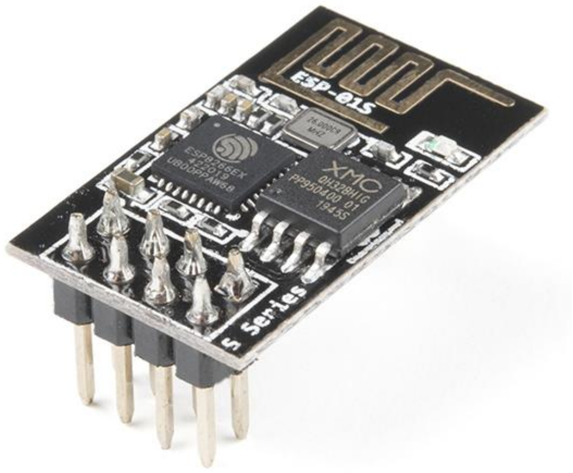


Figure 20: ESP8266 WiFi Module

3.3.2.3. Microcontroller

Since we do not have the knowledge of using Robot Operating System, Arduino controller was chosen for controlling the robot.

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button (*Mega 2560 Rev3 | Arduino Documentation | Arduino Documentation*, n.d.).

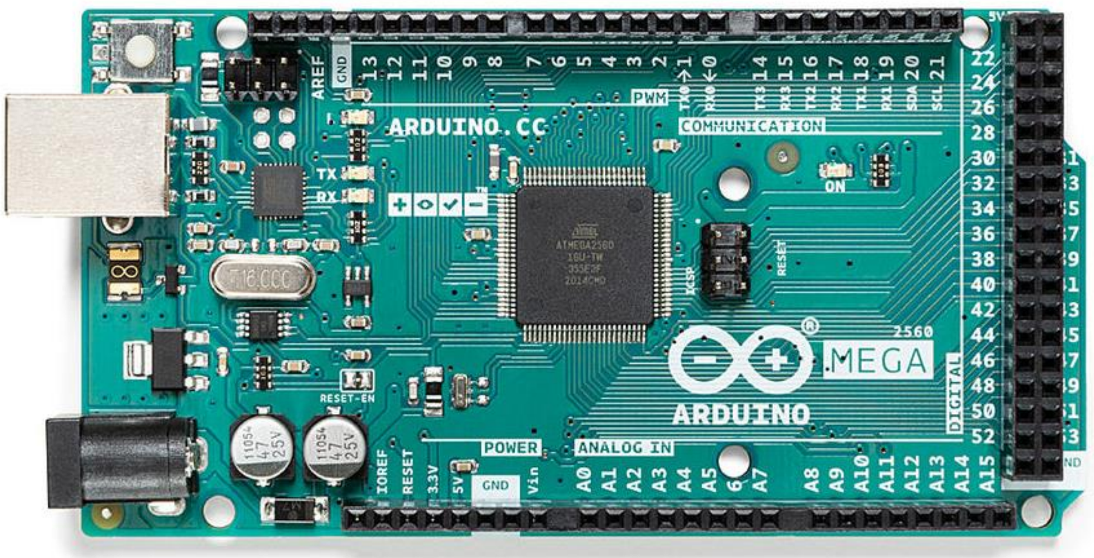


Figure 21: Arduino Mega 2560 Rev3

Arduino Mega 2560 Rev3 as shown in Figure 21 was selected by considering the number of pins needed for the connecting the motors and Wi-Fi module. Since eight servomotors will be used, 8 PWM pins are needed and Arduino Mega 2560 Rev3 provides that number of pins.

3.3.2.4. Battery

In this section, the battery that will be used to power the robot will be chosen. There are two types of batteries. These are primary (non-rechargeable), and secondary (rechargeable).

> A primary cell is a battery (a galvanic cell) that is designed to be used once and discarded, and not recharged with electricity and reused like a secondary cell (rechargeable battery). In general, the electrochemical reaction occurring in the cell is not reversible, rendering the cell unrechargeable. (*Primary Cell - Wikipedia*, n.d.)

> A rechargeable battery, storage battery, or secondary cell (formally a type of energy accumulator), is a type of electrical battery which can be charged, discharged into a load, and recharged many times, as opposed to a disposable or primary battery, which is supplied fully charged and discarded after use. It is composed of one or more electrochemical cells. (*Rechargeable Battery - Wikipedia*, n.d.)

Secondary batteries will be selected for this project. This is because of the need to reduce the life-cycle cost for the consumer. This is one of the consumer’s requirements and it has to be achieved.

The four major types of secondary batteries are:

i. Lead-Acid Batteries
ii. Nickel-Cadmium Batteries
iii. Nickel – Metal Hydride Batteries
iv. Lithium – Ion Batteries

A decision matrix will be used to select the battery that will be used for the robot. The selection criteria are:

i. Cost
ii. Toxicity Level
iii. Power requirement
iv. Cycle life
v. Charge time

Selection Criteria	Weights	Lead-Acid Batteries	Nickel-Cadmium Batteries	Nickel – Metal Hydride Batteries	Lithium – Ion Batteries
Cost	5	8	5	5	2
Toxicity level	5	2	2	7	7
Power discharge	4	7	5	5	8
Cycle Life	3	4	7	5	9
Charge time	2	2	7	6	6
Total		94	90	107	116

The battery that will be selected in this project is the lithium-ion battery since it has the highest score in the decision matrix.

Figure 22: Lithium-Ion Batteries

A 12V Lithium-Ion battery pack will be used for powering the robot.

3.3.3. System Breakdown Structure

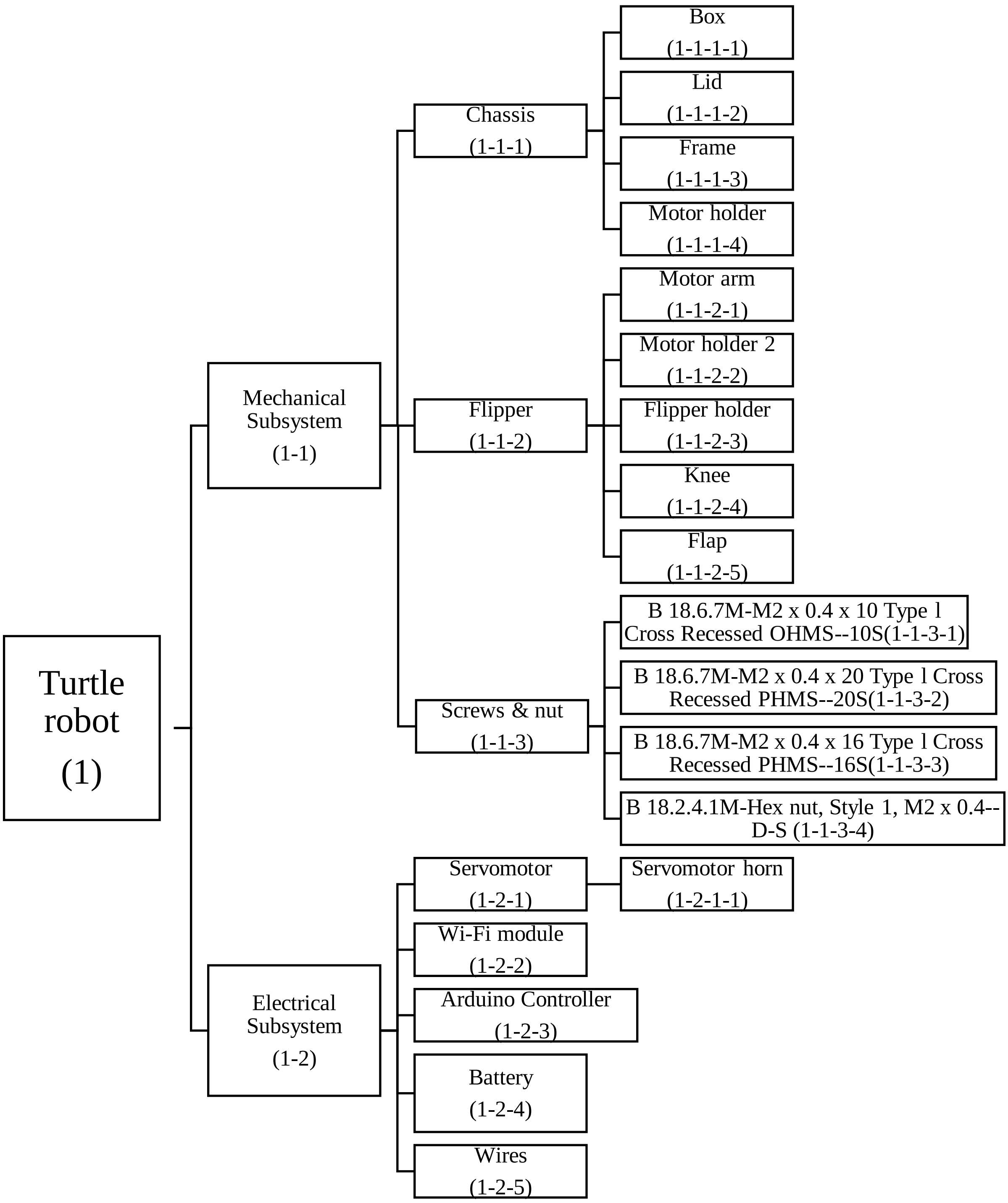


Figure 23: System Breakdown Structure

Figure 23 shows the system breakdown structure for the turtle robot with configuration management numbering system for each part.

3.4. Other Proposed Design

During the design phase, three design ideas were proposed with the layout drawing being the first of them. One of the three designs were selected. The layout design/sketch helped in imagining how the final design would look in the end. All designs made are included and discussed in this section.

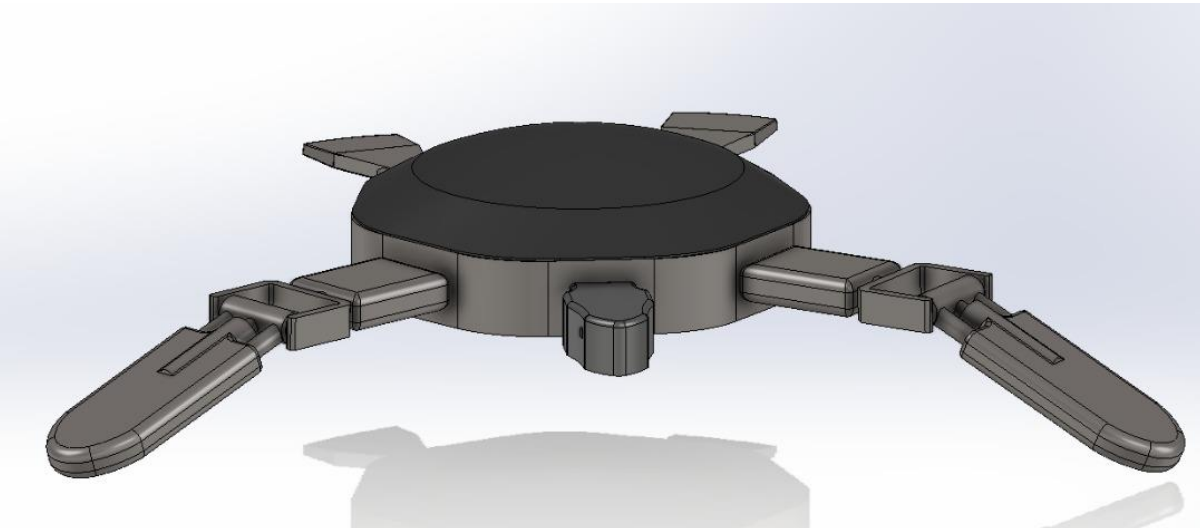


Figure 24: Design 2 (Front View)

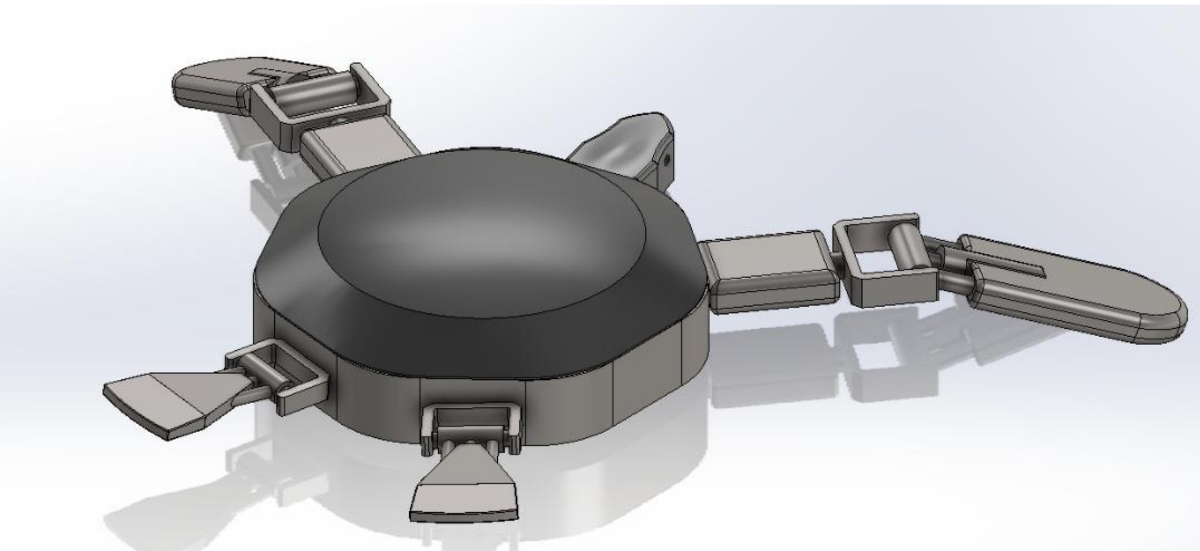


Figure 25: Design 2(Isometric View)

This design utilizes 7 motors and focuses mainly on motion in water (Figure and Figure 25). There are 2 motors in each front flipper used for rotation and swimming, a motor in each back flipper for balance and navigation & a central motor in the main body which is the primary cause of motion.

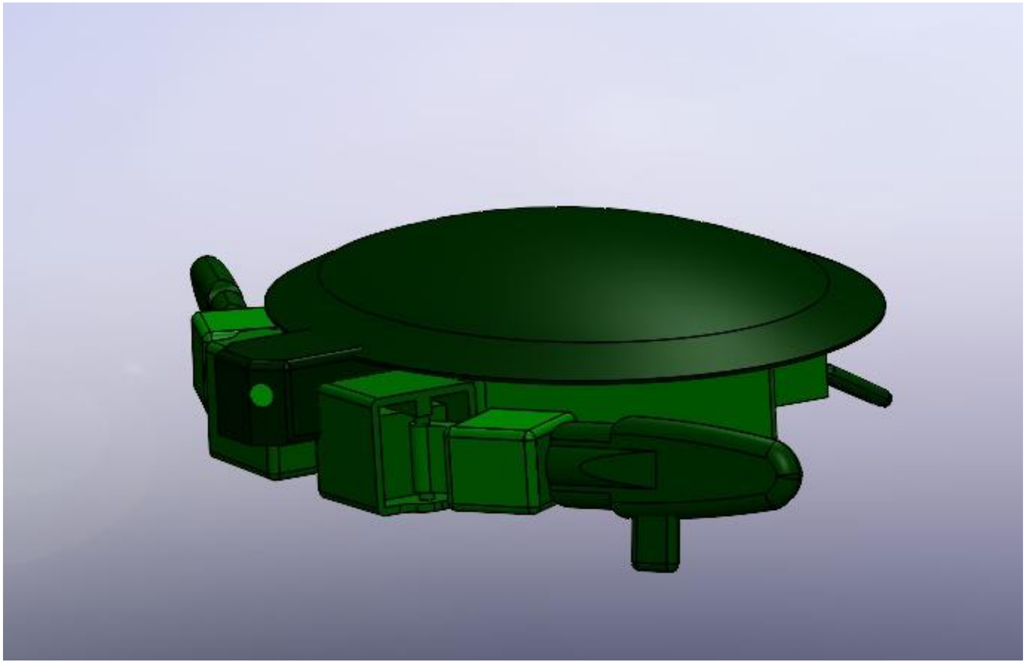


Figure 26: Design 3(Side View)

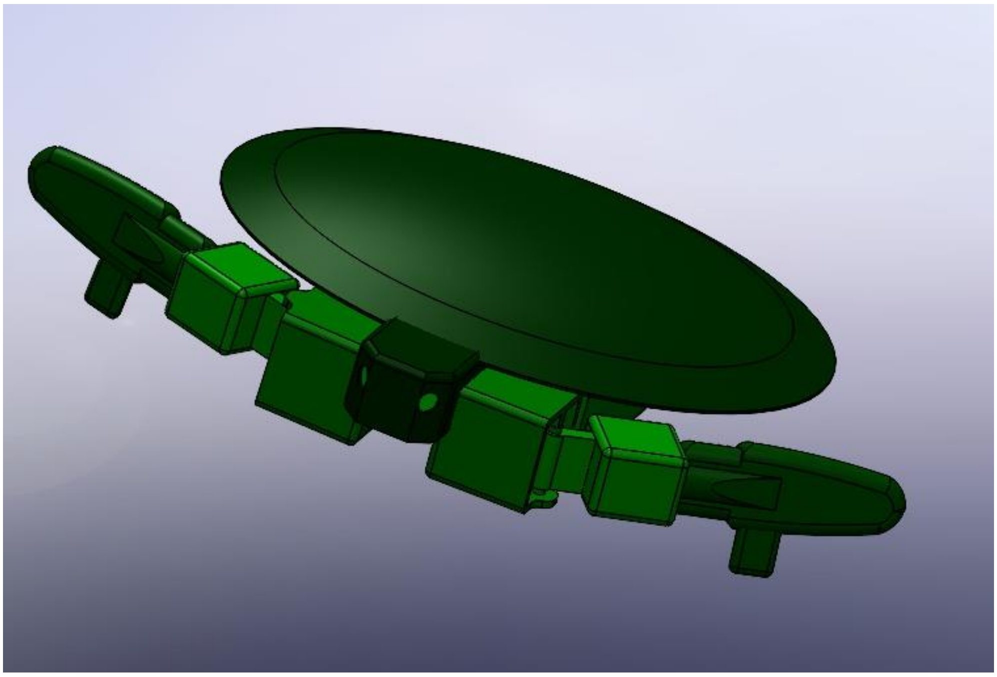


Figure 27: Design 3(Front View)

Figure 26 and Figure 27 shows the design of the flipper with a ball attached. This design has a number of features that satisfies the project objectives including better dimensions compared to the other designs. The ball attached to the flipper is responsible for the movement on land. The mechanisms by which the turtle achieves both movement in water and land has been studied in the literature review section but the motion has not been simulated nor has it been experimentally proven. Moreover, this design has 3DOF. The back flippers aid in swimming and also increases the speed of the turtle. The drawback about the design is its complexity and more developments and improvements are needed to carry out its functions. This design makes use of 8 motors. 3 motors in each front flipper to achieve three degrees of freedom & a motor in each back flipper which increases the speed of the turtle. The front flippers have a feature which allows the turtle to also walk on land, mimicking the behaviour of real sea turtles.

3.5. Engineering Standards

Engineering standards are summaries of industrial best practices. The specifications are written in terms of functional, mechanical and electrical aspects that allow proper usage of available components to build a system. According to the ISO, “when things don't work as they should, it often means that standards are absent” (*ISO - Standards*, n.d.). If the design is to be manufactured, Table 5 shows the engineering standards are to be adhered to.

Table 5: Selected design engineering standards

Part/Process	Standard	Description
Arduino Controller	EU RoHs	This is a directive of the EU that restricts the use of hazardous substances in electrical and electronic equipment to protect the environment and public health.
Servo motors	IEC 60034	This standard is related to efficiency, power output and size for motors.
Screws	ASME B18.6.3--2013	This standard is intended to cover the complete general and dimensional data for the various types of slotted and recessed head machine screws, tapping screws, and metallic drive screws recognized as American National Standard.
ESP8266 WiFi Module	RED	This is Radio Equipment Directive. It is a regulatory framework for placing radio equipment on the market in the EU.

Li-ion Battery	IEC 62133	This standard specifies the requirements and testing for the safe operations of portable, sealed secondary cells and batteries made from them, for use in portable applications.
	UL 1642	The UL 1642 certification is a cell level requirement that ensures any electrochemical device with 1.0 g of lithium and less than 5.0 g of lithium used for energy storage is safely manufactured
	IEC 62619	IEC 62619 ensures batteries are designed for their application and has several failure scenario tests.
	IEC 62281	This specifies test methods and requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal.
Soldering	IPC-J-STD-006	This standard prescribes the nomenclature, requirements and test methods for electronic grade solder alloys; for fluxed and non-fluxed bar, ribbon, and powder solders, for electronic soldering applications; and for "special" electronic grade solders.
3D printing	ISO/ASTM 52900	This document establishes and defines terms used in additive manufacturing (AM) technology, which applies the additive shaping principle and thereby builds physical three-

		dimensional (3D) geometries by successive addition of material.
Neoprene	ASTM D395	These test methods cover the testing of rubber intended for use in applications in which the rubber will be subjected to compressive stresses in air or liquid media. They are applicable particularly to the rubber used in machinery mountings, vibration dampers, and seals.
	ASTM D 412	ASTM D412 is the most common standard for determining the tensile properties of vulcanized (thermoset) rubber and thermoplastic elastomers.
	ASTM D 573	This test method covers a procedure to determine the influence of elevated temperature on the physical properties of vulcanized rubber. The results of this test method may not give an exact correlation with service performance since performance conditions vary widely.
	ASTM D 2240	Using rubber properties and a durometer hardness, the ASTM D2240 consists of pressing the indentation head at the bottom of the handheld device until the flat bottom part is resting on the material's surface to be tested.
	ASTM D 297	The test methods in ASTM D297 are used to perform a chemical analysis of rubber, evaluating the chemical composition in natural and synthetic crude rubbers.

Whole robot	ISO 9787:2013	ISO 9787:2013 defines and specifies robot coordinate systems. It also provides nomenclature, including notations, for the basic robot motions. It is intended to aid in robot alignment, testing, and programming.
	ISO 9283:1998	The tests described in this International Standard are primarily intended for developing and verifying individual robot specifications, but can also be used for such purposes as prototype testing, type testing or acceptance testing.
	ISO 8373:2021	This defines terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments.

3.6. Material Selection

To select the material that will be used for the body of the robot, a decision matrix will be used. Firstly, generalised materials will be used for material selection. Then, the specific materials with their codes will be used for selection. The scale for scoring is from 1-10.

The selection criteria are:

i. Cost
ii. Strength
iii. Density
iv. Availability
v. Machineability
vi. Corrosion resistivity

Table 6: Decision matrix for general materials (body)

Selection Criteria	Weights	Steel Alloy	Aluminium Alloy	Titanium Alloy	Polymer Composite	Wood
Cost	5	9	7	6	10	9
Yield Strength	2	10	10	8	6	4
Density	5	2	6	4	8	10
Availability	2	9	6	0	4	10
Machineability	4	4	6	1	10	8
Corrosion resistivity	4	3	5	9	9	7
Overall Weights		121	141	106	226	183

Table 6 shows that polymer composites is a good choice of material for the robot.

The materials will be more specific in the decision matrix shown in Table 7.

Table 7: Decision matrix for specific material (body)

Material consideration	Weights	ABS	Polystyrene	Nylon	Wood	Aluminium	Steel 4140	PLA
Cost USD/Kg	5	8	10	5	8	4	10	10
Strength	2	5	2	6	3	8	10	6
Density	5	10	9	9	10	7	2	8
Availability	2	7	5	3	10	6	9	10
Manufacturability	4	10	7	9	8	5	4	10
Corrosion resistivity	4	10	10	10	9	9	6	10
Total		194	177	164	190	139	138	202

From the decision matrix, PLA will be chosen for the material for the body of the turtle.

The material that will be used for the flap of the turtle will be decided on using a decision matrix. The decision matrix is shown in Table 8.

Table 8: Material selection for the flap

Material consideration	Weights	PLA	Nitrile Rubber	Neoprene Rubber	Leather	ABS
Flexibility	5	5	9	9	9	5
Density	5	7	8	10	8	8
Waterproof	5	10	10	10	8	10
Strength	1	9	4	2	5	7
Availability	3	10	9	9	10	7
Manufacturability	2	10	10	10	10	10
Cost	5	10	6	8	9	8
Total		216	216	234	225	208

From the Table 8, Neoprene rubber will be selected as the material for the flaps.

3.7. Design Calculations

3.7.1. Mechanical Subsystem

The total mass of the designed turtle robot is 3.5kg. This was gotten from SolidWorks. The breakdown of the mass is shown in Table 9: Design calculations for mechanical sub-systems

$$Drag\ Force\ (N) = \frac{C_d \times \rho \times v^2}{2}$$

Where C_d = drag coefficient

ρ = density of the fluid

v = Velocity

A = Cross-sectional area of the face

To calculate the drag force, only the body (1-1-1-1) will be considered.

Drag coefficient of a cube = 1.05

The velocity of the robot will be assumed to be 71.882mm/s

$$Drag\ Force = \frac{1.05 \times 1000 \times 0.071882^2}{2} N = 2.71N$$

Buoyancy Force (F_b) = $\rho_f \times g \times V$

The weight of the flippers (1-1-2) will be considered negligible for calculating the buoyancy force.

Density of fluid (water) = 1000kgm^{-3}

Acceleration due to gravity = 9.81ms^{-2}

Volume (V) = $L \times B \times H = 0.2m \times 0.11m \times 0.11m = 0.00242m^3$

$$F_B = 1000 \times 9.81 \times 0.0022\ N = 23.7N$$

Table 9: Design calculations for mechanical sub-systems

Parameters	Method of calculation	Value
Weight of the robot (N)	SolidWorks	34.3
Buoyancy Force (N)	Calculations	23.74
Drag Force (N)	Calculations	2.71

The total weight of the knee is $\frac{14.5}{1000} \times 9.81N = 0.142N$

3.7.2. Electrical Subsystem

The power required by the servomotors and other electrical components will be calculated in this section.

3.7.2.1. Servo motors

8 DS3225 servomotors were selected to be used in this project. The values in Table are the specifications of DS3225 servomotor. This was gotten from the datasheet of the motor.

Table 10: Technical Specifications for the DS3225 servomotor

Mass (grams)	60
Dimensions (mm)	40 x 20 x 40.5
Operating Voltage (V)	4.8 – 6.8
Idle Current (mA) @ 5V	4
Operating Speed @ 5V	0.15s/60
Operating Frequency (Hz)	50-330
Stall Torque (kgcm) @ 5V	21
Stall Current (A) @ 5V	1.9
Dead band width (µsecs)	3

The 8 servomotors will be connected in parallel with the power source. This parallel configuration makes the voltage across the motors to be 5V (assuming that the power supply provides 5V). The current that will be used for calculation is the stall current.

$$Operating\ Voltage = 5V$$

$$Number\ of\ servomotors = 8$$

$$Total\ current\ needed = Number\ of\ servomotors\ \times Stall\ Current = 8 \times 1.9A = 15.2A$$

$$\therefore Power\ required\ for\ operation = 15.2A \times 5V = 76W$$

Note: The power calculated here is the maximum amount of power required since stall current was used.

3.7.2.2. Wi-Fi Module

The power required by the Wi-Fi module will be calculated in this section.

Table 11: Specifications for ESP8266 Wi-Fi Module

Operating Voltage Value (V)	2.5 – 3.6
Maximum Current (mA)	12
Typical Voltage (V)	3.3

Power required for the operation of the Wi-Fi module = $12 \times 10^{-3} \times 3.3W = 0.0396W$

3.8: Simulink and Simscape Model

After completing the design using Solidworks, the CAD model was exported to Simscape using the solidworks Simscape multibody Link add-in tool. The model in the Simscape environment is as shown in Figure 28 below.

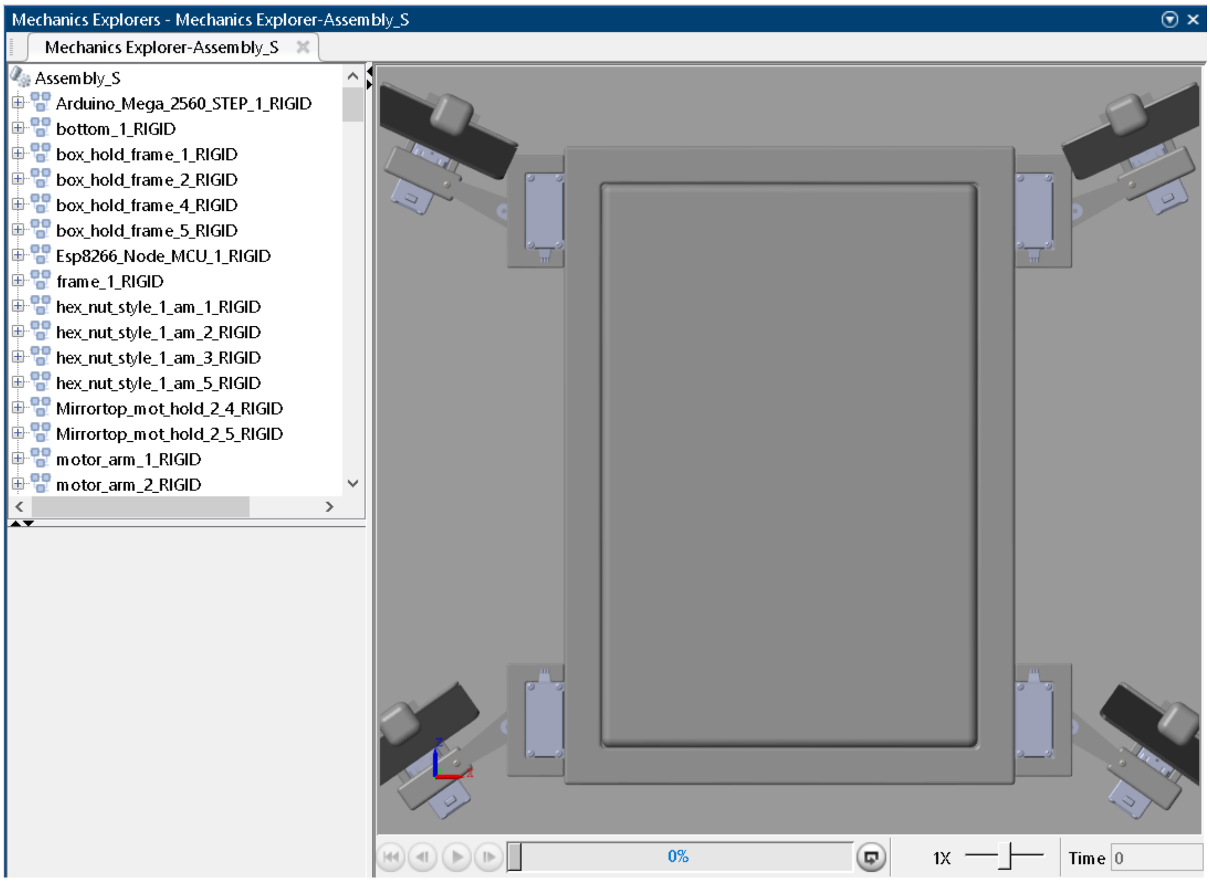


Figure 28: Exported model in Simscape

The Simulink block models are provided in APPENDIX H: . Some errors occurred which were solved by making some changes to the mates in the design. After these changes, the errors were reduced to issues arising from rigid joints between parts.

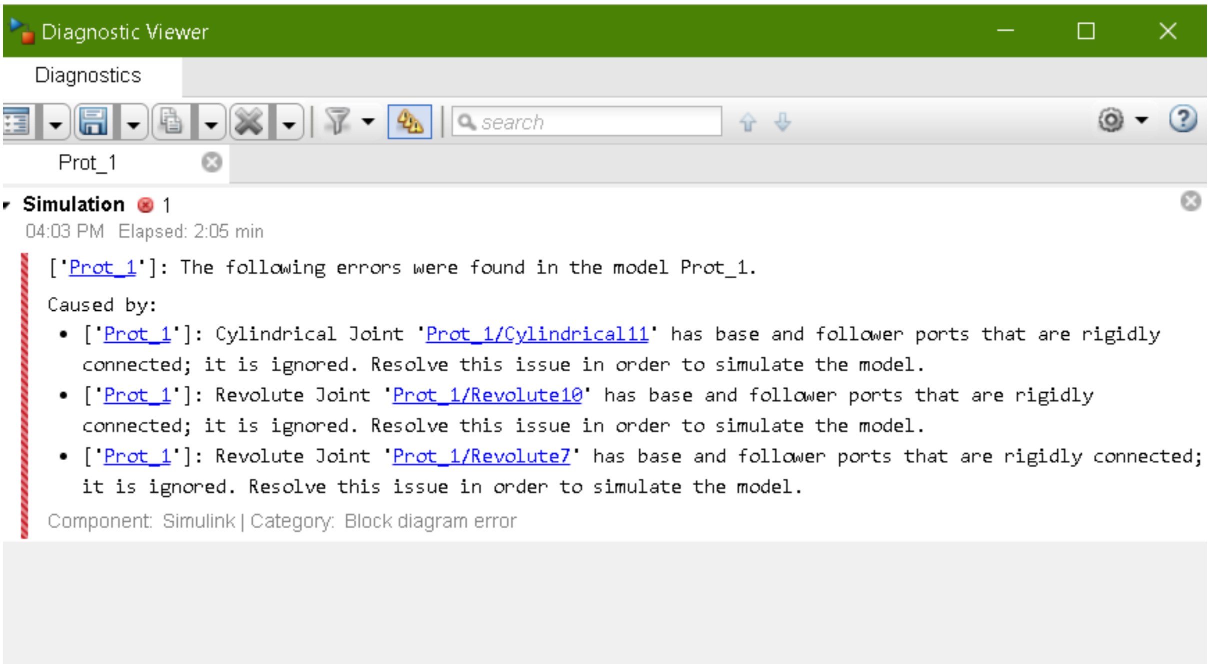


Figure 2929: Errors displayed by Diagnostic Viewer in Simscape

Figure 2929 shows the errors that were displayed by the diagnostic viewer. The errors can be solved by simply configuring the software to not show warnings or errors for rigidly constrained blocks in the Simscape multibody diagnostics tab found in model settings. It should be noted that this solution only clears the error messages and runs the simulation but no motion is observed. By knowing which block parameters to alter, motion can be achieved. Alternatively, the model in SolidWorks can be edited and mates done properly to enable Simscape mirror what type of joints are present between parts and accurately predict the desired motion.

3.9: Static/Stress Analysis

To observe how the force exerted by the flippers act on the frame, a static analysis is done to estimate the displacements and strains on the frame. Using the Ultimaker Cura software to observe the 3D printing process of the product, the printing time as well as the mass of each component can be realized. The total mass of the turtle was found to be 2.54 Kg, which is lesser than the mass obtained from Solidworks. This results in a weight of 25N acting on the frame. The figures below show the results of the analysis excluding all components but the top cover, the box and the frame to ensure no meshing failure occurs.

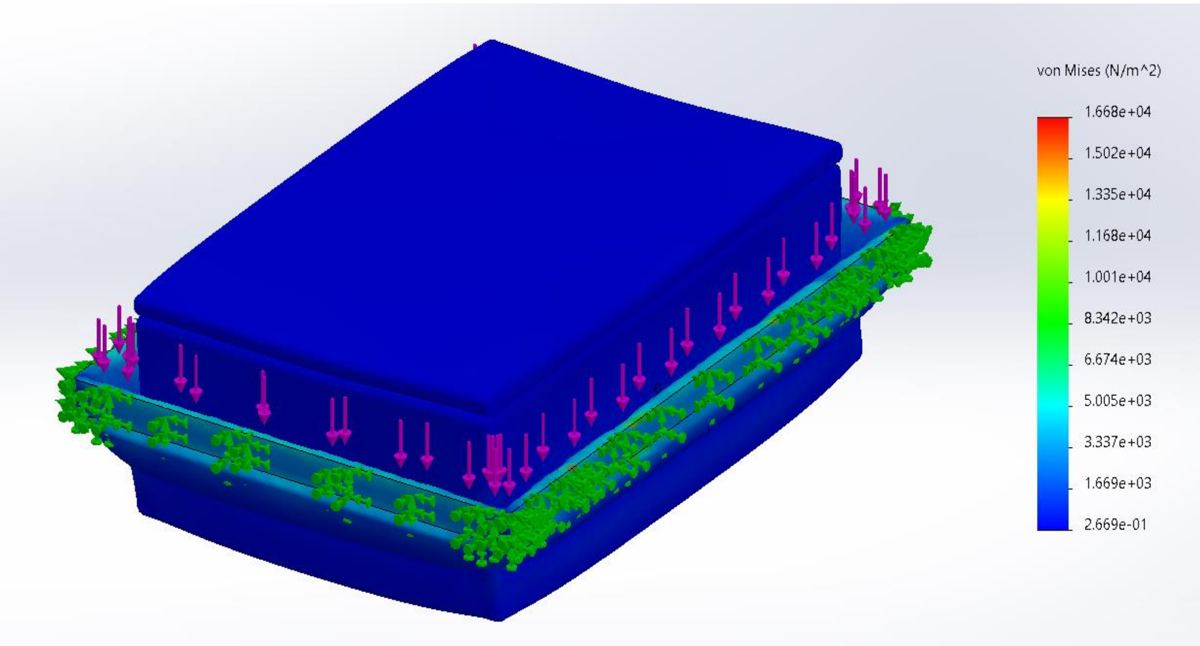


Figure 30: Stress Results

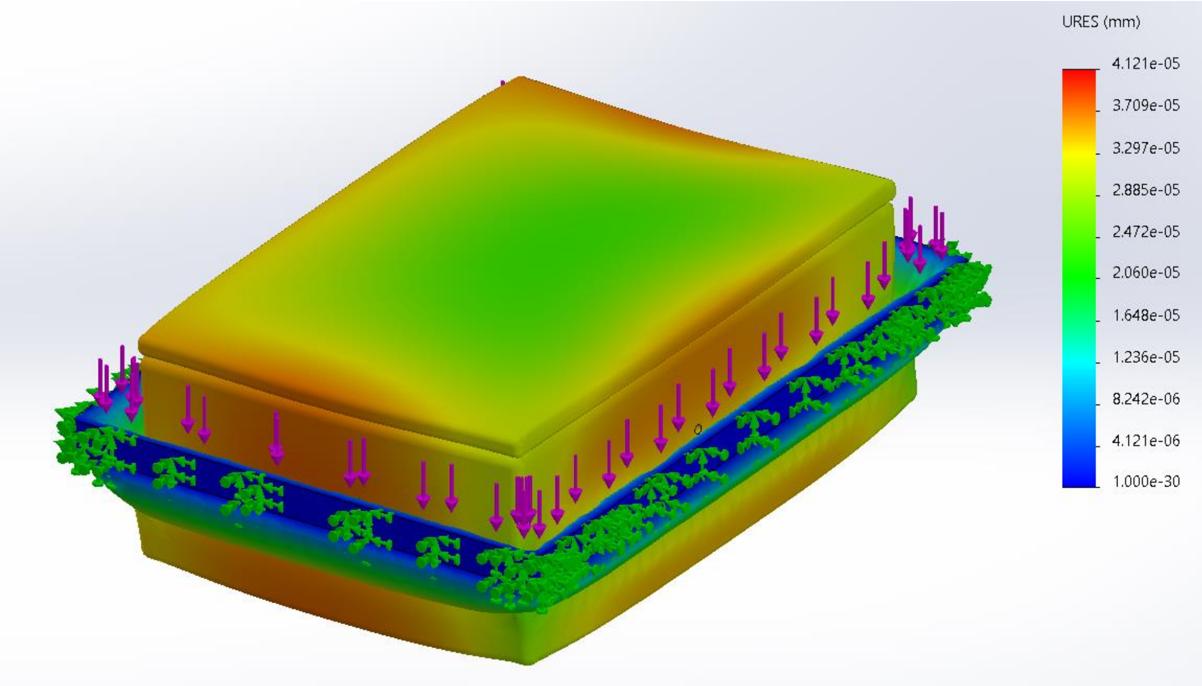


Figure 31: Displacement Results

From the displacements results obtained above, it is observed that since the frame is fixed to the box, the box experiences more displacements than the frame. The accuracy of this analysis cannot be proven due to lack of calculations to back up the results.

CHAPTER 4: MANUFACTURING PLAN

4.1. Manufacturing Process Selection

The method of creating three-dimensional solid objects from a digital file is known as 3D printing or additive manufacturing. Additive manufacturing technologies are used to create 3D printed objects. An object is built in an additive technique by laying down successive layers of material until the object is complete. Each of these layers can be viewed as a cross-section of the item that has been lightly cut. In this project, 3D printing will be used to create the main body (serves as a waterproof casing for the electronics), four legs (each with two actuated joints and a passive complaint flap), rectangular chassis (this houses the main body and four legs). The flippers servo motor mounts and base plates were also 3D printed. 3D printing was selected as opposed to acquiring off-the-shelf C-brackets because of some design uncertainties surrounding them. Biodegradable PLA+ was chosen due to its price and it is environmentally friendly since it degrades faster than plastic.

In this project, only two types of 3D printing will be considered, which are SLA (Stereolithography) and FDM (Fused Deposition Modelling) 3D printing. Only these two choices were considered because they are widely available and very affordable, other forms of 3D printing are used in professional settings, as a result, they are very expensive. Concept evaluation will be performed on SLA and FDM 3D printing to determine the 3D process most suitable for our project. Table 12 shows the decision matrix for 3D printing method.

Table 12: Decision matrix for 3D printing

Concept	SLA	FDM	Priority
Cost	7	9	X 5
Accuracy	10	7	X 2

Durability	6	8	X 3
Tolerance	8	7	X 1
Total	81	90	

After considering the cost, accuracy, durability and tolerance of SLA and FDM 3D printing using concept evaluation, we decided to use the FDM 3D printing device as shown in Figure 32 for our turtle robot project since it has a higher score in accordance with the project requirements.

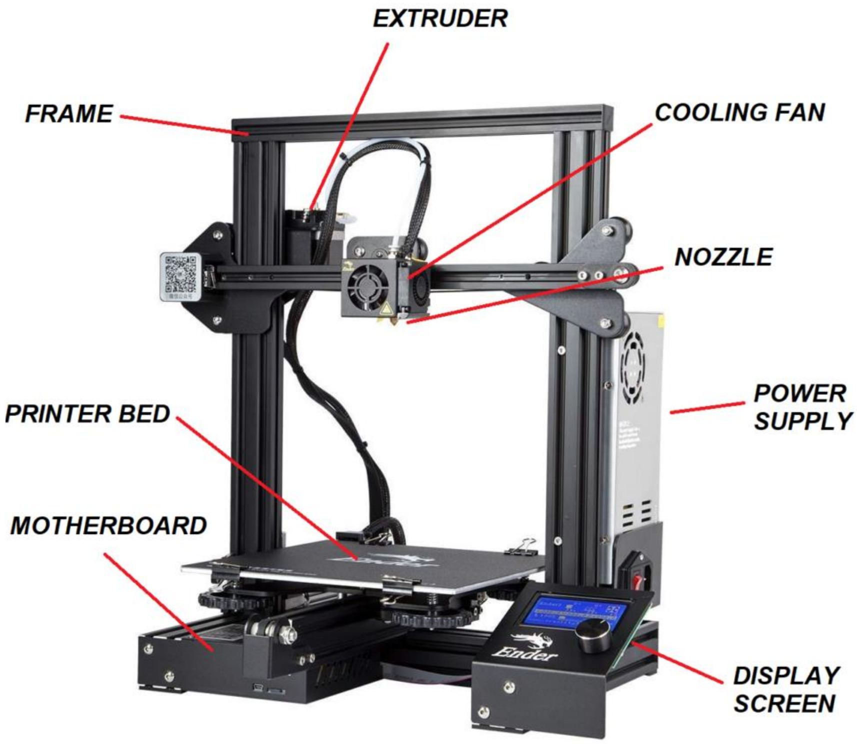


Figure 32: FDM 3D Printer

4.2. Detailed Manufacturing Process

In this section, the processes during manufacturing are summarized. The aim is to create a proof of product prototype through the assembly of the afore mentioned parts and components that were chosen during the design process with respect to our objectives. The head, joints, rectangular chassis and base plates modules are 3D printed. Other components like the Arduino UNO microcontroller, servo motors, sensors are purchased and assembled.

The steps taken for the 3D printed modules are as follows:

Pre-Processing

1. The parts required for 3D printing were designed on Solidworks.
2. The Solidworks file was saved as an .STI extension file in other for the “slicer” program to recognize it.
3. The design file was imported, the necessary options selected, and slices (layers) were created.
4. The slicer program then generates “tool paths” or building instructions which will drive the extrusion head. It gives instruction to the 3D printer through G-codes.

Production

5. Before starting the 3D printing process, nozzle must reach a certain temperature.
6. Afterwards, “print” was selected in other to start the building process.
7. Two materials, one to make the part and one to support it, enter the extrusion head.
8. Heat is applied to soften the plastics, which are extruded in a ribbon, roughly the size of a human hair.

Post-Processing

9. After 3D printing the required parts, the chamber of the FDM 3D printer is opened and the parts are removed.
10. The support material that held the part in place is either washed or stripped away.

Slicer program are programs that allow printing according to the specified properties of a design. Examples of slicer programs used in 3D printing are, Catalyst EX, Simplify3D, Creality, Ultimaker Cura etc.

4.3. 3D Printing parts Simulation

In this section, the estimated time taken to 3D printing individual parts of the turtle robot will be highlighted. The simulation was carried out using CURA. The parts that are 3D printed are: the Flap, the Frame, the knee holder, the knee, the motor arm, the motor holder 1, the motor holder 2, top cover and the box.

i. The Flap: It estimated that, it will take 23minutes for an FDM 3D printer to print the flap of the turtle robot. The mass of the flap is 9 grams.

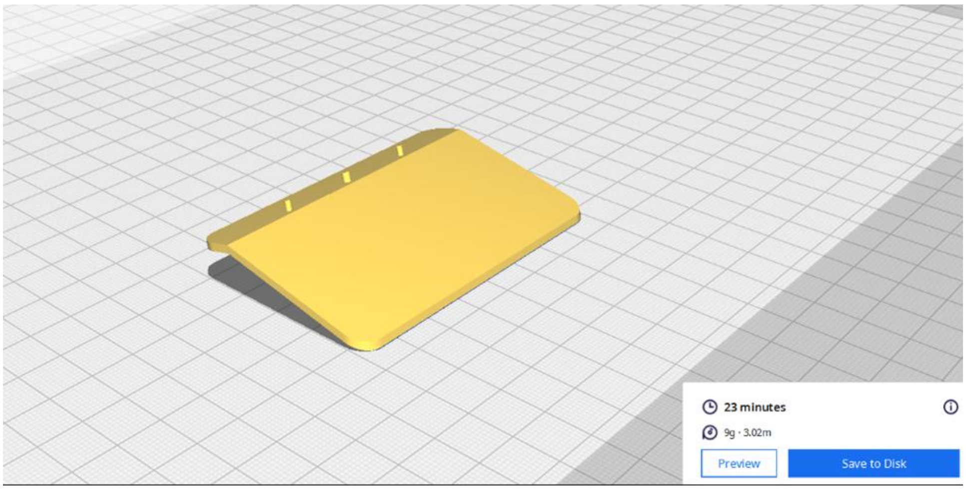


Figure 33: Simulation of Flap Using Cura

ii. The Frame: It is estimated that it will take 10hours 55minutes for an FDM 3D printer to print the frame. It has an approximate mass of 342 grams.

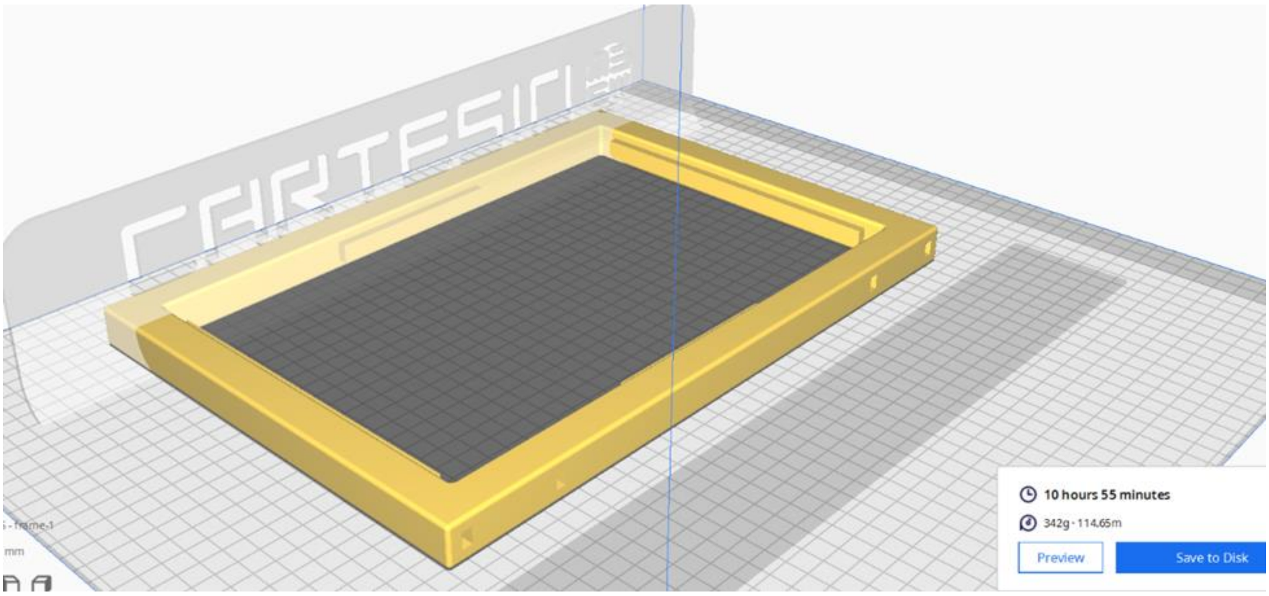


Figure 34: Simulation of Frame Using Cura

iii. The knee holder: It is estimated that it will take 23 minutes for an FDM 3D printer to print the knee holder. It has an approximate mass of 4 grams.

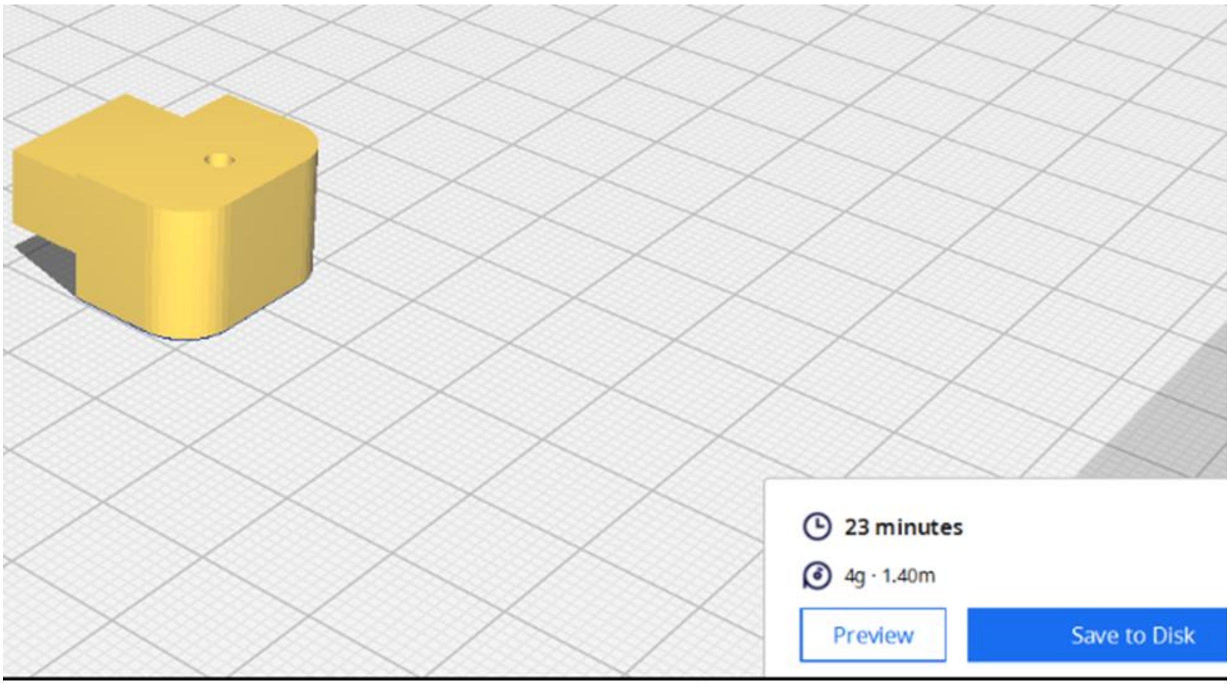


Figure 35: Simulation of Knee Holder Using Cura

iv. The Knee: It is estimated that it will take 2 hours 12 minutes for an FDM 3D printer to print the knee. It has an approximate mass of 10 grams.

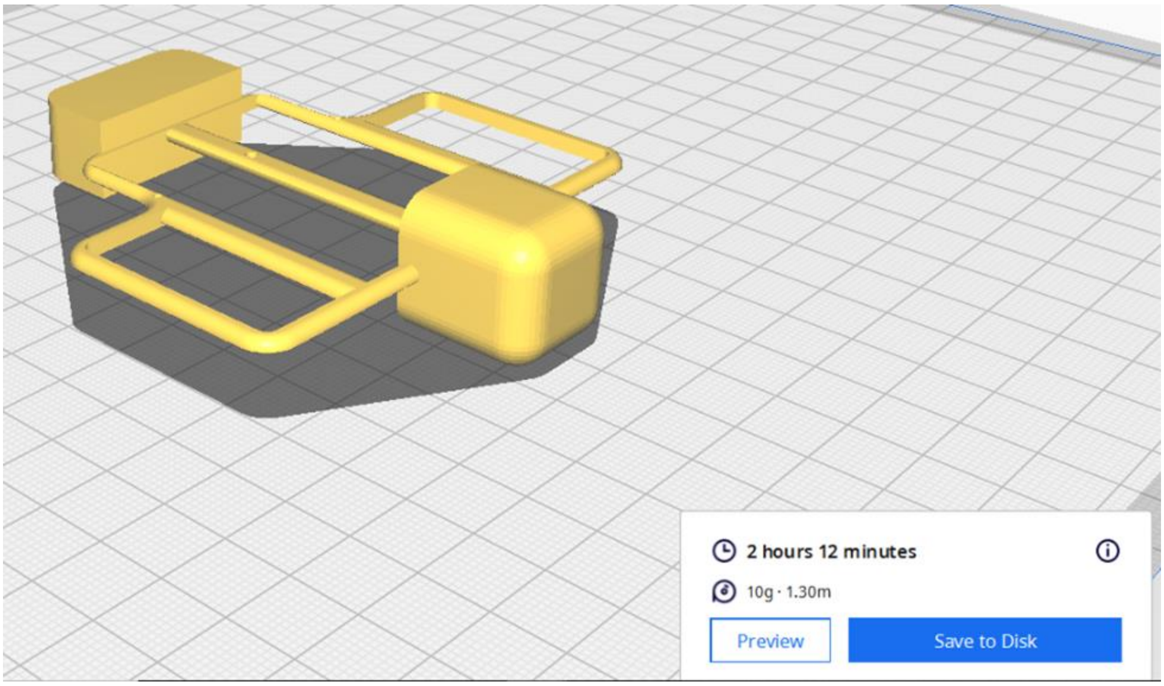


Figure 36: Simulation of Knee Using Cura

v. The motor arm: It is estimated that it will take 22 minutes for an FDM 3D printer to print the motor arm. It has an approximate mass of 8 grams.

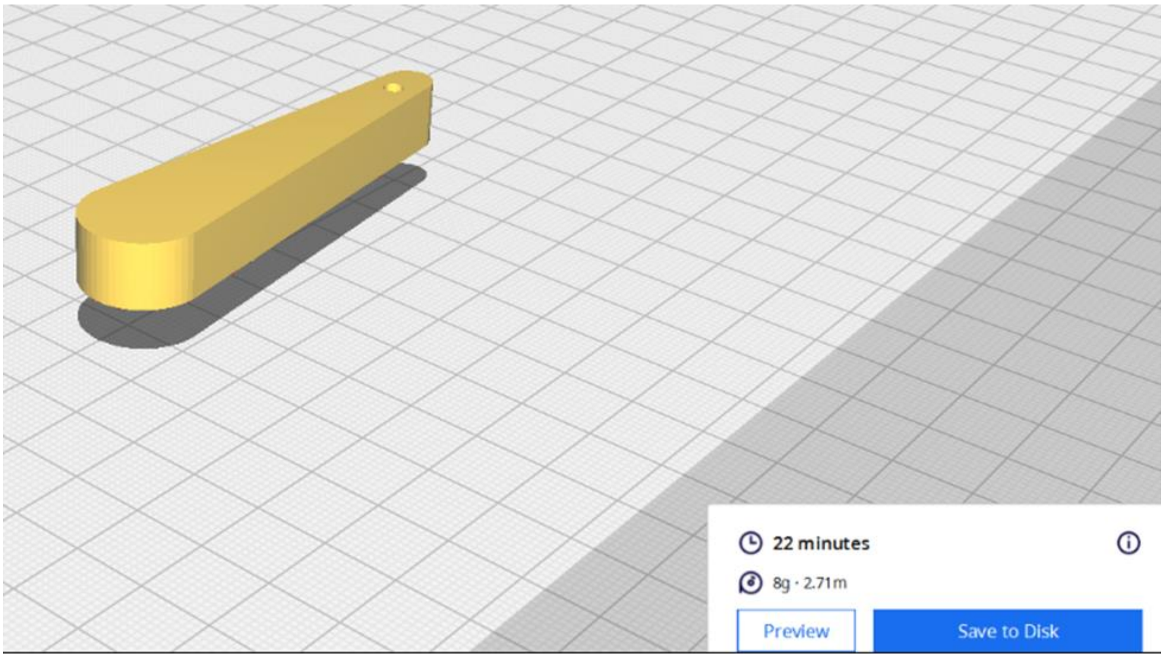


Figure 37: Simulation of Motor arm Using Cura

vi. The motor holder 1: It is estimated that it will take 40 minutes for an FDM 3D printer to print the motor holder 1. It has an approximate mass of 16 grams.

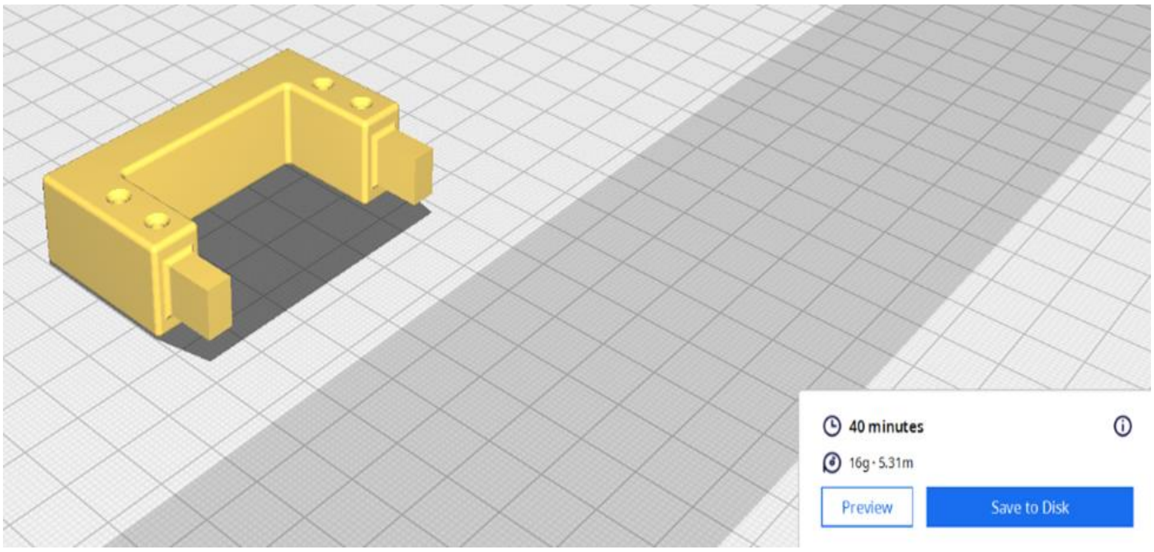


Figure 38: Simulation of Motor Holder_1 Using Cura

vii. The motor holder 2: It is estimated that it will take 1 hour 9 minutes for an FDM 3D printer to print the motor holder 2. It has an approximate mass of 24grams.

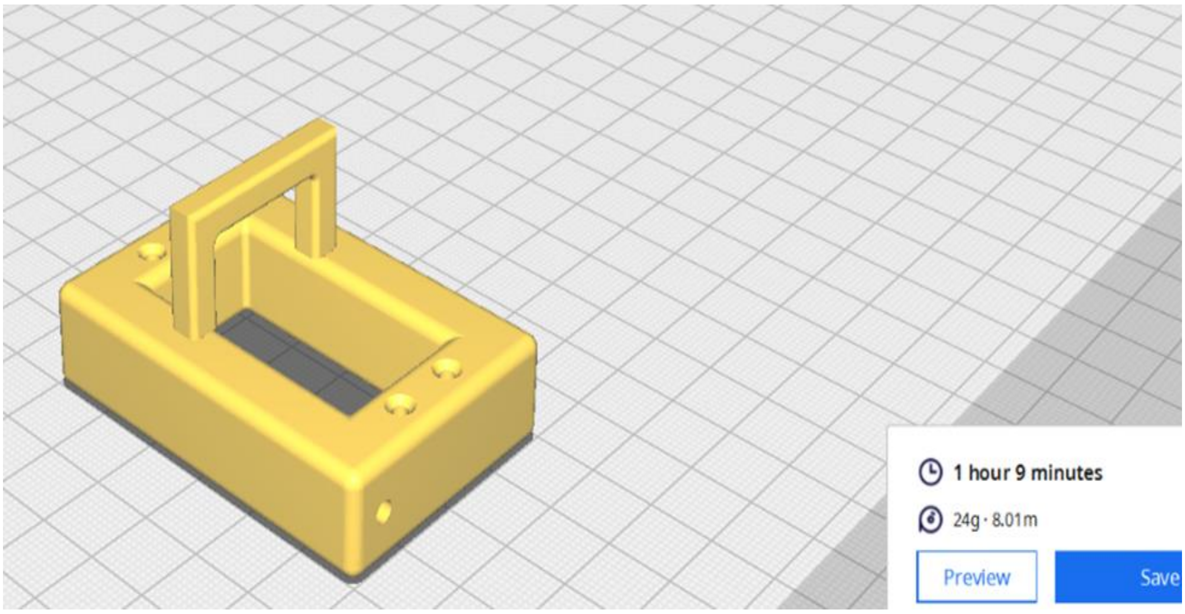


Figure 39: Simulation of Motor Holder_2 Using Cura

viii. Top cover: It is estimated that it will take 10 hours 30 minutes for an FDM 3D printer to print the top cover. It has an approximate mass of 327 grams.

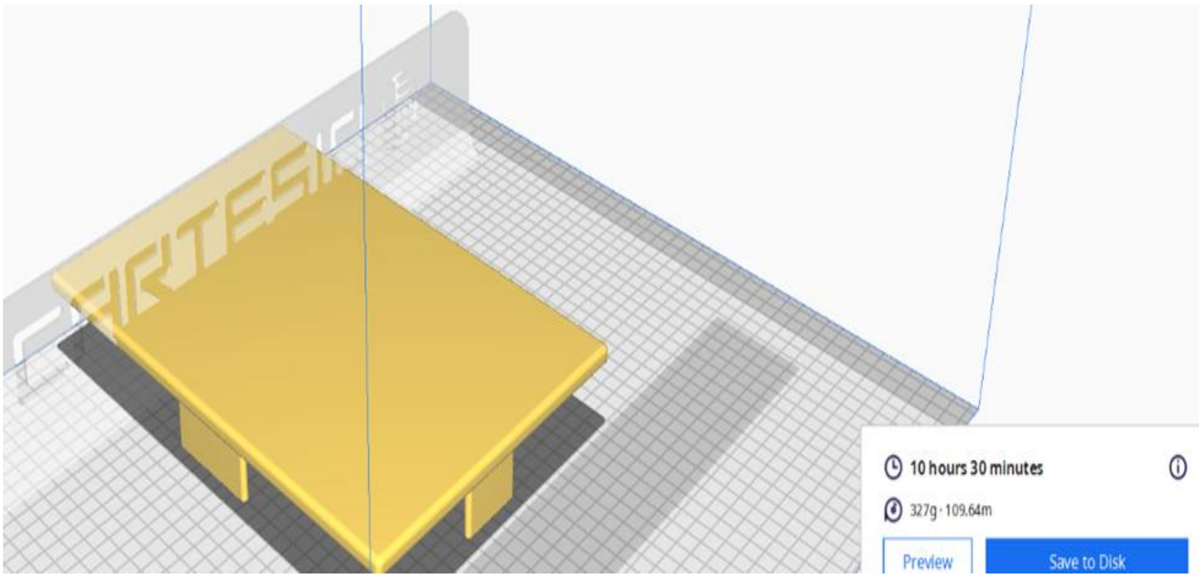


Figure 40: Simulation of Top Cover Using Cura

ix. The box: It is estimated that it will take 1 day 11 hours 9 minutes for an FDM 3D printer to print the box. It has an approximate mass of 1020grams.

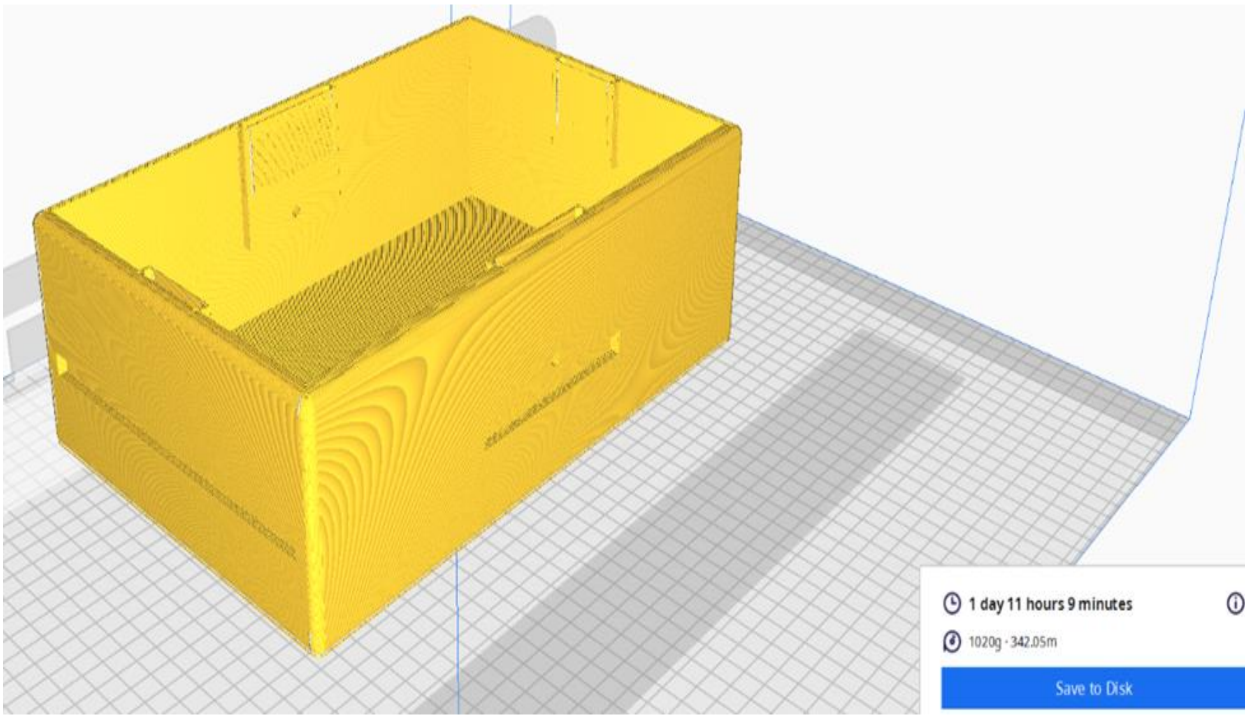


Figure 41: Simulation of Box Using Cura

4.4. Bill of Materials

A table was created during the duration of the design to keep track of the parts, materials, sources, quantity as the project evolved. The bill of materials is shown below (Table 13).

Table 13: Bill of Materials

Turtle Robot Project (BOM)						
u = unit, g = gram						
Item	Part #	Quantity	Name	Material	Source	Price
1	1-1-1-3	1	Frame	PLA	Fermented Plant Starch	$0.009/g
2	1-1-1-1	1	Body	PLA	Fermented Plant Starch	$0.009/g
3	1-1-1-2	1	Rectangular chassis	PLA	Fermented Plant Starch	$0.009/g
4	1-1-1-4	1	Motor holder 1	PLA	Fermented Plant Starch	$0.009/g
5	1-2-1-1	8	Servo Motor Horn	Aluminium		
6	1-1-2	4	Flipper leg	PLA	Fermented Plant Starch	$0.009/g
7	1-1-2-3	4	Flipper leg top	PLA	Fermented Plant Starch	$0.009/g
8	1-1-2-5	4	Flap	Neoprene	Natural chloropene	$0.895/g

9	1-1-2-1	4	Servo horn arm	PLA	Fermented Plant Starch	$0.009/g
10	1-2-2-1	8	Servo Motors MG996R			$ 21.9/u
11	1-2-3	1	Arduino Controller Mega			$ 32.82/u
12	1-2-2	1	Wi-Fi Module ESP8266			$ 16.9/u
13	1-1-3	44	Screws/Fasteners	Aluminum	Bauxites	
14	1-2-4	12	12V lithium-ion Battery			$5.97/u
15	1-2-5	40	Jumper Wires			$0.17/u
16	1-1-2-2	1	Motor Holder 2	PLA	Fermented Plant Starch	$0.009/g
17	1-1-2-1	1	Motor Arm	PLA	Fermented Plant Starch	$0.009/g
18	1-1-2-4	4	Knee	PLA	Fermented Plant Starch	$0.009/g

4.5. Cost Analysis

Table 14: Cost Analysis

Cost of Components ($)	393.36
Cost of Shipping ($)	$45
3D printing ($)	$85
Tax ($)	$11
Total cost ($)	534.36

Table 14 shows the cost analysis i.e., direct and indirect approximate cost for the project. The cost of the servo motor is the highest in comparison with other electronic components. This is followed by the cost of the 3D printing filament which will be used to generate the structural components such as the rectangular chassis, flap, frame, motor arm etc. Other components that take up a significant amount of the cost are, Arduino mega, Wifi Module and batteries.

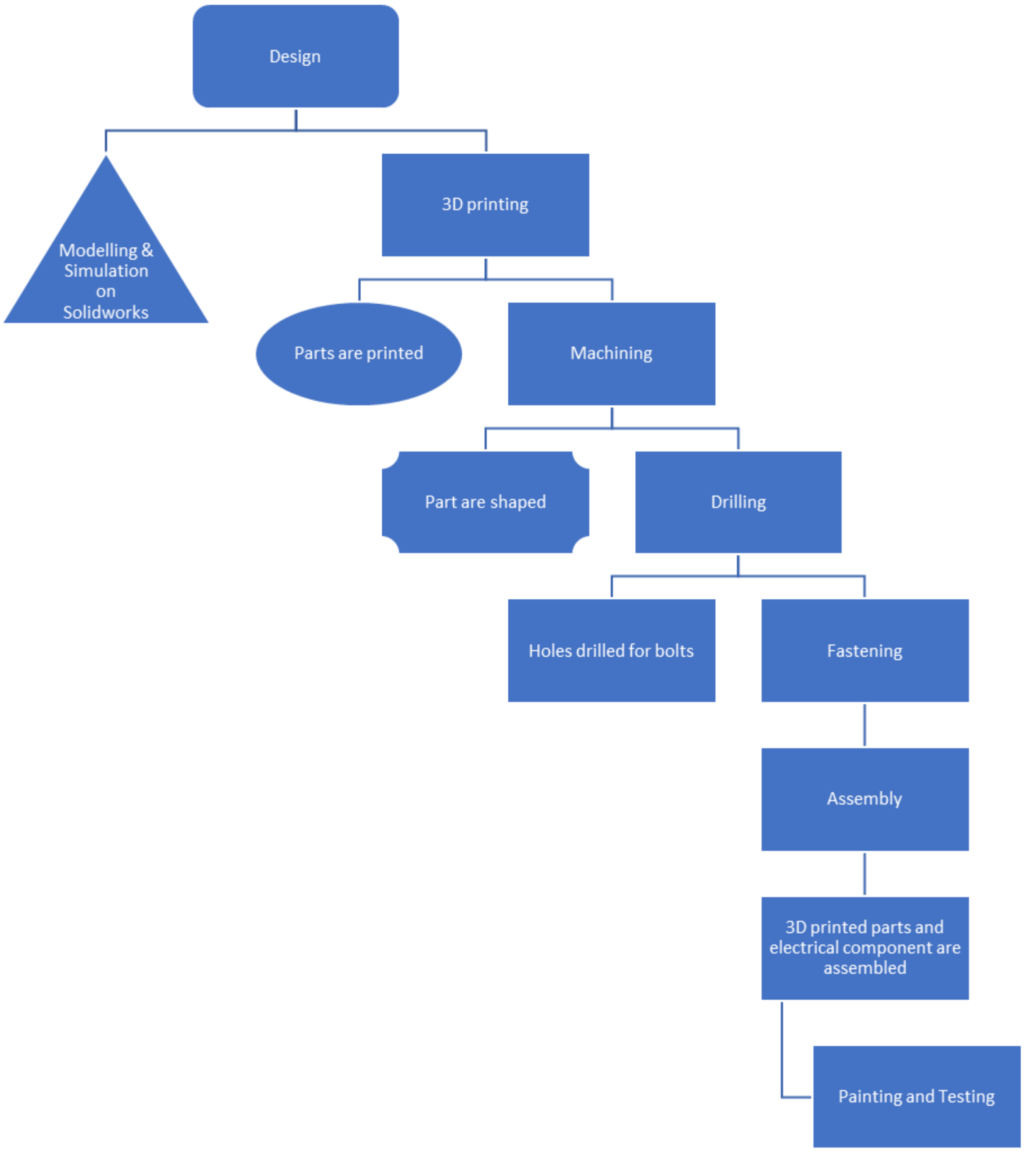


Figure 42: Flowchart of the manufacturing process

Figure 42 displays the manufacturing process flowchart that was used in the manufacturing of the turtle robot.

Design for Assembly:

Table 15: Design for assembly

(DFA) Design For Assembly		
Assembly Evaluation for: Turtle Robot		1. BAD 10 – VERY GOOD
	OVERALL ASSEMBLY	
1	Overall part count minimized	6
2	Minimum use of separate fasteners	3
3	Base part with fixturing features (locating surfaces and holes)	2
4	Repositioning required during assembly sequence	5
5	Assembly sequence efficiency	5
	PART RETRIEVAL	
6	Characteristics that complicate handling (flexibility, tangling) have been avoided	4
7	Parts have been designed for a specific feed approach (flippers)	7
	PART HANDLING	
8	Parts with end-to-end symmetry	4
9	Parts with Symmetry about the axis of insertion	2
10	Where symmetry is not possible, parts are clearly asymmetric	2

	PART MATING	
11	Straight-line motions of assembly	6
12	Chamfers and features that facilitate insertion and self-alignment	2
13	Maximum part accessibility	4

CHAPTER 5: PRODUCT TESTING PLAN

5.1. Verification plan of the objectives.

- **Design for cost:** Revise the current cost analysis to ensure more inexpensive and more readily available materials are used in the manufacturing of the turtle robot. It is ensured that the materials selected are of high quality.
- **Design for assembly:** Review of the turtle design and each component of the turtle body so as to make the components assembly fit. Coming up with an efficient assembly line so as to make the production process easier.
- **Design for manufacturability:** Redesign the manufacturing process so as to avoid unnecessary steps to increase production rates. Redesign the turtle robot so as to eliminate manufacturing of complicated and unnecessary parts.
- **Design for safety**: Revise and redesign the turtle body and components to eliminate those that are harmful to the users.
- **Design for sustainability**: Review the files of the tests carried out so as to understand how sustainable the turtle robot is and making necessary changes to create a more sustainable turtle robot.

5.1.1. Test for the electronic components

The electronic components selected for the turtle body should be able to function feasibly without having to outsource power or use more than the supplied power input. The components should also possess the ability handle and operate easily under the given tasks.

Test for Arduino controller:

The Arduino board should be plugged into a USB port on the computer and check that the green LED power indicator on the board illuminates.

Servo motors:

The servo motors can either be tested by using servo motor testing software, and additional circuit or using a small servo motor tester device.

Battery:

The battery can be tested by using a voltmeter and connecting it to the ends of the battery.

5.1.2. Test for the turtle fin

The turtle flippers are one of the main components of the turtle robot thus the designed turtle flipper should possess the ability to withstand the turtle's weight as well as withstand the environments at which it functions in. A test on the function ability of the flipper is also carried out. The flipper consists of three horizontal PLA bars that are joined together with a rubber flap at the back. To test for the flipper durability, the flipper is left to operate in the simulated environments for numerous times and the ability to survive the test is noted. High loads are also loaded into the turtle to test for how much load the turtle can hold.

5.1.3. Test for the 3D printer

To test the accuracy of the 3D printer, the tolerance gauge test is used. This is done by first properly calibrating the printer and its extruder with the help of a calibration cube. Three-to-five-dimensional accuracy tests or calibration cubes are then printed out and measured.

5.2. Verification plan of the applied engineering standards

To make sure that the product is up to standards, all the parts bought or manufactured must follow a certain standard. Even after manufacturing, the product will be tested according to standards. The following are standards that must be adhered to during and after the manufacturing of the product.

i. IEC 60034
ii. ASME B18.6.3—2013
iii. IEC 62133
iv. UL 1642
v. IEC 62619
vi. IEC 62281
vii. IPC-J-STD-006
viii. ISO/ASTM 52900
ix. ASTM D395
x. ASTM D 412
xi. ASTM D 573
xii. ASTM D 2240
xiii. ASTM D 297
xiv. ISO 9787:2013
xv. ISO 9283:1998
xvi. ISO 8373:2021

5.3. Verification for movement mechanism

To verify the principle in which the turtle robot moves, a proof-of-concept prototype called Turtlev1 was designed. This prototype was only able to achieve motion on water. The components used for designing the proof-of-concept model are:

i. Arduino Uno
ii. HC-05 Bluetooth Module
iii. Jumper wires
iv. 9V Battery
v. Medium Size Breadboard
vi. 4 MG90s Servomotors

The material that was used for Turtlev1 is Polystyrene. Polystyrene was selected because of its low density and no cost for purchase since it is a disposable material. The proof-of-concept model that was made can be seen in Figure 43. The code used for controlling Turtlev1 is shown in APPENDIX J: Codes.

Figure 43: Proof of concept prototype (Turtlev1)

5.3.1. Electrical Connections for Turtlev1

The electrical connections for Turtlev1 are shown in Figure 44. A 9 volts battery was used to power the Arduino Uno R3. HC-05 Bluetooth Module was connected to the 5V power pin of the Arduino Uno. 4 AA batteries were connected in series to get 6V to power the servomotors. The 4 servomotors were connected in parallel to the 6V power supply. Pin 9, 10, 11 and 6 of the Arduino Uno R3 controller were connected to the PWM pins of the motors.

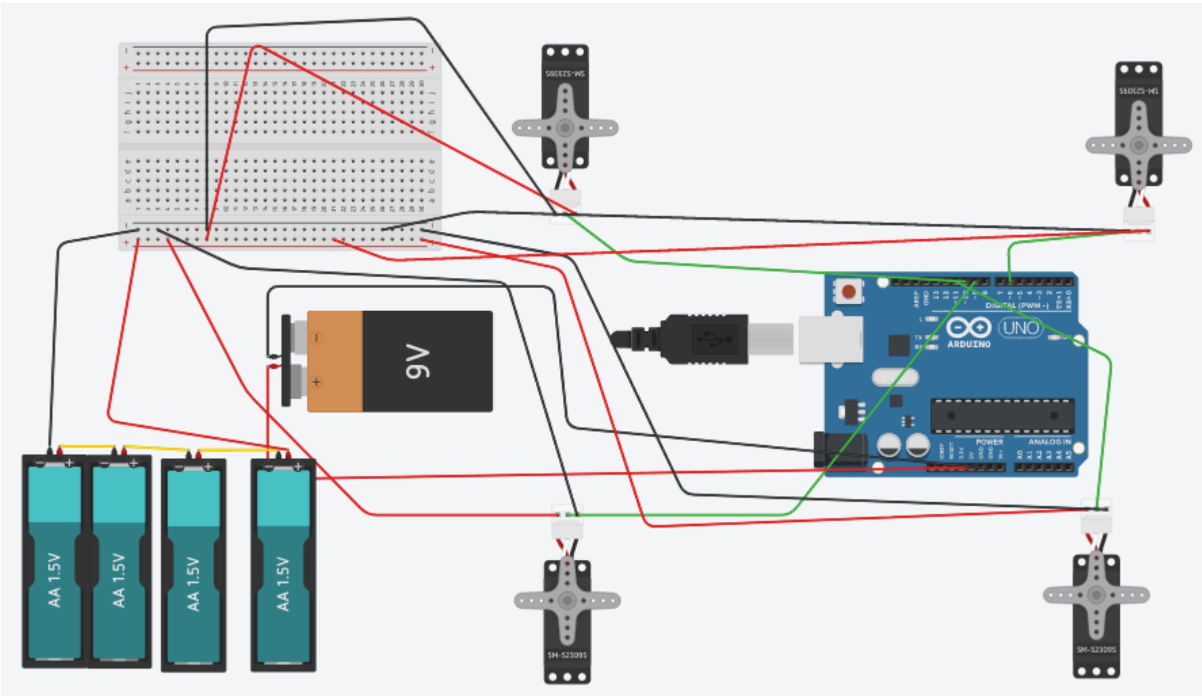


Figure 44: Electrical connections for Turtlev1

The two left-most servomotors are made to move in the same orientation. The two right-most servomotors were also made to move in the same orientation.

5.3.2. Wireless Control of Turtlev1

In order to control Turtlev1, a custom-made Android application called 'Turtle_bluetooth' was designed using MIT App Inventor. The front page of the application is shown in Figure 45. To control the robot, the following steps are required:

- The servomotors and the Arduino have to be powered on.
- The application for controlling the robot should be installed on the Android phone.

- The Bluetooth of the phone used for controlling the robot should be turned on.
- The Android phone should be paired with the HC-05 Bluetooth Module
- The application for controlling the robot should be opened and the option “Turtle Robot Controller” on the home screen should be clicked.
- HC-05 Bluetooth mac address should be selected from the list.
- If the robot is needed to move, ‘Move’ option in green should be selected.
- If the robot is needed to stop, ‘Stop’ option in red should be selected.

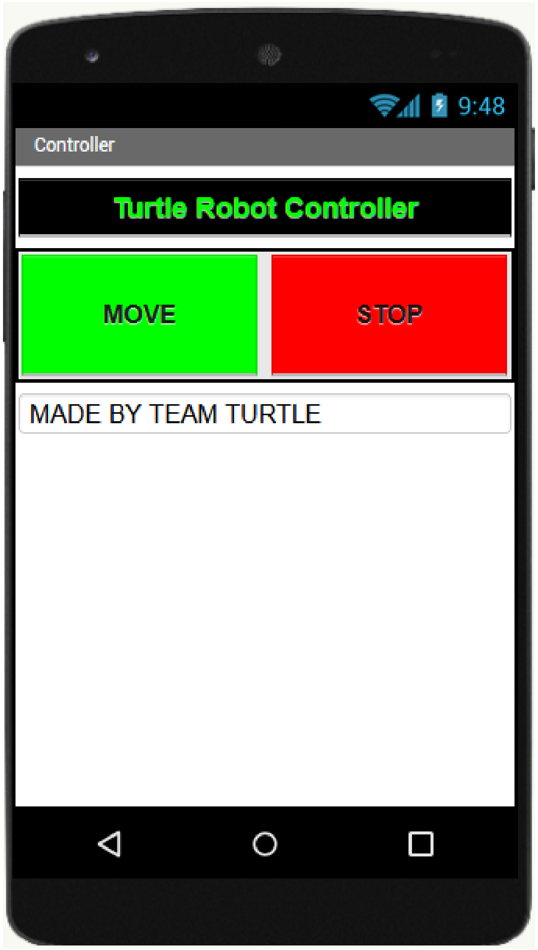


Figure 45: Home screen of Turtle_bluetooth

5.3.3. Result gotten from the proof of concept (Turtlev1)

When Turtlev1 was tested, the following observations were made.

- The concept of using a flap on the flipper for water movement works

- The speed of the robot depends largely on the torque delivered by the motor
- Wireless communication is possible

It should be noted that this design was taken from Vogel et al., 2014. When the gaits proposed for swimming was tried, we found out that the turtle's position does not change; the turtle cannot move forward. When the two left-most motors were made to move in the same orientation and the two right-most motors were made to move in the same orientation, we achieved forward motion.

Unfortunately, the robot was not made to turn left or right. This is due to time which was against us. An idea for turning left was to turn off the right-most motors and turn on the left-most motors. Also, for turning right, we propose turning off the left-most motors and turning on the right-most motors.

5.4. Cost Analysis for proof of concept

The cost analysis for proof-of-concept model is shown in Table 16.

Table 16: Cost analysis for proof of concept

Components	Quantity	Price (TL)
HC05 Serial Port Bluetooth Module	1	78.67
Medium Size Breadboard	1	14.87
9 V Battery Barrel Converter Cable - 9 V to DC Barrel Adapter	1	4.89
MG90s Servo Motor	4	53.45
Foam material	1	10
Tape	1	17
Wood	1	42
Nylon	1	5
Glue	1	40
Glue wires	6	2
Batteries	2	35
Shipping Cost		126
Total		693.23

5.5. Identification of Failure Modes and their Effect Analysis (FMEA)

Table 17: Failure Mode and Effect Analysis of the design

Failure Mode and Effects Analysis (FMEA)															
Process/Product Name:		Turtle robot 1				Prepared By:			JOSEPH ADWEKA						
Responsible:		ADWEKA JOSEPH				FMEA Date (Orig.):			06-Jun						
Item #	**Item**	**Potential Failure Mode**	**Potential Failure Effects**	**SEVERITY (1 - 10)**	**Potential Causes**	**OCCURRENCE (1 - 10)**	**Current Controls (Prevention)**	**Current Controls (Detection)**	**DETECTION (1 - 10)**	**RPN**	**Action Recommended**	**SEVERITY (1 - 10)**	**OCCURRENCE (1 - 10)**	**DETECTION (1 - 10)**	**RPN**
1-2-3	**Arduino Controller**	Overload	Damaging of other electronic components	8	Connecting numerous components to the controller	**7**	Using numerous controllers. Adhere to rules provided by Arduino	Use of an overload detection device	3	**168**	Do not connect numerous electronic components to one controller	6	5	3	**90**
		Short circuit	Damaging of other electronic components	6	Use of high voltages	7	Use high resistant wires and voltage sensors. Use of a fuse	Burnt circuit. Burnt smell of wiring, fumes or overheating of the system	4	**168**	Notify customers on recommended batteries with a specific battery voltage	6	3	4	**72**
		Rust	Breakage of the controller	7	Leakage of liquids into the electronic section	5	Adding layers of sealant into separable sections	Use of a humidity and liquid sensor.	3	**105**	Use of water proof covering	7	3	3	**63**
		Software complications	Inoperable controller	5	Poorly written software	7	Testing software before use	Use of software error messages	1	**35**	Check for errors during coding	5	5	1	**25**
1-2-1	**Servo Motors**	Bearing failure	Excessive noise and vibrations	7	Excessive cyclic loading, gear/shaft misalignment	7	Adhere normal operating conditions	Observe for any noise and vibrations	3	**147**	Use of high-quality bearings	7	4	3	**84**

		Overheating	Damage of the servo motor and other components	5	High voltages and excessive operation of the motors	10	Adhere normal operating conditions. Set up near highly thermal conductive materials	Use of heat sensors	3	**150**	Recommend Usage limitations	5	7	3	**105**
		Winding and cable failure	Inoperable servo motor	6	Poor quality cables used, poor insulation, power faults	5	Use of high-quality windings and cables	Highly undetectable, Observe for unusual noise	9	**270**	Use of high-quality servo motors	6	3	9	**162**
1-2-2	**Wi-Fi-module**	Failure to connect	Lack of communication with the turtle robot	6	IP configuration failure	9	Using high quality WIFI-modules and use of Bluetooth module as a backup	Regular troubleshoot for errors	2	**108**	Use of stronger range and fast WIFI modules	3	7	2	**42**
1-2-4	**Battery**	Over heating	Inoperable turtle robot, Need for battery replacement	6	Weak battery, Excessive demand from the system	8	Engraving Informative information on specific required battery on where to place battery	Use of heat sensors	3	**144**	Use of suitable batteries that can handle supplying power to the robot	6	7	3	**126**
		Expansion	Explosion of the battery, Leakage of the battery	9	Excessive heat in contact with the battery	5	Use of high-quality rechargeable batteries	Observe for expansion and overheating around the battery section.	7	**315**	Use of rechargeable Lithium Polymer Batteries (Li-Po)	9	3	7	**189**
1-2-5	**Wires**	Entanglement	Loosening of wire connections	1	Use of long excess wire	3	Use of perfect length of wires	Detectable through observation	3	**9**	Use of proper length of wires	1	3	3	**9**
		Short circuit	Damaging of other electronic components	6	Contact with other wires and water/humidity	8	Well sealing of the wires and wire connections	Observe for burn smell	4	**192**	Using proper coated cables, avoid removing of excess wire coating	6	4	4	**96**
		Over heating	Causes poor power supply	5	High wire resistance	7	Use of high-quality wires, with low resistance	Highly undetectable	7	**245**	Use of high-quality wires and cables	5	4	7	**140**
1-1-2	**Flipper**	Breakage	Turtle robot won't swim or walk	8	Absorption of water by fin valve	4	Coating of the turtle fins	Observe for cracks	4	**128**	Use of high strength materials	8	3	4	**96**

		Buckling	Turtle robot won't swim or walk	8	Excessive weight of the turtle body	4	Use of an interior skeletal structure	Observe for any bending of the flipper structure	2	**64**	Use of high strength materials	8	3	2	**48**
1-1-2-5	**Flaps**	Fracture	Inability to swim forward	8	High temperatures	7	Using stronger materials	Watch for cracks	7	**392**	Use thicker parts	5	4	7	**140**
		Corrosion	Breakage of the flipper	6	Wrong material selection	4	Using highly corrosive resistant materials	Watch for change in color of the flap	7	**96**	Annealing or coating with corrosive resistant paint	2	3	4	**24**
		Deflection/deformation	Adding excess weight onto the turtle robot	8	Adding excess weight onto the turtle robot	7	Using stronger material	Watch for any change in the shape	7	**392**	Regular checks for deflection, tightening if bolts and screws	5	4	7	**140**
		Vibration	Loosening of joints and bolts	7	Vibration from the motors	8	Using materials with high natural frequencies	Look out for loud noises	3	**168**	Changing the natural frequencies of highly vibrative parts.	2	3	3	**18**
1-1-2-4	**Knee**	Fracture	Robot does not swim	8	Excess weight	7	Use of stronger materials	Highly observable	7	**392**	Using high strength materials	5	4	7	**140**
		Deformation	It does not move as desired	8	Contact with hard surfaces	7	Use of thicker sections	Observable for any changes in shape	7	**392**	Using high strength materials	5	4	7	**140**
1-1-1-3	**Frame**	Fracture	Improper Robot movements	8	Different temperatures	7	Using stronger material	Watch for any cracks	7	**392**	Using stronger materials	5	4	7	**140**
		Corrosion	Breakage of the frame	6	Wrong material selection	4	Using highly corrosive resistant materials	Watch for change in color of the frame	4	**96**	Coating of the frame	2	3	3	**18**
		Vibration	Loosening of joints and bolts.	8	Adding excess weight onto the turtle robot, vibration from the motors.	7	Using stronger material, using materials with high natural frequencies.	Watch for any change in the shape, look out for loud noises	7	**392**	Increasing the natural frequency	5	4	7	**140**

Table 18: Severity Rating Criteria

Severity (S) Rating	Type of effects	Description
10	***Catastrophic***	Causes injury to people, property and or the environment
9	Extremely Harmful	Causes damage to product, property or environment
8	Very Harmful	Causes damage to product
7	***Harmful***	Major degradation of function
6	Moderate	Causes partial malfunction of product
5	Significant	Performance loss causes customer complaints
4	***Annoying***	Loss of function is annoying, cannot be overcome
3	Minor	Some loss of performance, but can be overcome
2	Insignificant	Very little function degradation
1	***None***	No noticeable effects in function or harm to others

Table 19: Occurrence Rating Criteria

Occurence (O) Rating	Likelihood	Description	
10	***Expected***	>30 %	> One per *day*
9	Very likely	30 % (3 per 10)	
8	Probable	5 % (5 per 100)	One per week
7	***Occasional***	1 % (1 per 100)	One per *month*
6	More plausible	0.3 % (3 per 1,000)	One per three months
5	Plausible		
4	***Remote***	0.006 % (6 per 10^5)	One per *year*
3	Unlikely	0.00006 % (6 per 10^7)	One per three years
2	Very unlikely		
1	***Improbable***	< 2 per 10^9 events	> *five years* per failure

Table 20: Detection Rating Criteria

Detection (D) Rating	**Detectability**	**Description**
10	***Impossible***	Impossible to detect, or no inspection
9	Very rare	
8	Rare	
7	***Possible***	Some chance of detecting, or 50% inspection
6	Quite possible	
5	Somewhat likely	
4	***Likely***	Quite likely to detect, or 75% inspection
3	Quite likely	
2	Almost certain	
1	***Certain***	Will be detected, or 100% inspection

5.6. Fault Tree Analysis

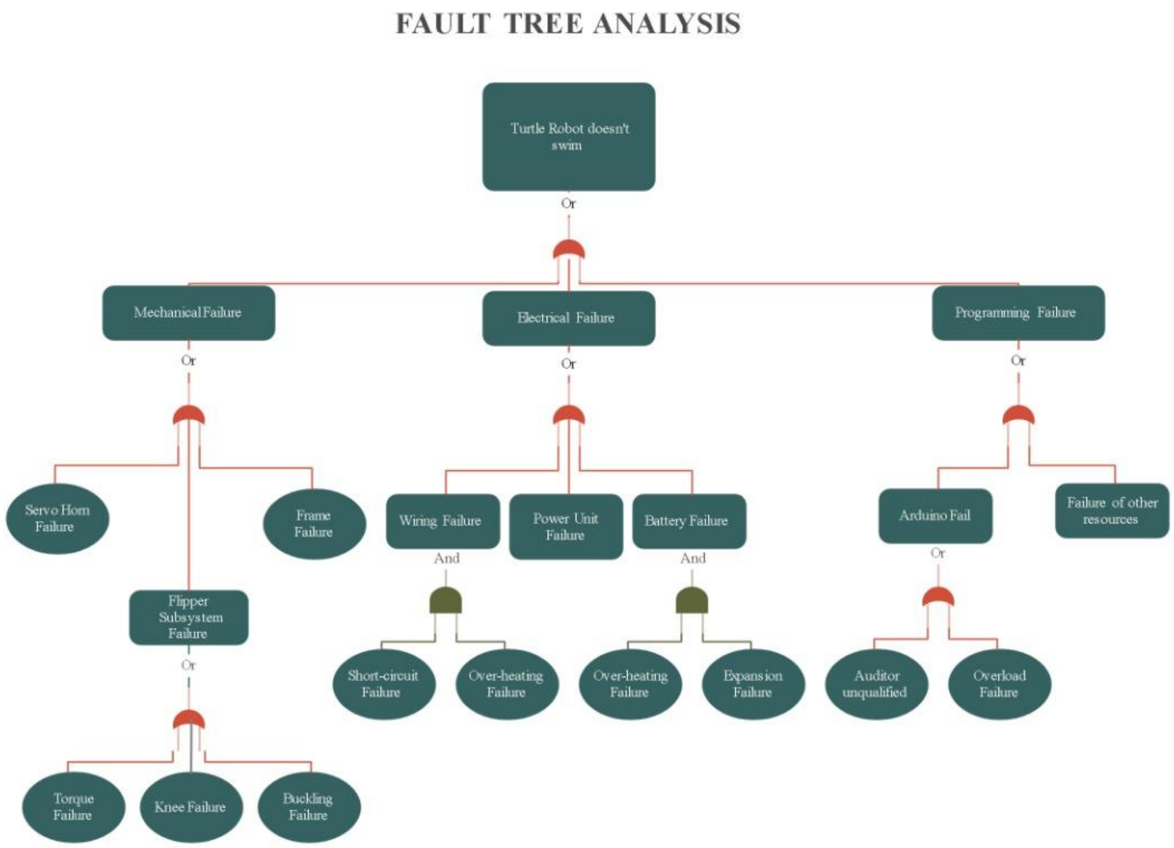


Figure 46: Fault Tree Analysis

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

Biomimicry is important in creating highly sustainable and reliable technological devices that aid humans in solving complicated tasks and objectives. A turtle is selected in the case of this project because they are capable of surviving in both water and land environments. The importance of nature in aiding this project is that it offers numerous and direct solutions to many arising challenges that are faced during the whole process of designing and manufacturing. To be able to work as desired, the turtle robot uses a switching mechanism that changes the style of its walk to be able move on the environment its currently at.

The turtle robot uses reliable parts that suit it's required needs, such as a highly responsive Wi-Fi module that functions over large ranges, the use of polythene waterproofing to avoid water coming in contact with the electronic components of the turtle. Using of reliable DS3225 25kg RC servomotors that offer necessary required motion desired. The use of Power-Xtra 9V zinc manganese batteries that are highly cheap and readily available thereby reducing costs.

Projects such as these are important because they record useful data that can be used later on to create better and more successful future versions of the robot being manufactured. It is important to note that numerous challenges were faced when in the design and manufacturing of the turtle robot. Such difficulties include;

- High costs; The process of buying the structural materials of the turtle body and the electronic components e.g., servo motors, Arduino boards created huge costs. Other costs include those that are incurred in the manufacturing process of the turtle through 3D printing. This is due to the lack of readily available 3D printers to use and the high cost of PLA.

- Time played a huge factor considering that the design process and the manufacturing process had many difficult obstacles to overcome. The process of importing key parts and necessary materials also slowed down the manufacturing process, because manufacturing could not begin on time as scheduled.
- The manufacturing process was a difficult task to take on as many difficulties were faced in the process of trying to use 3D printing that led the team to create an alternative solution to any arising challenges
- Information was also a difficult obstacle because important information on standards and concurrent solutions are hard to access there by challenges in other sectors arose such as in the quality control, human and environment requirement standards, thereby it was a challenge to meet these requirements.

The applications of the bio-inspired robots in the human day to day life ranges depending on the problems being faced, such us using the turtle robot to explore reefs, observe and collect scientific data used for solving problems such as climate change and water pollution. Such robots could be used in interplanetary colonisation, as they can be used in place of humans to explore space.

6.2. Recommendations

As shown in the report above, the process of gathering information to the process of manufacturing are detailed as shown. The prototype designed as shown above has many areas and sections that needed a great deal of improvement because they are not reliable and useful in the long run. In future models, a better less energy consuming gait will be designed to overcome the process of changing its style of gait motion thus eliminating the need for change of the gait motion to achieve movement. The issue of battery replacement will be solved by using more reliable, rechargeable and stronger batteries that will eliminate the need to open the turtle robot to replace the batteries. The turtle body shape will be improved to create a more streamlined and hydrodynamically fit turtle body that can swim easily in water without use of more energy than the current prototype of the turtle robot. The use of more lightweight material that meets the weight requirements intended for the turtle robot. Introducing the use of a simpler and reliable software that will solve operational problems that are faced when controlling the actions of the turtle robot. Introduction of a sleeker design that resembles nature so as to be more environment friendly looking. The current prototype of the turtle robot uses externally manufactured parts that inherently increases costs, therefore to overcome such a difficulty, future designs will feature locally made parts to reduce costs and create more desired outcomes. Introduction of a camera module at the head of the turtle robot so as to enable the turtle robot to be self-functioning and more self-decision making. Introduction of a proper wiring system that can function fully even in hard and wet conditions to avoid short circuits when in contact with water. Creation of a more environmentally safe robot with near net zero carbon footprint so as to meet environmental requirements and also work safely in the environment without pollution. Such ideas are to be implemented into future models of the turtle robot. The main goal of future turtle robots manufactured is for them to be reliable, sustainable and also environmentally friendly.

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APPENDIX A: Electronic Media

Eastern Mediterranean University
"Virtue, Knowledge, Advancement"

Team TMNT

Turtle Robot

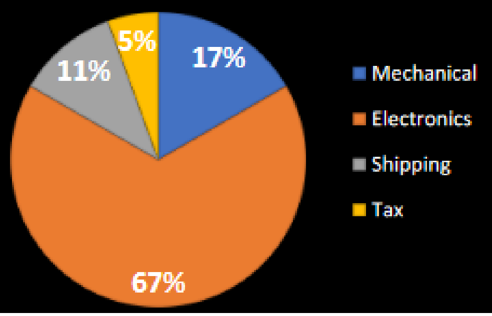
Olukare Jonathan, Precious Ifeoluwa, Joseph Adeweka, Jamal Khader, Muhammed Lasisi
Department of Mechanical and Mechatronics Engineering

OVERVIEW OF THE PROJECT

- The following project describes the design, integration, manufacturing plan of a lost cost turtle robot.
- The turtle robot will achieve land and water locomotion with the use of servo motors.
- The project will be carried out by analyzing past designs of turtle robots and modifying them in other to improving the design.

COST ANALYSIS

The servo motors is the most expensive in comparison with other electronics components used in this project. This is followed by the cost of 3D printing filament which will be used to generate the structural components of the Turtle robot. Other expenses include shipping and tax.



TECHNICAL SPECIFICATION

Actuation Type	DS3225 Servo Motor
Control Unit	Arduino Mega
Remote Control System	Bluetooth
Locomotion Modes	Walking and Swimming
Operating Environment	Terrestrial and Aquatic environment
Power Unit	Rechargeable Li-ion Battery

BREAKDOWN STRUCTURE

Design → 3D Printing → Machining → Fastening → Assembly → Testing

Design

The Turtle Robot design was inspired by RoboTerp robotics project with the Arduino as well as various ongoing robotics research and development projects.

PROPOSED DESIGN

ACTUAL DESIGN

APPENDIX B: Standards

IEC 60034-1:2022: Rotating electrical machines - Part 1: Rating and performance

IEC 62133: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary lithium cells, and for batteries made from them, for use in portable applications

IEC 62619: Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications

IEC 62281:2019: Safety of primary and secondary lithium cells and batteries during transport

UL 1642: Standards for Lithium Ion Batteries

ISO 128-21: Technical Drawings: General principles of presentation - Part 21: Preparation of lines by CAD systems.

ISO 13482:2014: Robots and robotic devices: Safety requirements for personal care robots.

ISO/ASTM 52900:2015: Additive manufacturing — General principles — Terminology

ISO/DIS 10218-2 ROBOTICS: Safety requirements for robot systems in an industrial Environment

ASTM D395: Standard Test Methods for Rubber Property—Compression Set

ASTM D412-16(2021): Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

ASTM D573: Standard Test Method for Rubber—Deterioration in an Air Oven

ASTM D2240: Standard Test Method for Rubber Property—Durometer Hardness

ASTM D297: Chemical Analysis Test Procedures for Rubber Products

ISO 8373:2012 Robots and robotic devices: Defines terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments.

ISO/IEC DIS 23510: Information technology — 3D Printing and scanning — Framework for additive manufacturing service platform (AMSP).

ISO 9283:1998: Manipulating industrial robots — Performance criteria and related test methods

ISO 9787:2013: Robots and robotic devices — Coordinate systems and motion nomenclatures

ASME B18.6.3--2013: Screw Standards

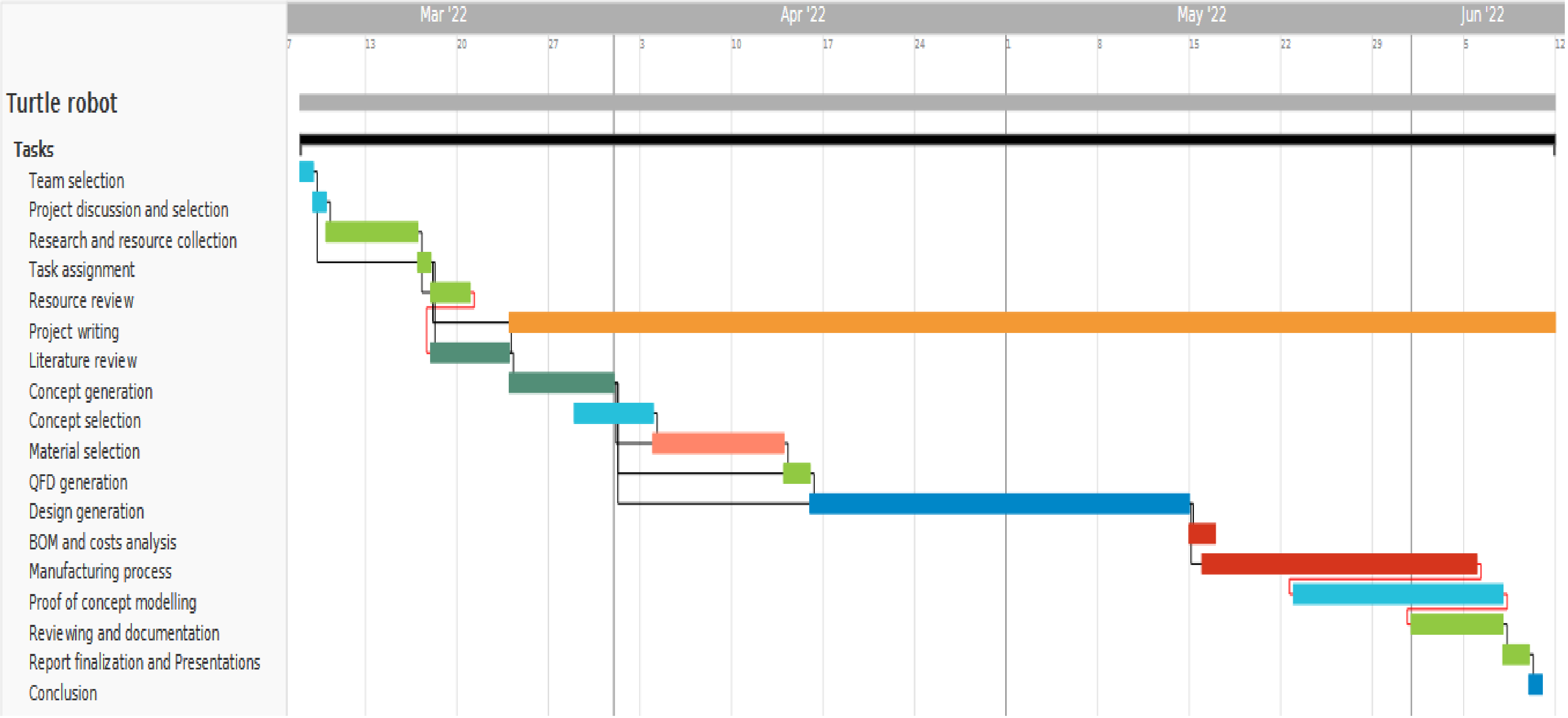
ASME B 18.2.4.1M: Nut Standards

ANSI J-STD-001: Requirements for soldered electrical and electronic assemblies

APPENDIX C: Constraints

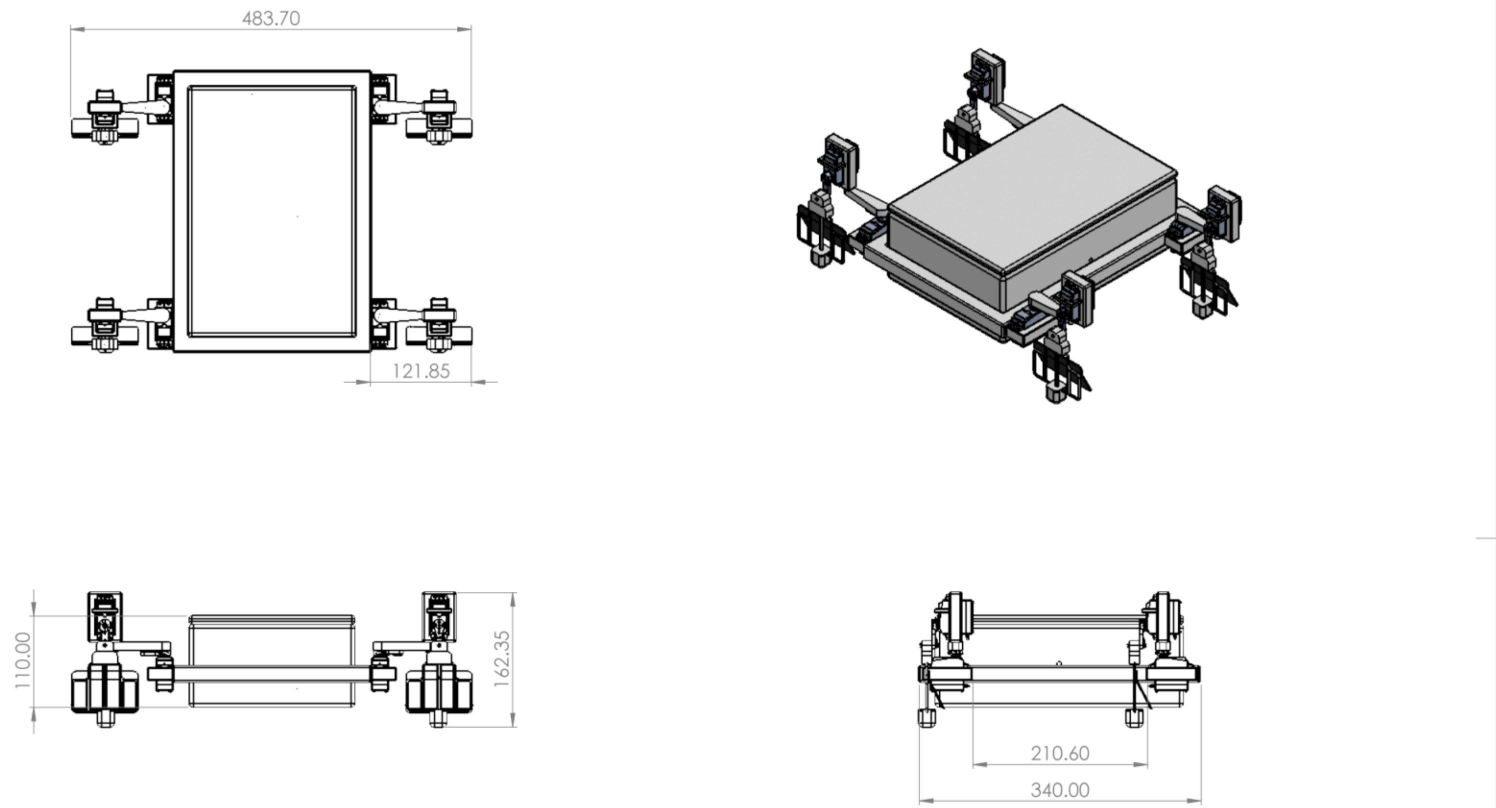
Constraint	**Yes**	**No**
Cost	X	
Manufacturability	X	
Availability of materials and resources		X
Time		X
Health and Safety	X	
Environment	X	
Reliability	X	
Efficiency	X	
Ethical	X	

APPENDIX D: Project Plan



APPENDIX E: Engineering Drawings

Assembly and detailed drawings are shown in the following pages



NOTE:

- Most of the parts are 3D printed
- Material used is PLA except the servo motor, servo horn and the flap
- Flap material is Neoprene (rubber)
- A total of 40 screws and 4 nuts were used (32 screws to connect motors to the first motor holders, 4 screws and 4 nuts to connect knees to the servo motor horns, & 4 screws to connect motor arm to the second motor holders).
- Top cover connects to the body by self locking mechanism
- 8 waterproof Motors
- Arduino, Wi-Fi module & battery are all enclosed in the body
- Flaps are open to allow flow of water

DIMENSIONS ARE IN MILLIMETERS & DEGREES

TOLERANCES: 180-9001

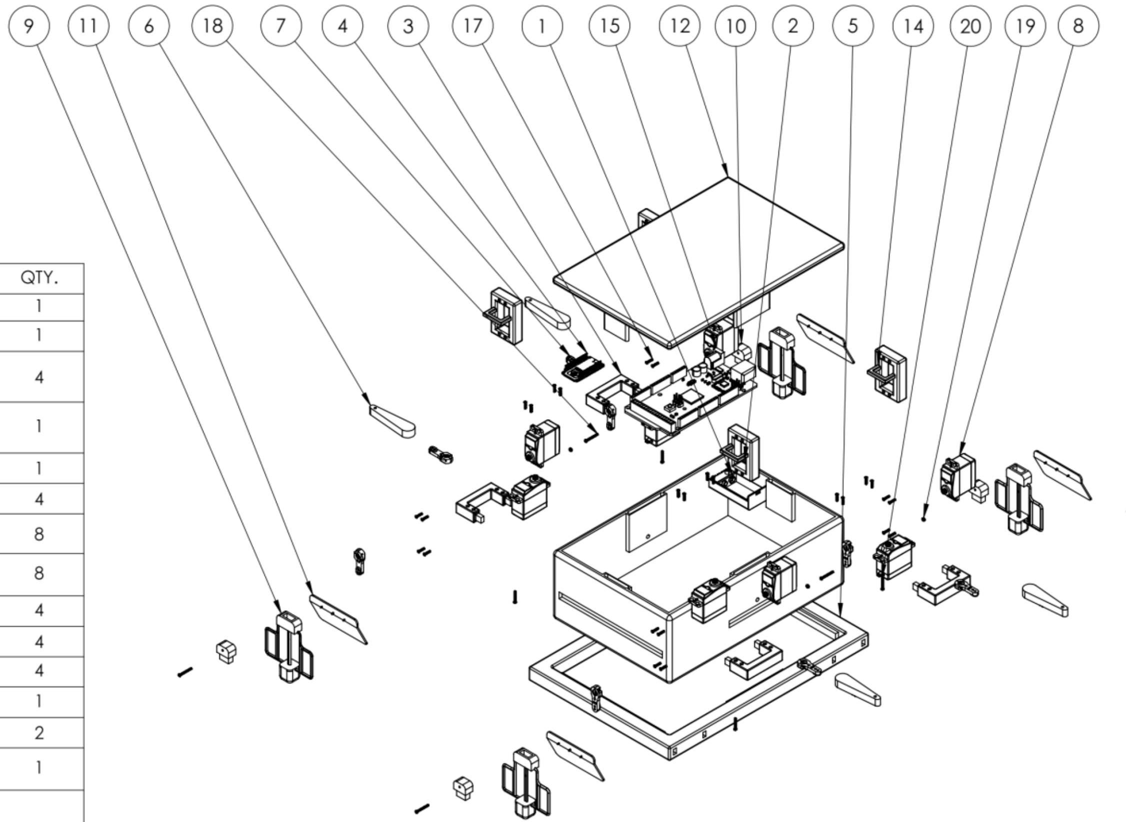
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.

	NAME	SIGNATURE	DATE
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22

TITLE: PROTOTYPE 1

PART NO. 1

SCALE: 1:5 MATERIAL: PLA



ITEM NO.	Description	Part No.	QTY.
1	Battery	1-2-4	1
2	Body	1-1-1-1	1
3	Motor - Frame Holder	1-1-1-4	4
4	Esp8266 Node MCU (Wi-Fi Module)	1-2-2	1
5	Frame	1-1-1-3	1
6	Motor arm	1-1-2-1	4
7	SW2020 Aluminium 25T Servo Horn	1-2-1-1	8
8	SW2020 DS3225MG Servo 25Kg 4.8-6.8V	1-2-1	8
9	Flipper	1-1-2	4
10	Knee	1-1-2-4	4
11	Flap	1-1-2-5	4
12	Top cover	1-1-1-2	1
14	Motor Holder_2	1-1-2-2	2
15	Arduino Mega 2560.STEP	1-2-3	1
17	B18.6.7M - M2 x 0.4 x 10 Type I Cross Recessed OHMS --10S	1-1-3-1	32
18	B18.6.7M - M2 x 0.4 x 20 Type I Cross Recessed PHMS --20S	1-1-3-2	4
19	B18.2.4.1M - Hex nut, Style 1, M2 x 0.4 --D-S	1-1-3-4	4
20	B18.6.7M - M2 x 0.4 x 16 Type I Cross Recessed PHMS --16S	1-1-3-3	4

DIMENSIONS ARE IN MILLIMETERS & DEGREES
TOLERANCES: 180-9001

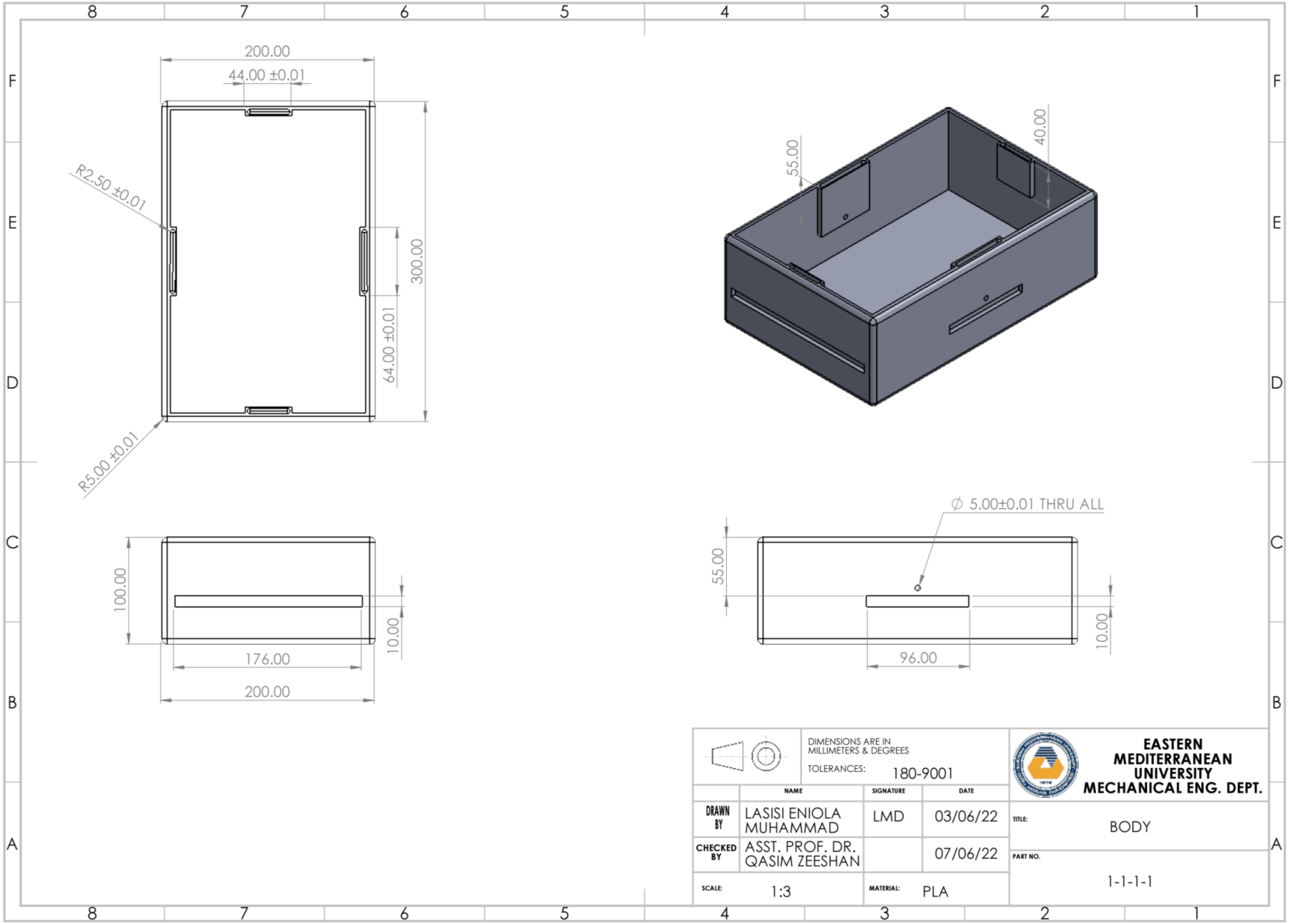
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.

	NAME	SIGNATURE	DATE
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22

SCALE: 1:5
MATERIAL: PLA

TITLE: EXPLODED VIEW OF PROTOTYPE 1

PART NO. 1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44.00 ±0.01
R2.50 ±0.01
300.00
64.00 ±0.01
R5.00 ±0.01
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DIMENSIONS ARE IN MILLIMETERS & DEGREES
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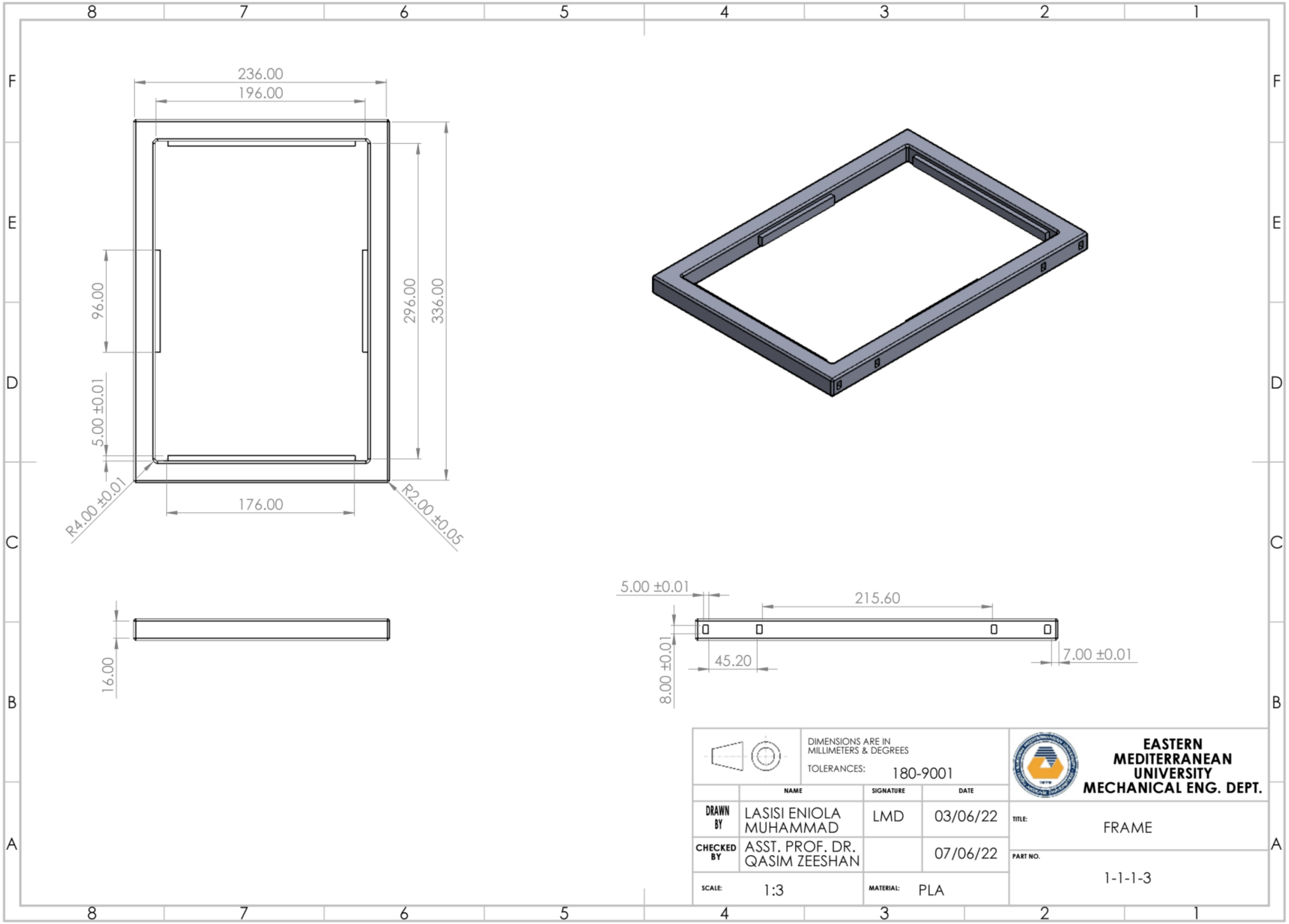
NAME
SIGNATURE
DATE
DRAWN BY
LASISI ENIOLA MUHAMMAD
LMD
03/06/22
CHECKED BY
ASST. PROF. DR. QASIM ZEESHAN
07/06/22
SCALE: 1:3
MATERIAL: PLA
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
TITLE: BODY
PART NO. 1-1-1-1


236.00
196.00
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336.00
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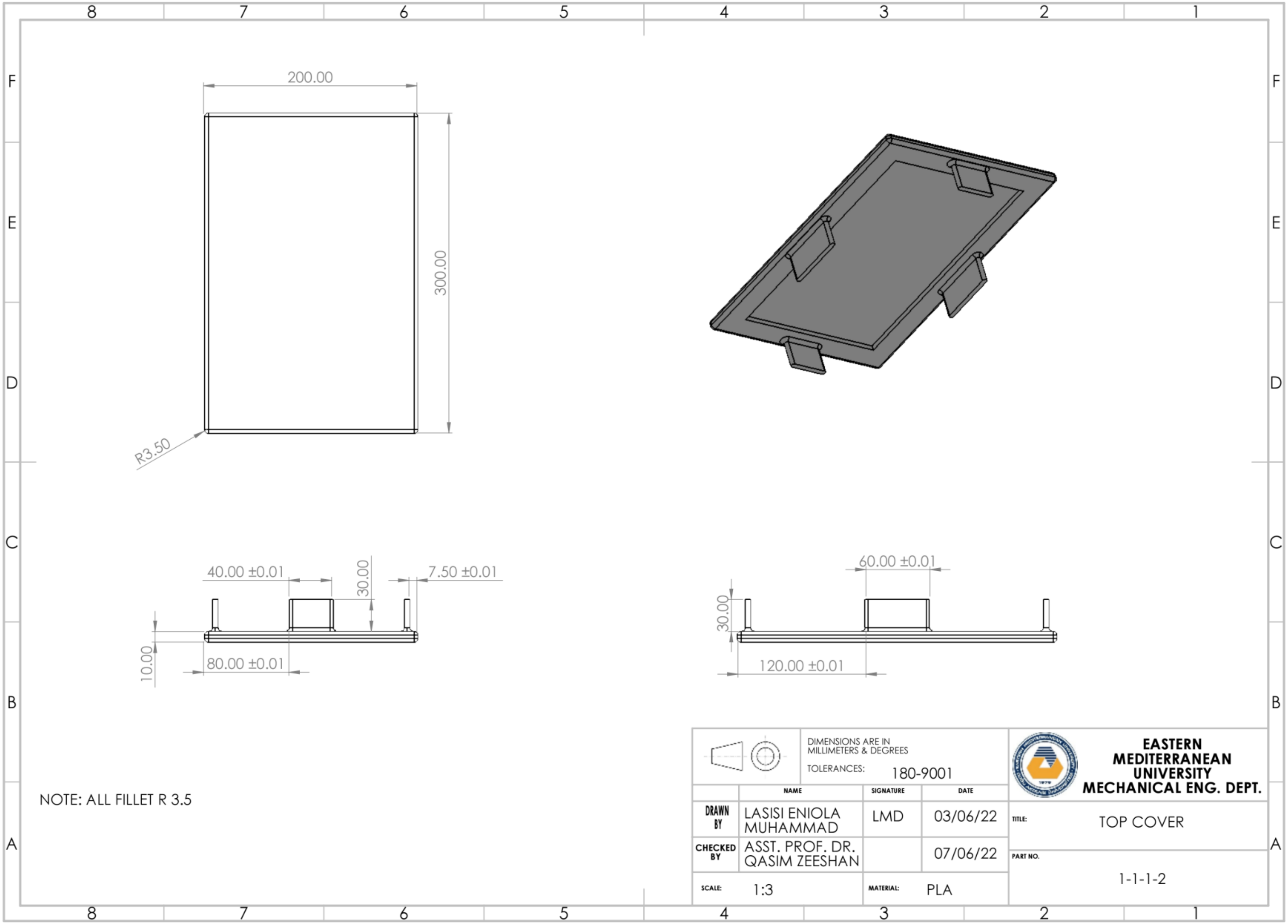
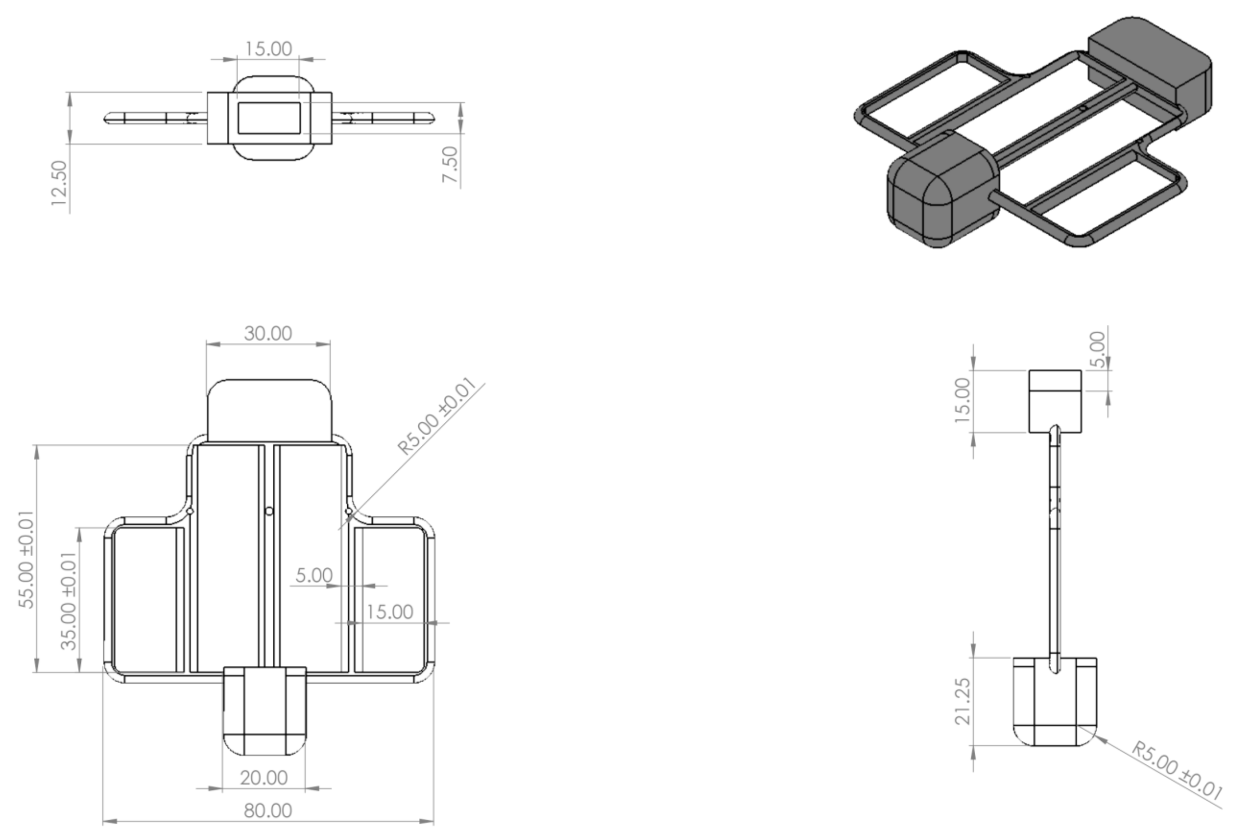
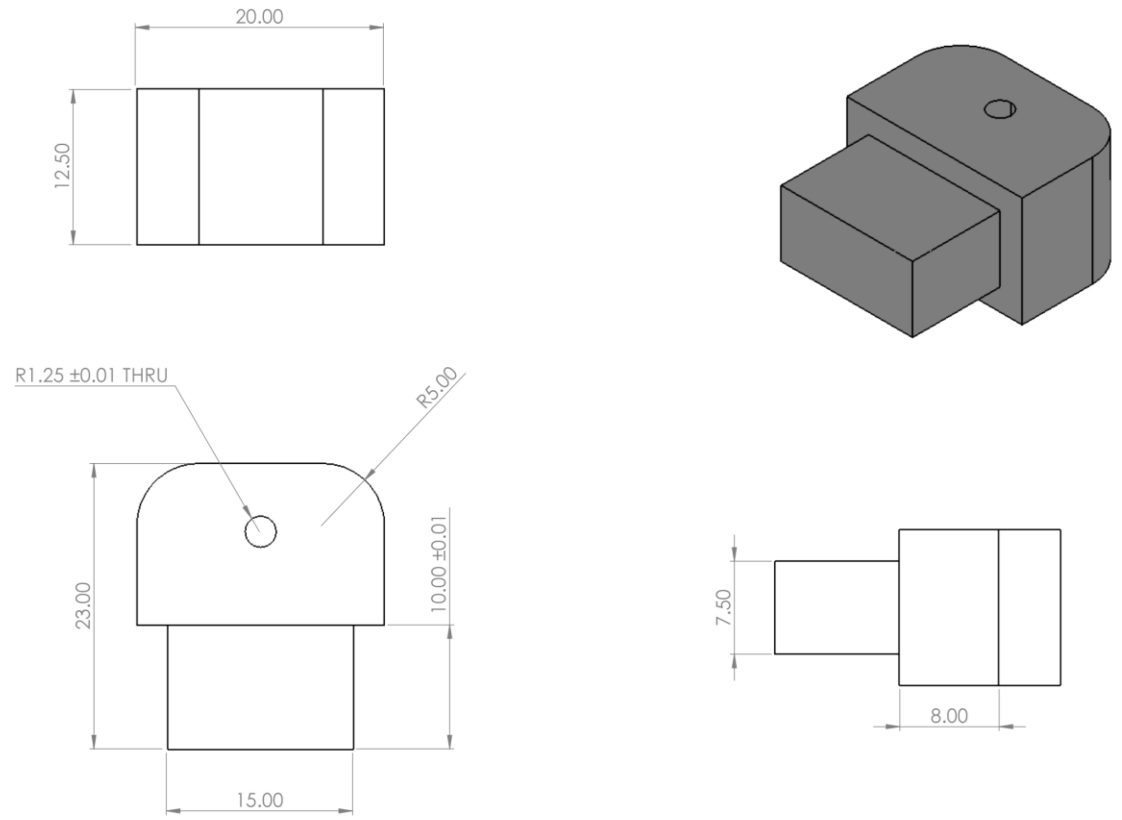
176.00
R2.00 ±0.05
16.00
5.00 ±0.01
215.60
8.00 ±0.01
45.20
7.00 ±0.01
DIMENSIONS ARE IN MILLIMETERS & DEGREES
TOLERANCES: 180-9001
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
NAME
SIGNATURE
DATE
DRAWN BY
LASISI ENIOLA MUHAMMAD
LMD
03/06/22
CHECKED BY
ASST. PROF. DR. QASIM ZEESHAN
07/06/22
TITLE: FRAME
PART NO. 1-1-1-3
SCALE: 1:3
MATERIAL: PLA

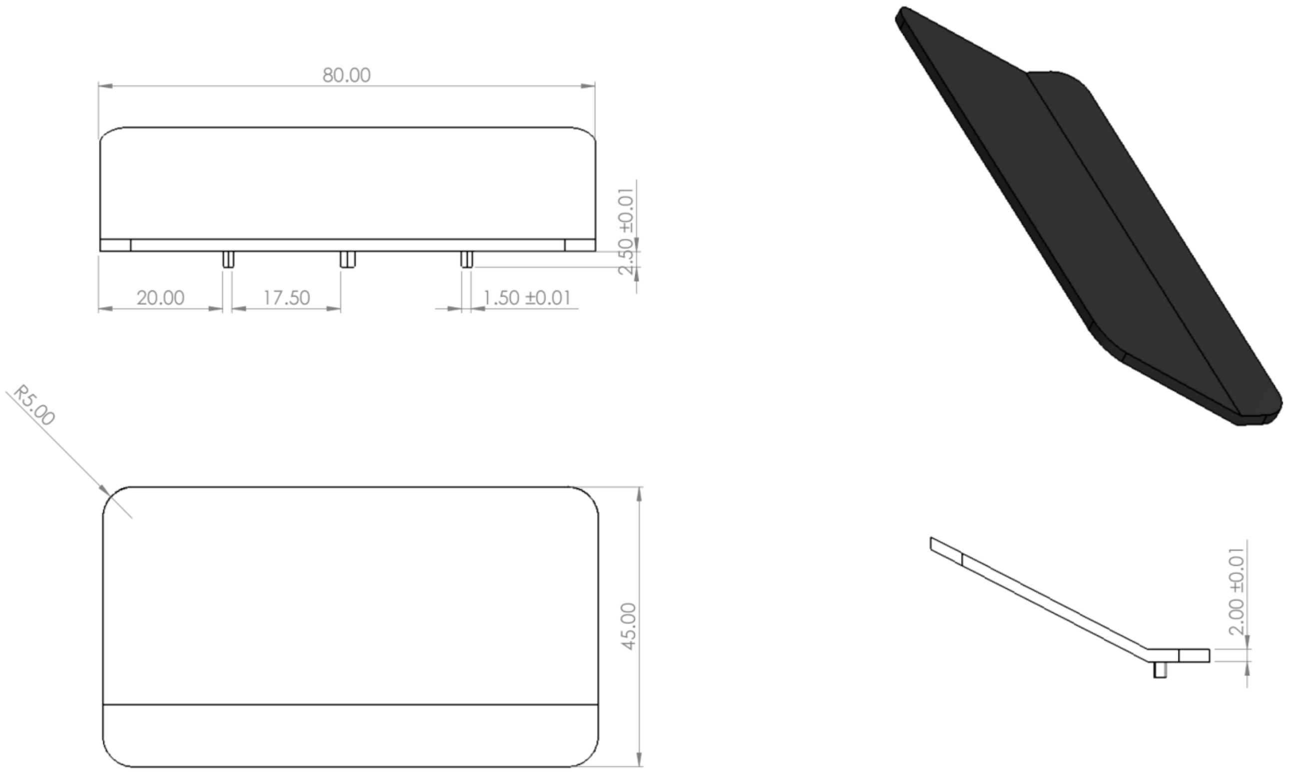

200.00
300.00
R3.50
40.00 ±0.01
30.00
7.50 ±0.01
10.00
80.00 ±0.01
60.00 ±0.01
30.00
120.00 ±0.01
NOTE: ALL FILLET R 3.5
DIMENSIONS ARE IN MILLIMETERS & DEGREES
TOLERANCES: 180-9001
NAME
SIGNATURE
DATE
DRAWN BY
LASISI ENIOLA MUHAMMAD
LMD
03/06/22
CHECKED BY
ASST. PROF. DR. QASIM ZEESHAN
07/06/22
SCALE: 1:3
MATERIAL: PLA
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
TITLE: TOP COVER
PART NO. 1-1-1-2



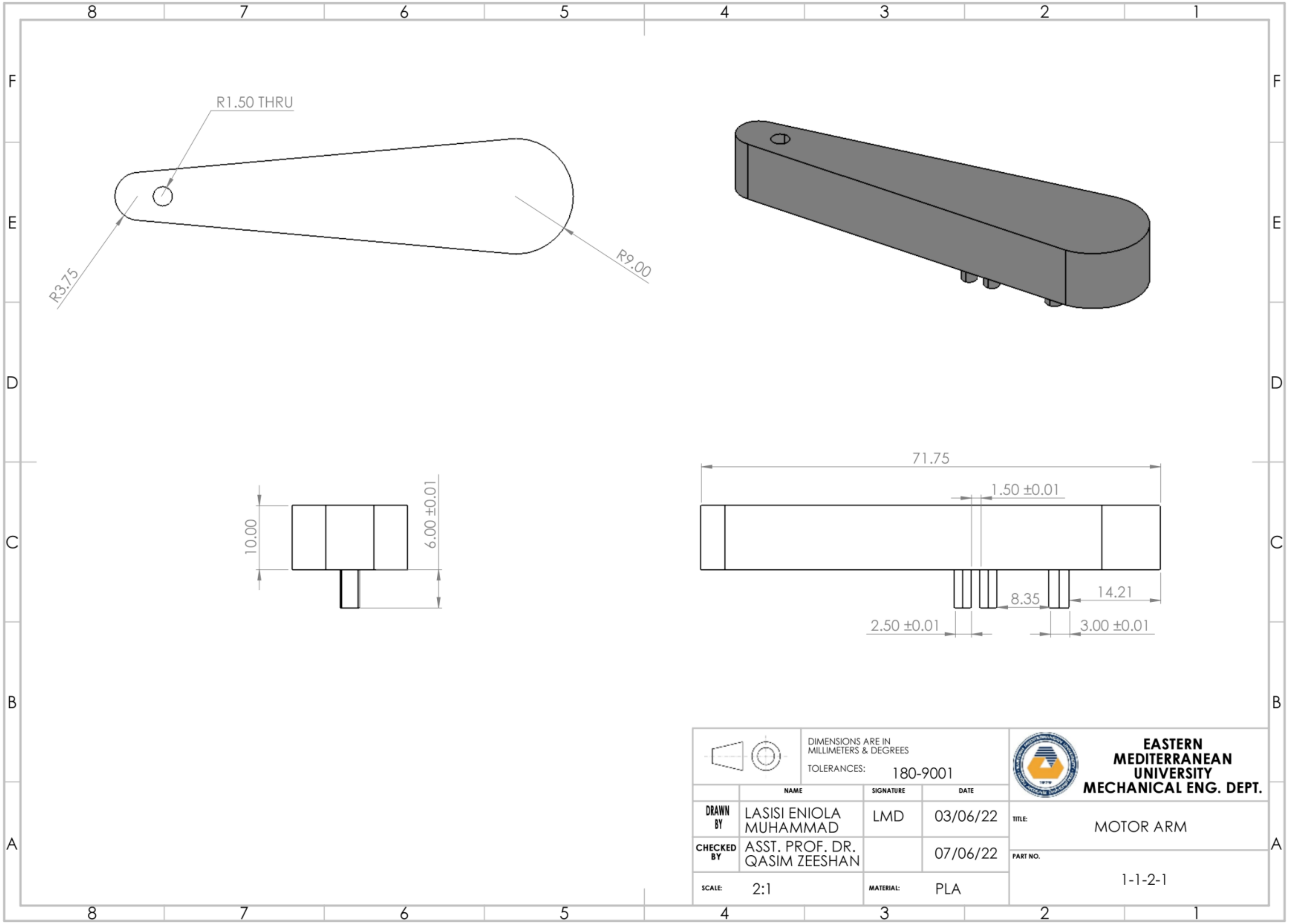
	DIMENSIONS ARE IN MILLIMETERS & DEGREES TOLERANCES: 180-9001			EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
	NAME	SIGNATURE	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22	TITLE: FLIPPER
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22	PART NO. 1-1-2
SCALE:	1:1	MATERIAL:	PLA	

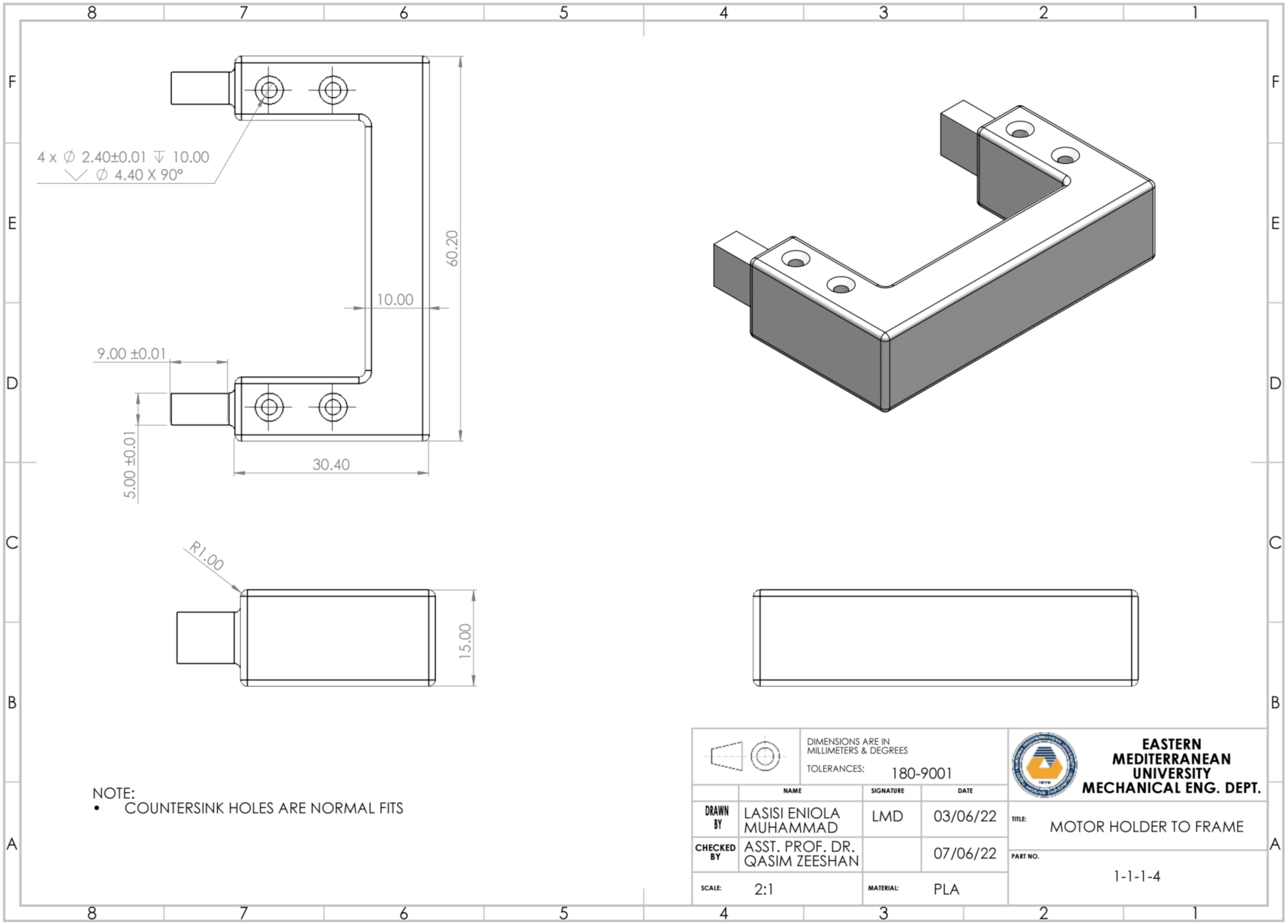


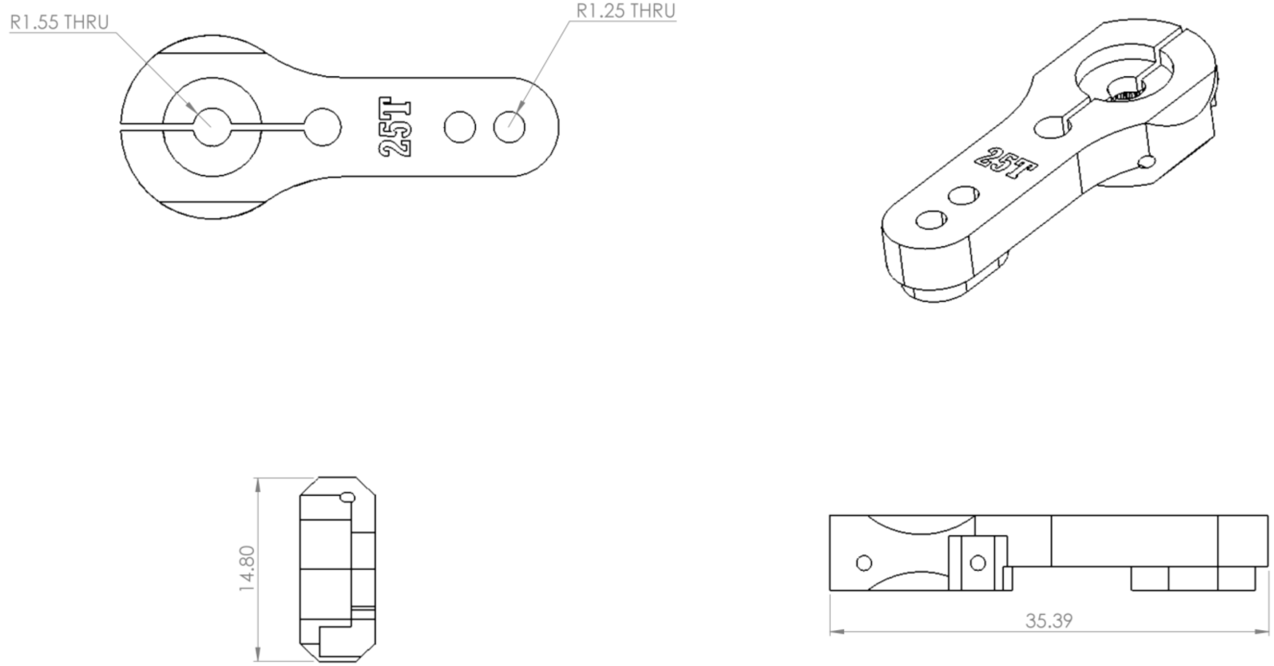
DIMENSIONS ARE IN MILLIMETERS & DEGREES TOLERANCES: 180-9001				EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
	NAME	SIGNATURE	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22	TITLE: KNEE
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22	PART NO. 1-1-2-4
SCALE:	3:1	MATERIAL:	PLA	



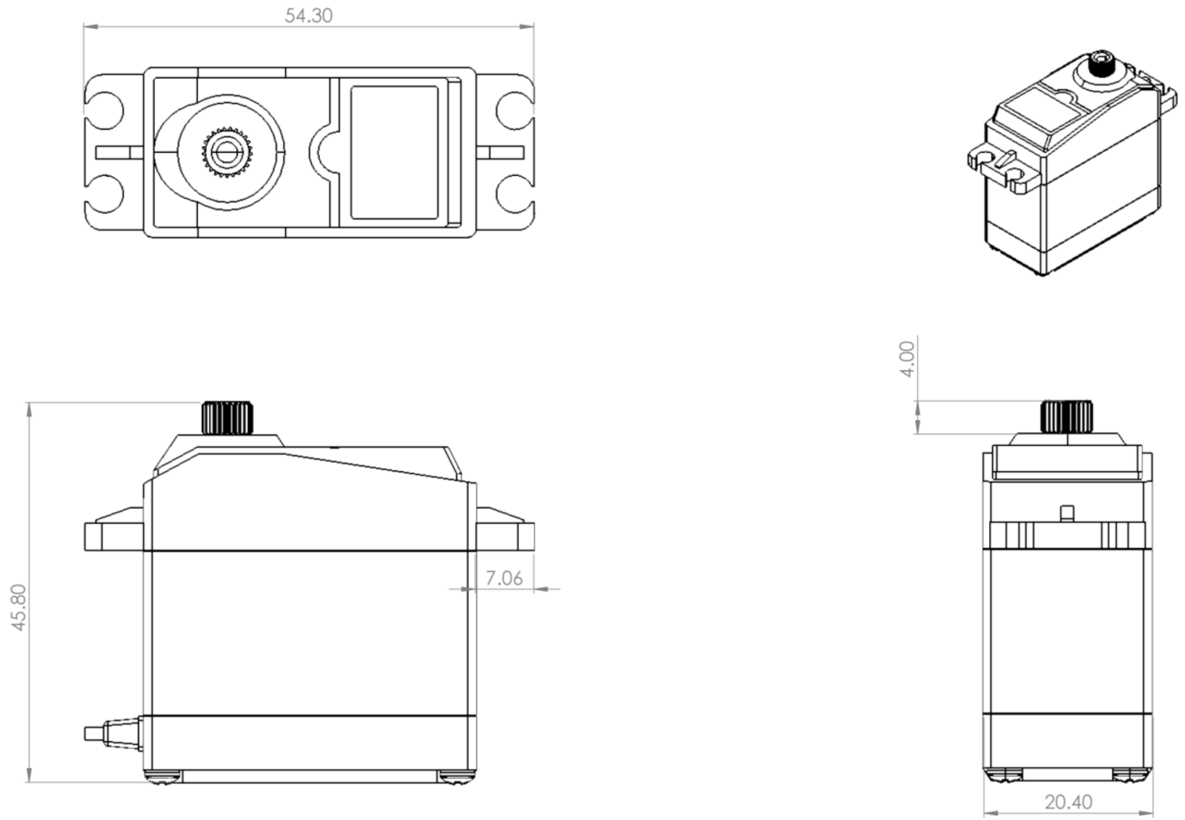
DIMENSIONS ARE IN MILLIMETERS & DEGREES TOLERANCES: 180-9001			EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
	NAME	SIGNATURE	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22	TITLE: FLAP
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22	PART NO. 1-1-2-5
SCALE: 1.5:1		MATERIAL: NEOPRENE		


R1.50 THRU
R3.75
R9.00
10.00
6.00 ±0.01
71.75
1.50 ±0.01
8.35
14.21
2.50 ±0.01
3.00 ±0.01
DIMENSIONS ARE IN MILLIMETERS & DEGREES
TOLERANCES: 180-9001
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
NAME
SIGNATURE
DATE
DRAWN BY
LASISI ENIOLA MUHAMMAD
LMD
03/06/22
CHECKED BY
ASST. PROF. DR. QASIM ZEESHAN
07/06/22
TITLE:
MOTOR ARM
PART NO.
1-1-2-1
SCALE:
2:1
MATERIAL:
PLA


4 x ∅ 2.40±0.01 ↧ 10.00
⌵ ∅ 4.40 X 90°
60.20
10.00
9.00 ±0.01
5.00 ±0.01
30.40
R1.00
15.00
NOTE:
• COUNTERSINK HOLES ARE NORMAL FITS
DIMENSIONS ARE IN MILLIMETERS & DEGREES
TOLERANCES: 180-9001
EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
NAME
SIGNATURE
DATE
DRAWN BY
LASISI ENIOLA MUHAMMAD
LMD
03/06/22
CHECKED BY
ASST. PROF. DR. QASIM ZEESHAN
07/06/22
TITLE: MOTOR HOLDER TO FRAME
PART NO. 1-1-1-4
SCALE: 2:1
MATERIAL: PLA



DIMENSIONS ARE IN MILLIMETERS & DEGREES TOLERANCES: 180-9001				EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
	NAME	SIGNATURE	DATE	
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22	TITLE: SERVO HORN
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22	PART NO. 1-2-1-1
SCALE:	3:1	MATERIAL:		



NOTE:
- TOP, FRONT & RIGHT VIEWS HAVE A SCALE OF 2:1
- ISOMETRIC VIEW IS 1:1

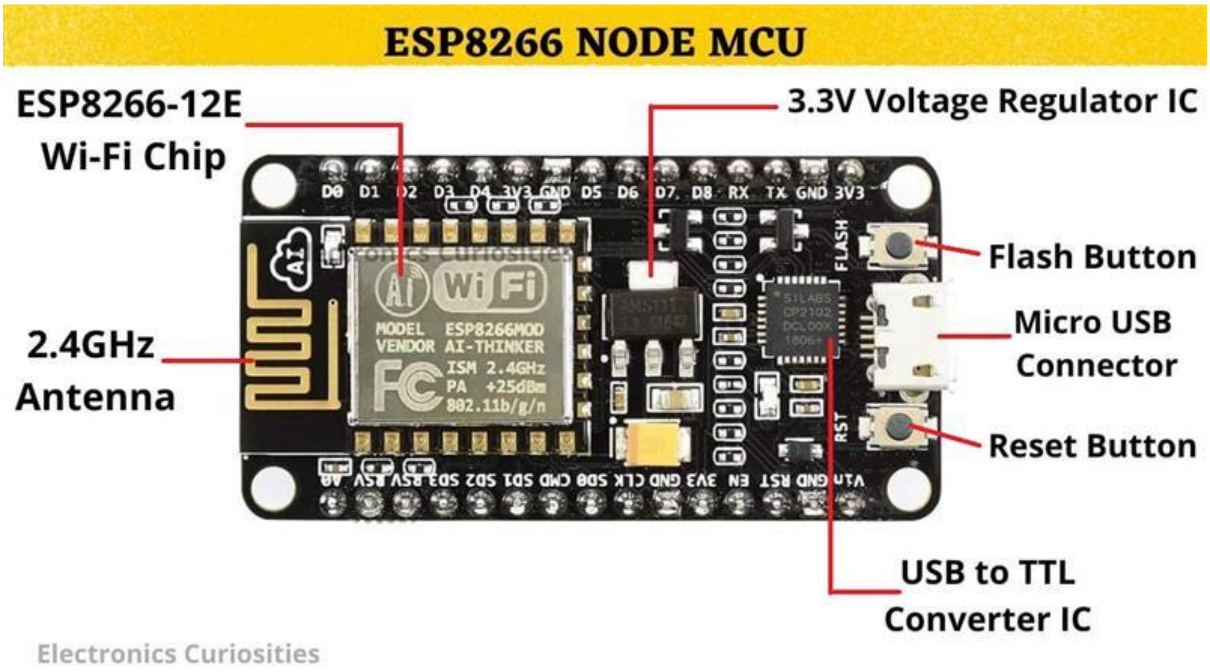
DIMENSIONS ARE IN MILLIMETERS & DEGREES TOLERANCES: 180-9001			EASTERN MEDITERRANEAN UNIVERSITY MECHANICAL ENG. DEPT.
	NAME	SIGNATURE	DATE
DRAWN BY	LASISI ENIOLA MUHAMMAD	LMD	03/06/22
CHECKED BY	ASST. PROF. DR. QASIM ZEESHAN		07/06/22
SCALE:	2:1	MATERIAL:	
TITLE:	SERVOMOTOR		
PART NO.	1-2-1		

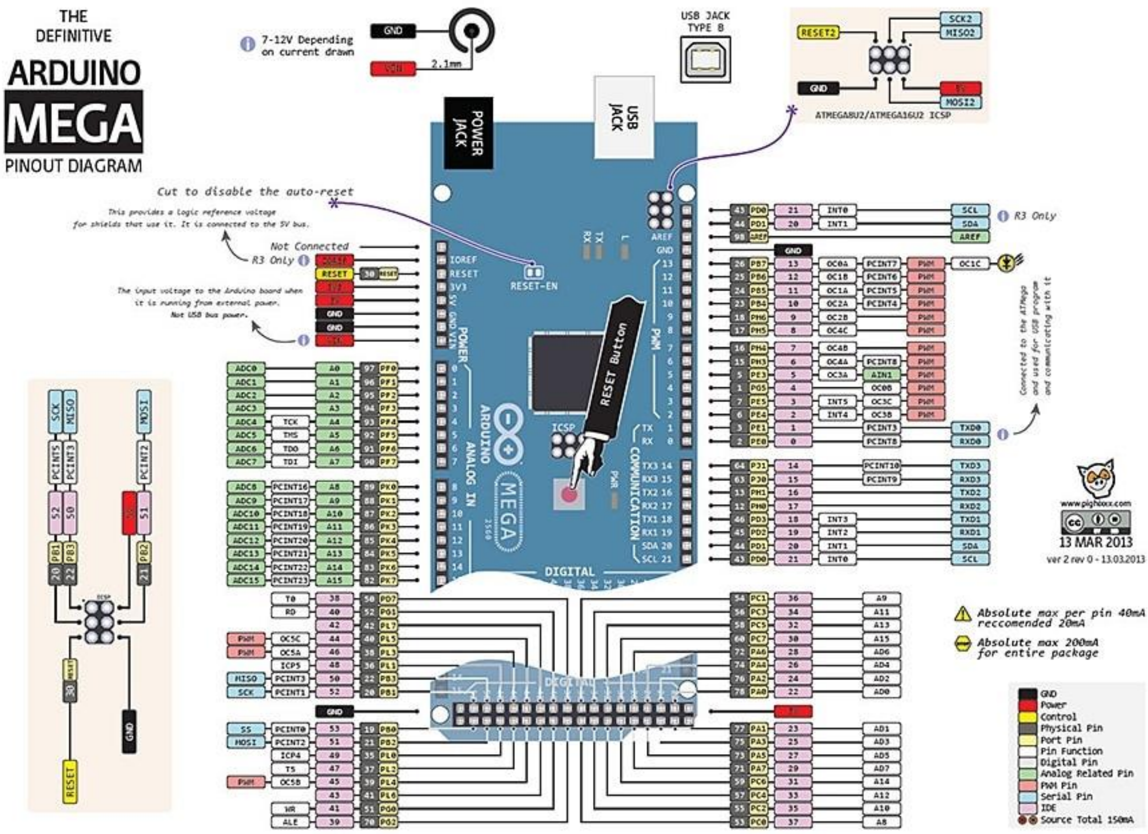
APPENDIX F: Rechargeable Batteries

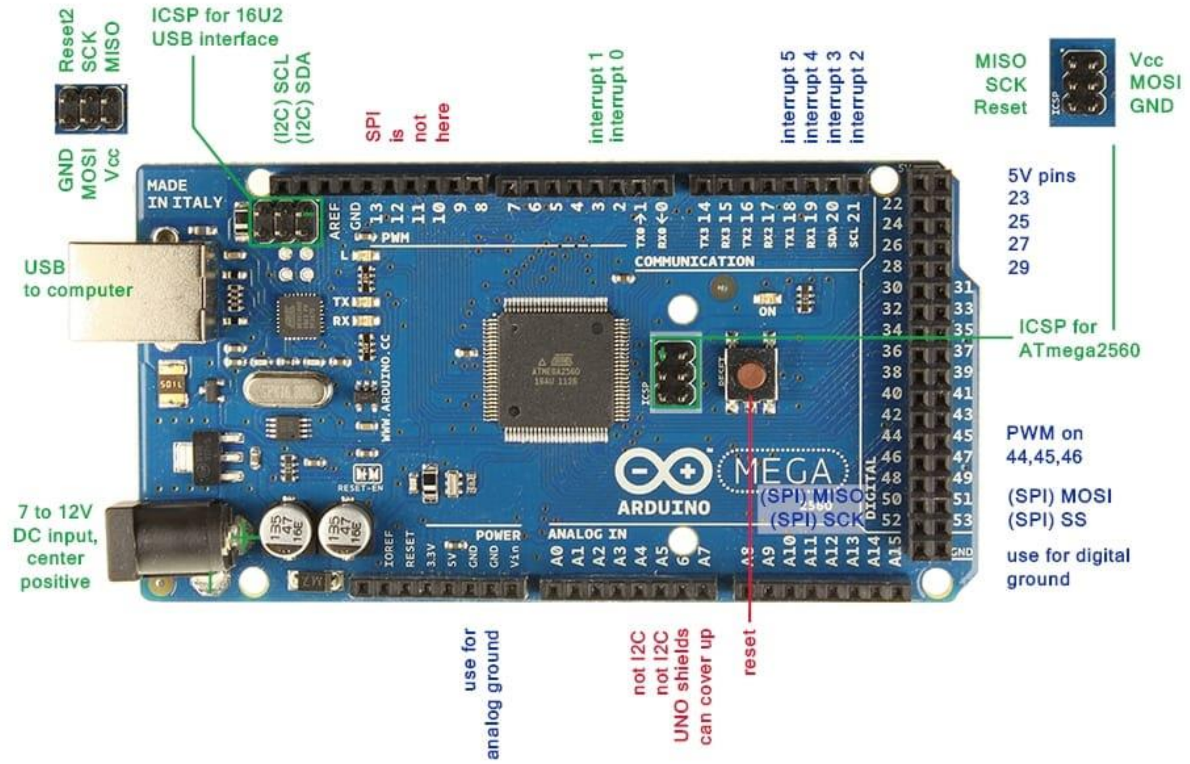
Specifications	Lead Acid	NiCd	NiMH	Li-ion[1]		
				Cobalt	Manganese	Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

Source: https://batteryuniversity.com/article/bu-107-comparison-table-of-secondary-batteries

APPENDIX G: Data Sheets






Reset2
SCK
MISO
GND
MOSI
Vcc
ICSP for 16U2
USB interface
(I2C) SCL
(I2C) SDA
SPI
is
not
here
interrupt 1
interrupt 0
interrupt 5
interrupt 4
interrupt 3
interrupt 2
MISO
SCK
Reset
Vcc
MOSI
GND
5V pins
23
25
27
29
USB
to computer
ICSP for
ATmega2560
PWM on
44,45,46
(SPI) MOSI
(SPI) SS
use for digital
ground
7 to 12V
DC input,
center
positive
(SPI) MISO
(SPI) SCK
use for
analog ground
not I2C
not I2C
UNO shields
can cover up
reset

DS3225 6V 25KG RC Coreless Digital Servo

1, Apply Environmental Condition

No.	Item	Specification
1-1	Storage Temperature Range	-30 C.degree to 80 C.degree
1-2	Operating Temperature Range	-15 C.degree to 70 C.degree
1-3	Operating Voltage Range	4.8-6.8V

2, Mechanical Specification

No.	Item	Specification
2-1	Size	40*20*40.5mm
2-2	Net weight	60g
2-3	Gear ratio	275
2-4	Bearing	Double bearing
2-5	Servo connecting wire	300+/-5mm
2-6	Motor	3-poles
2-7	Waterproof level	IP66

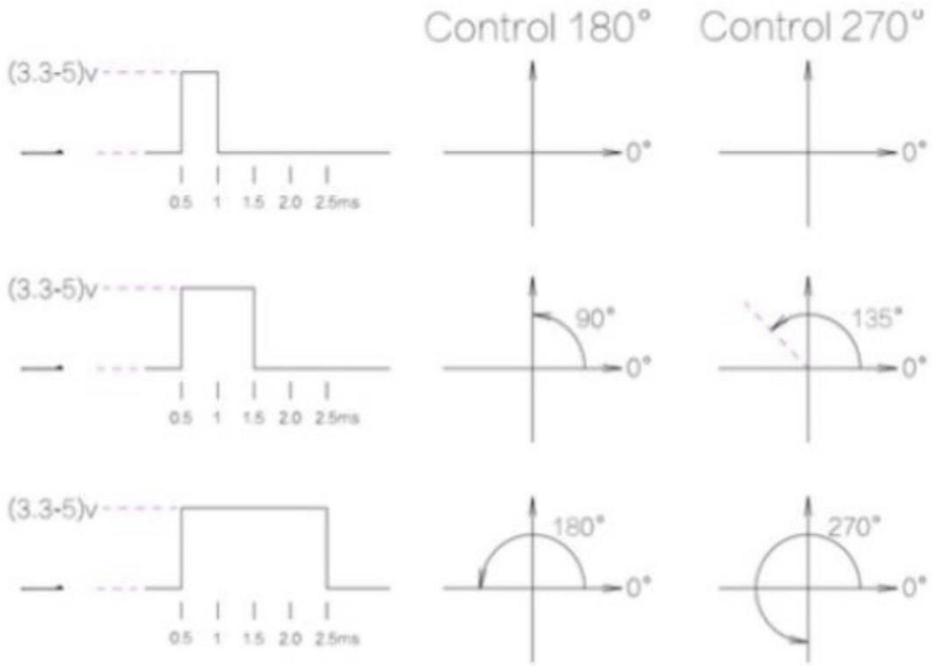
3, Electrical Specification

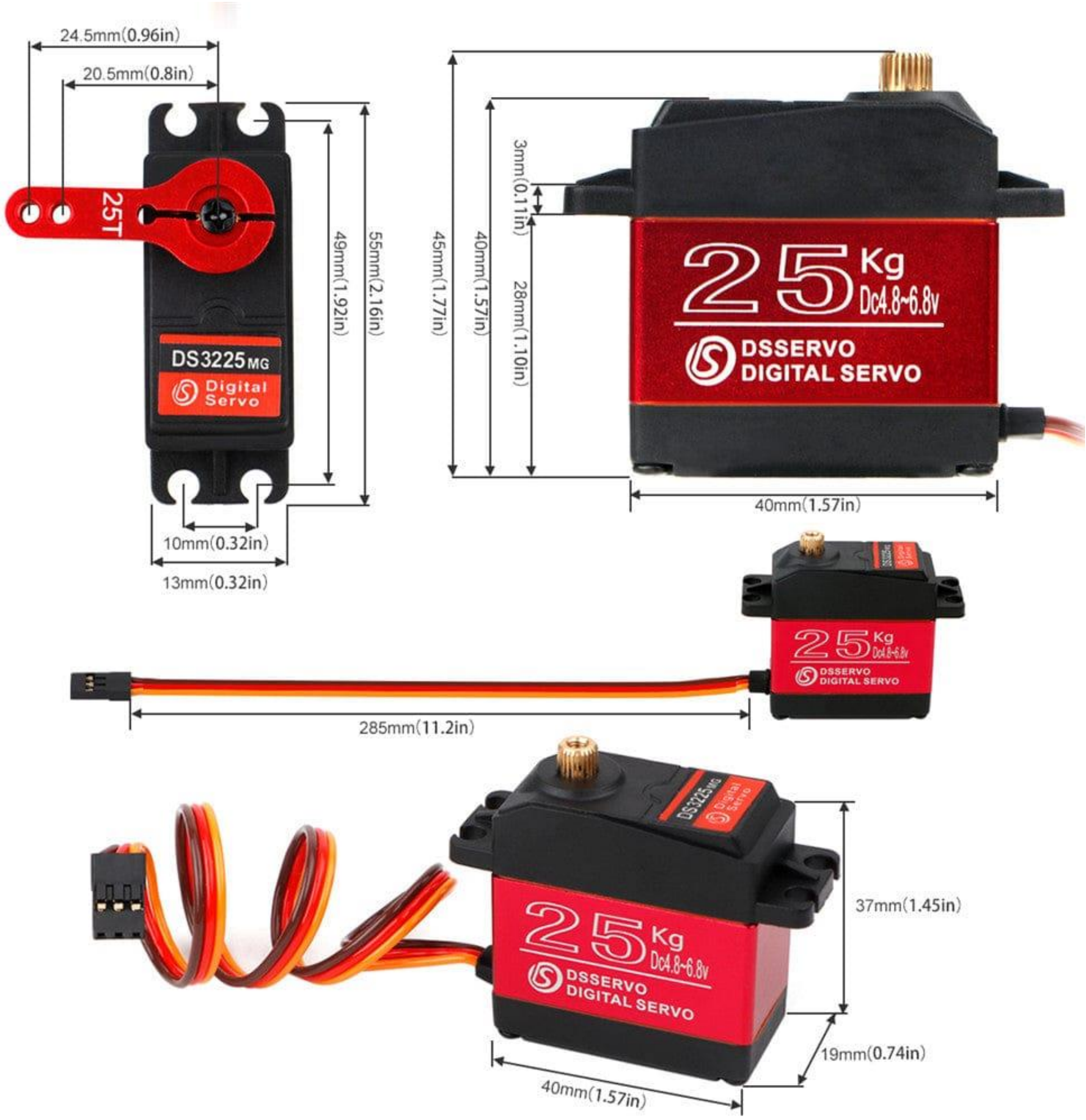
No.	Item	5V	6.8V
3-1	Idle current (at stopped)	4mA	5mA
3-2	Operating Speed (at no load)	0.15s/60°	0.13s/60°
3-3	Stall torque (at locked)	21kg-cm	24.5kg-cm
3-4	Stall current (at locked)	1.9A	2.3A

4, Control Specification

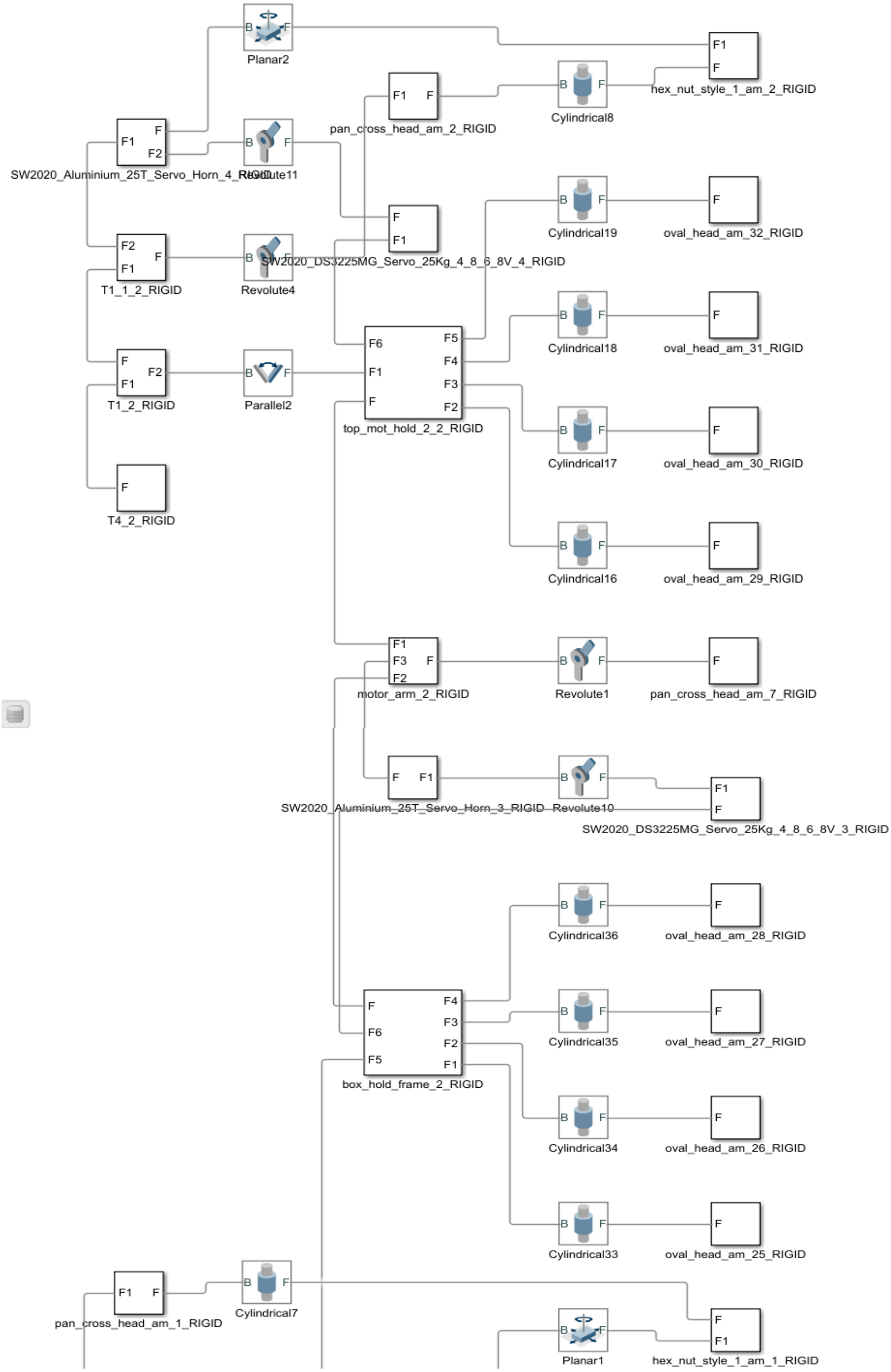
No.	Item	Specification
4-1	Control system	PWM(pulse width modification)
4-2	Pulse width range	500 to 2500μ sec
4-3	Neutral position	1500μ sec
4-4	Running degree	180° or 270° (when 500 to 2500μ sec)
4-5	Dead band width	3 μsec
4-6	Operating frequency	50-330Hz
4-7	Rotating direction	Counterlockwire (when 500 to 2500μ sec)

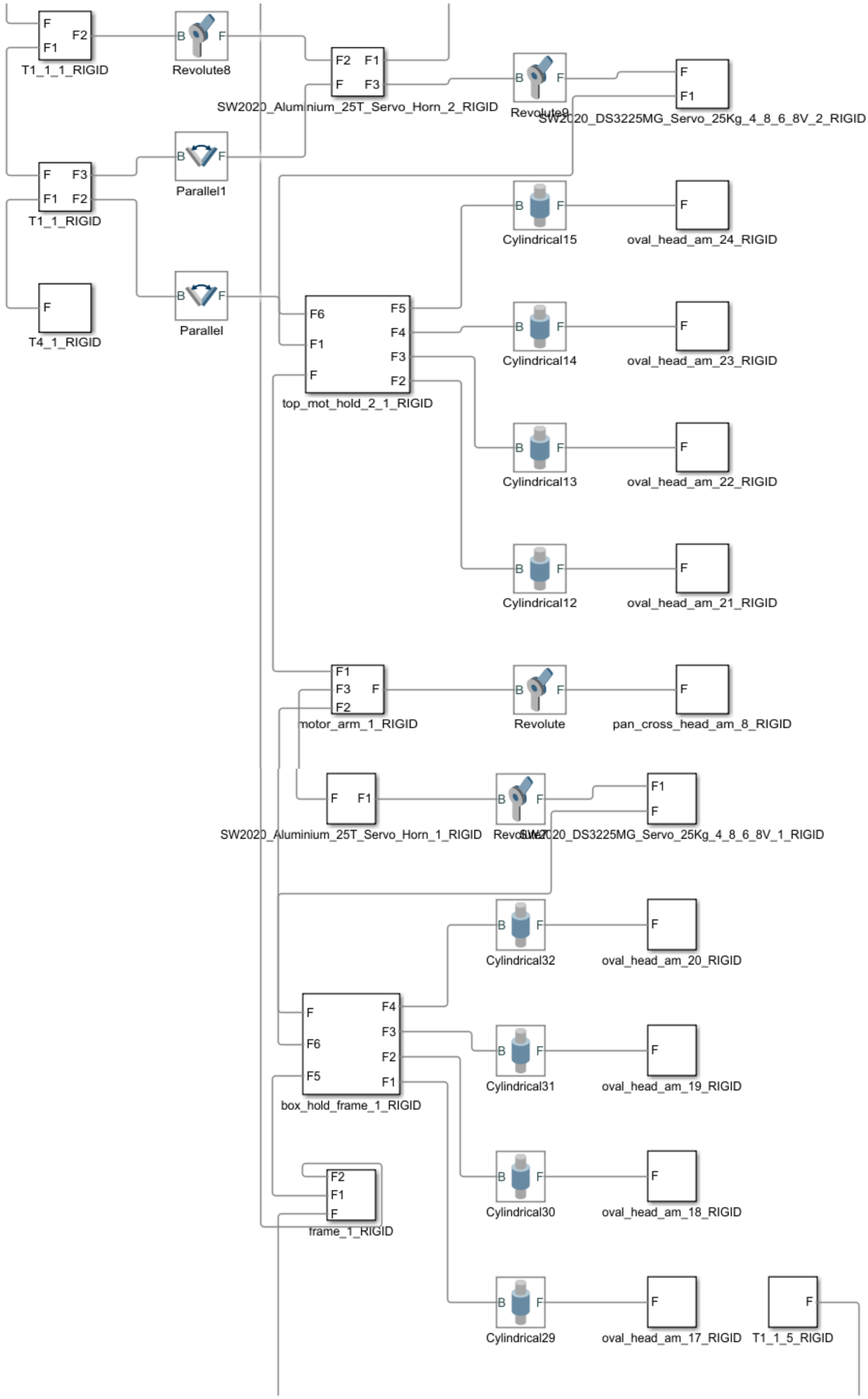
5, About PWM Control

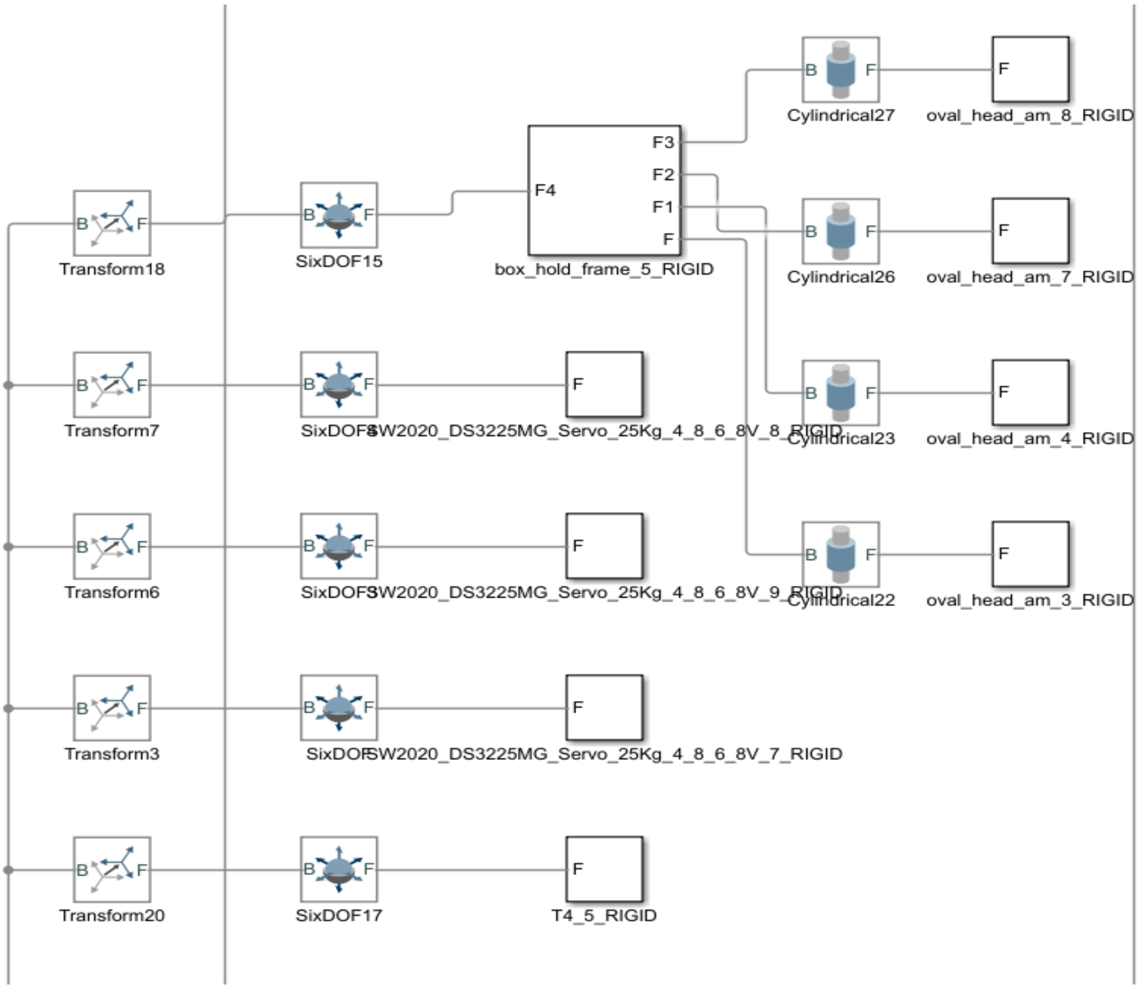


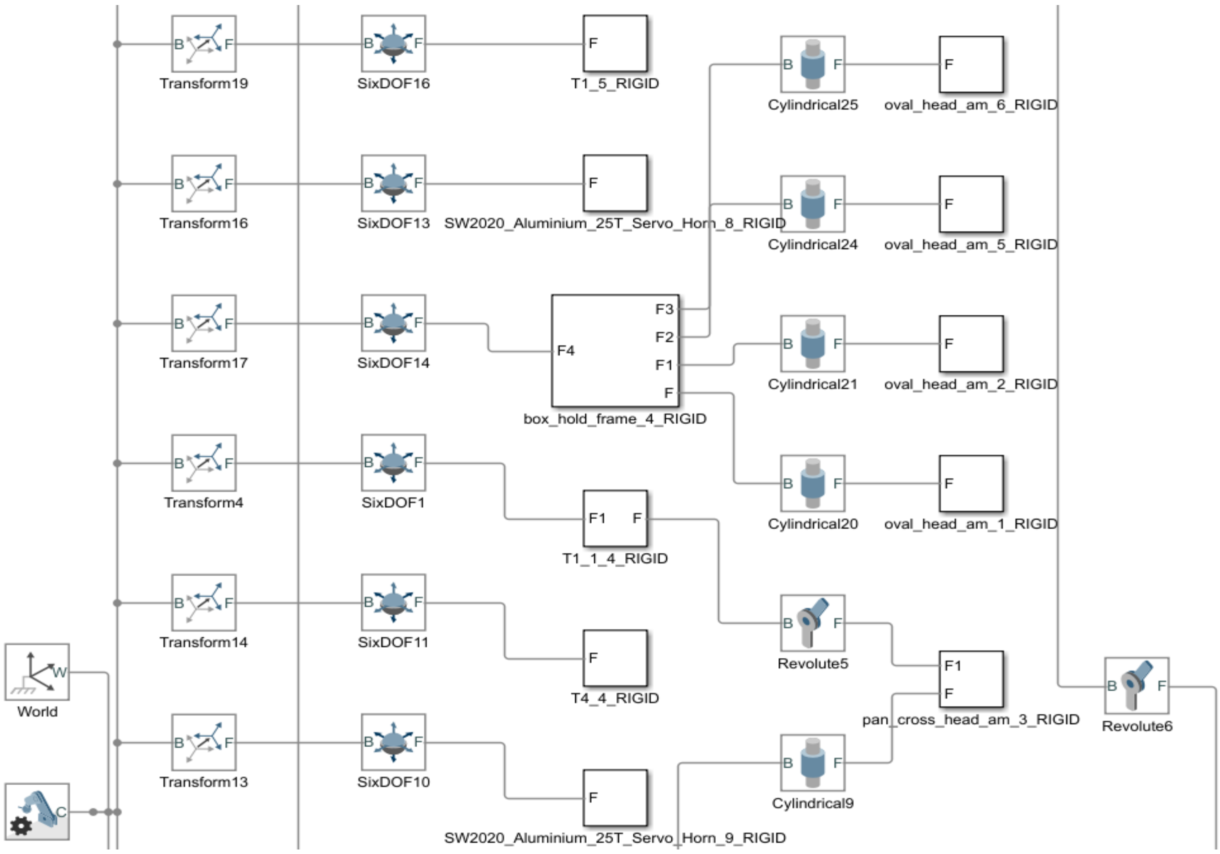

24.5mm(0.96in)
20.5mm(0.8in)
25T
DS3225MG
Digital Servo
49mm(1.92in)
55mm(2.16in)
10mm(0.32in)
13mm(0.32in)
45mm(1.77in)
40mm(1.57in)
3mm(0.11in)
28mm(1.10in)
25 Kg
Dc4.8~6.8v
DSSERVO
DIGITAL SERVO
40mm(1.57in)
285mm(11.2in)
37mm(1.45in)
19mm(0.74in)
40mm(1.57in)

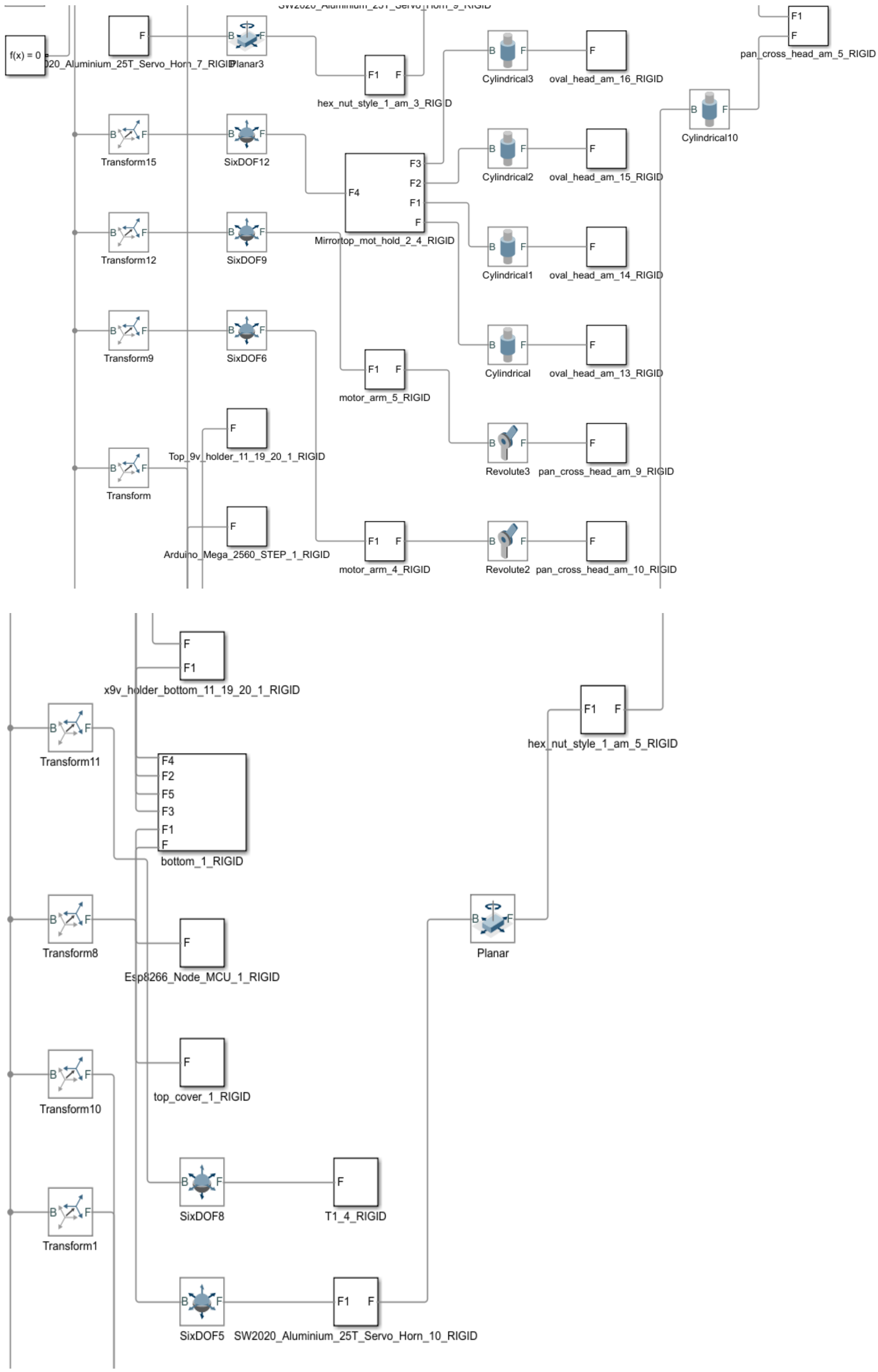
APPENDIX H: Simulink Block Model

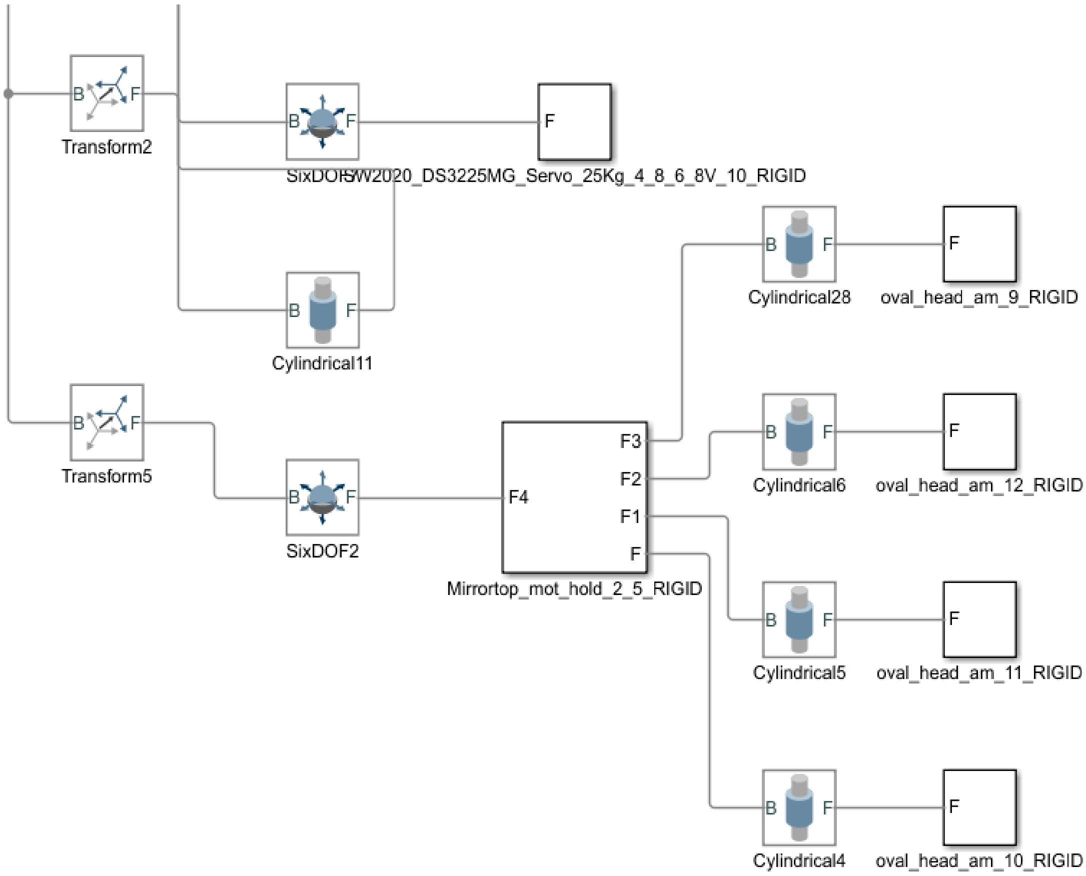



T1_1_1_RIGID
Revolute8
SW2020_Aluminium_25T_Servo_Horn_2_RIGID
Revolute9
SW2020_DS3225MG_Servo_25Kg_4_8_6_8V_2_RIGID
T1_1_RIGID
Parallel1
Cylindrical15
oval_head_am_24_RIGID
T4_1_RIGID
Parallel
top_mot_hold_2_1_RIGID
Cylindrical14
oval_head_am_23_RIGID
Cylindrical13
oval_head_am_22_RIGID
Cylindrical12
oval_head_am_21_RIGID
motor_arm_1_RIGID
Revolute
pan_cross_head_am_8_RIGID
SW2020_Aluminium_25T_Servo_Horn_1_RIGID
Revolute7
SW2020_DS3225MG_Servo_25Kg_4_8_6_8V_1_RIGID
Cylindrical32
oval_head_am_20_RIGID
box_hold_frame_1_RIGID
Cylindrical31
oval_head_am_19_RIGID
Cylindrical30
oval_head_am_18_RIGID
frame_1_RIGID
Cylindrical29
oval_head_am_17_RIGID
T1_1_5_RIGID

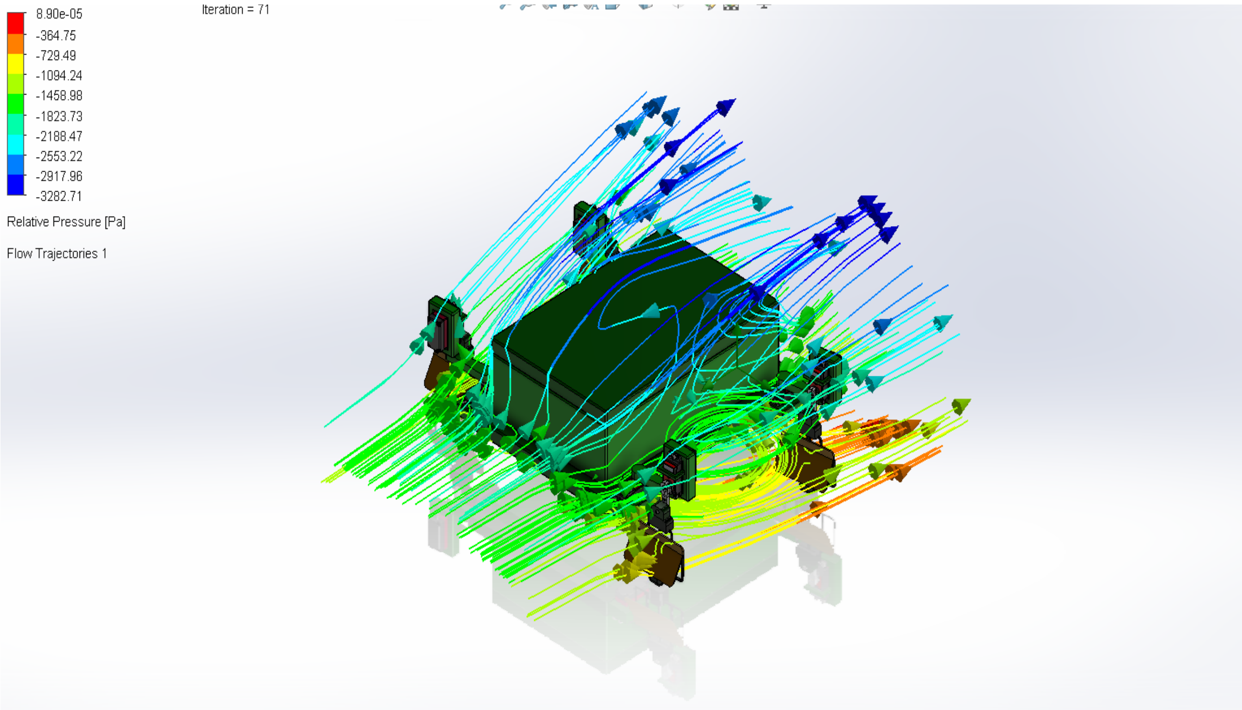

Transform18
Transform7
Transform6
Transform3
Transform20
SixDOF15
SixDOF17
T4_5_RIGID
box_hold_frame_5_RIGID
F4
F3
F2
F1
F
SW2020_DS3225MG_Servo_25Kg_4_8_6_8V_8_RIGID
SW2020_DS3225MG_Servo_25Kg_4_8_6_8V_9_RIGID
SW2020_DS3225MG_Servo_25Kg_4_8_6_8V_7_RIGID
Cylindrical27
Cylindrical26
Cylindrical23
Cylindrical22
oval_head_am_8_RIGID
oval_head_am_7_RIGID
oval_head_am_4_RIGID
oval_head_am_3_RIGID

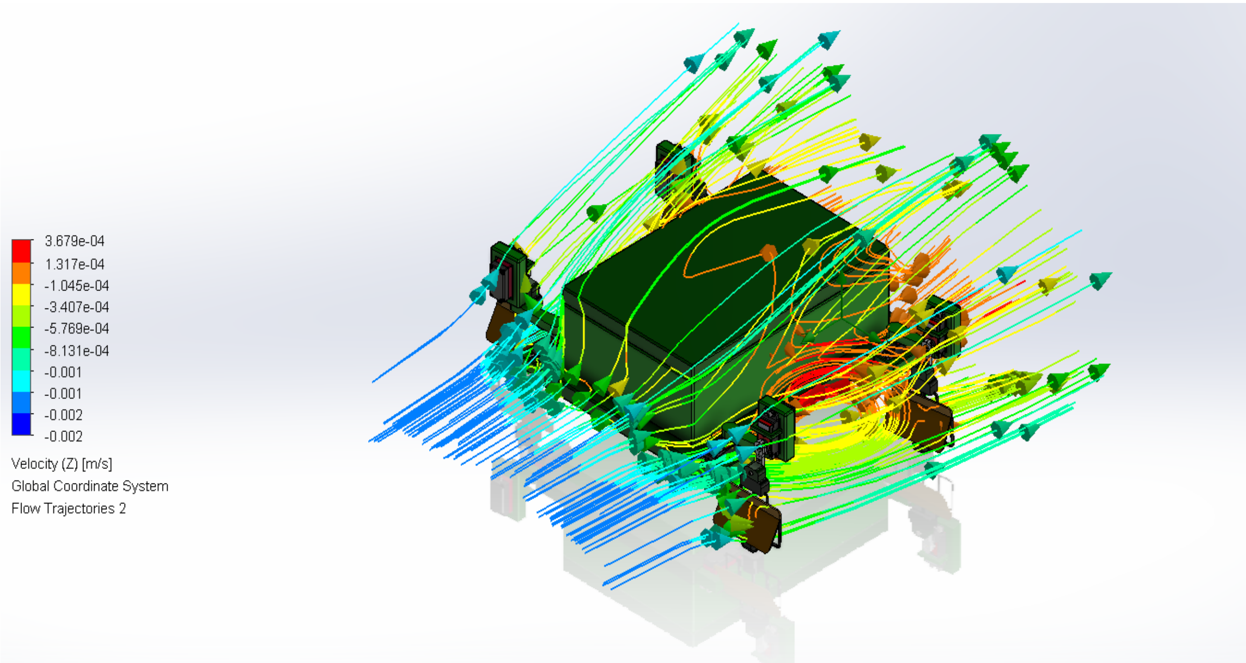

World
Transform19
Transform16
Transform17
Transform4
Transform14
Transform13
SixDOF16
SixDOF13
SixDOF14
SixDOF1
SixDOF11
SixDOF10
T1_5_RIGID
SW2020_Aluminium_25T_Servo_Horn_8_RIGID
box_hold_frame_4_RIGID
T1_1_4_RIGID
T4_4_RIGID
SW2020_Aluminium_25T_Servo_Horn_9_RIGID
Cylindrical25
Cylindrical24
Cylindrical21
Cylindrical20
Cylindrical9
Revolute5
Revolute6
oval_head_am_6_RIGID
oval_head_am_5_RIGID
oval_head_am_2_RIGID
oval_head_am_1_RIGID
pan_cross_head_am_3_RIGID

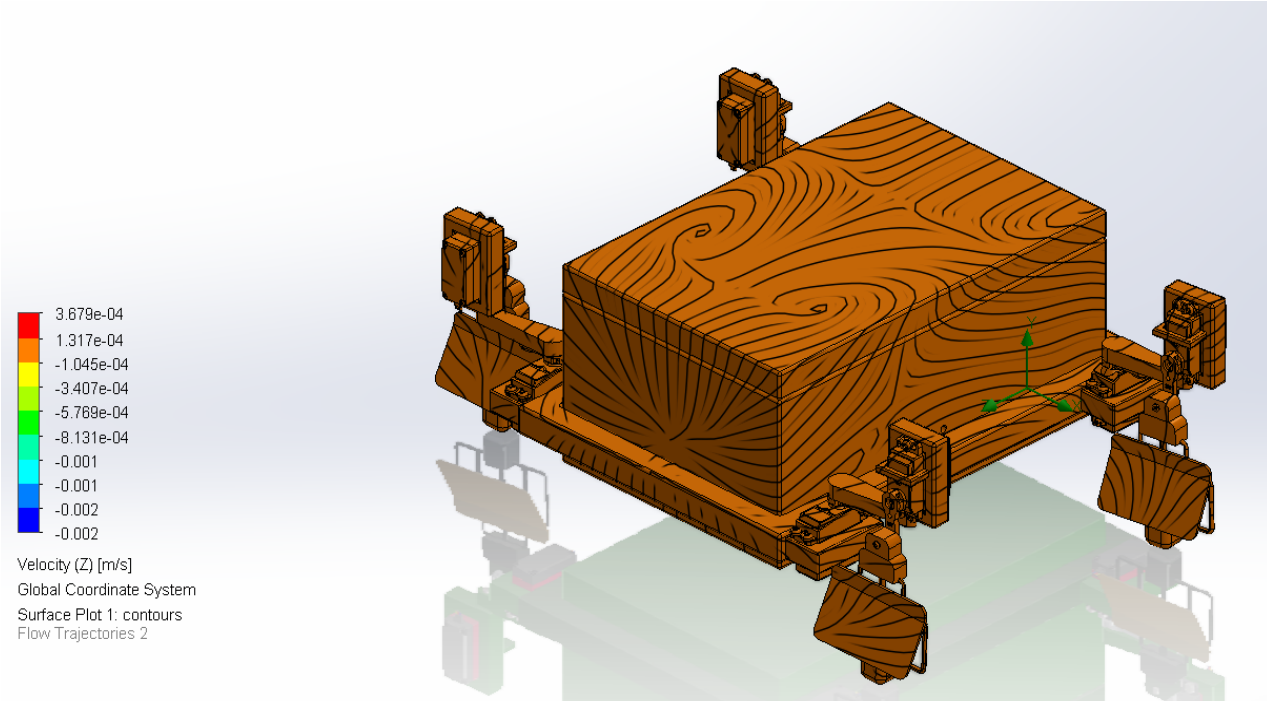

f(x) = 0
F
Planar3
F1 F
hex_nut_style_1_am_3_RIGID
Cylindrical3
oval_head_am_16_RIGID
F1
F
pan_cross_head_am_5_RIGID
Cylindrical10
Transform15
SixDOF12
F3
F2
F1
F4
F
Mirrortop_mot_hold_2_4_RIGID
Cylindrical2
oval_head_am_15_RIGID
Transform12
SixDOF9
Cylindrical1
oval_head_am_14_RIGID
Transform9
SixDOF6
motor_arm_5_RIGID
Cylindrical
oval_head_am_13_RIGID
Top_9v_holder_11_19_20_1_RIGID
Revolute3
pan_cross_head_am_9_RIGID
Transform
Arduino_Mega_2560_STEP_1_RIGID
motor_arm_4_RIGID
Revolute2
pan_cross_head_am_10_RIGID
x9v_holder_bottom_11_19_20_1_RIGID
Transform11
hex_nut_style_1_am_5_RIGID
F4
F2
F5
F3
F1
F
bottom_1_RIGID
Transform8
Esp8266_Node_MCU_1_RIGID
Planar
Transform10
top_cover_1_RIGID
SixDOF8
T1_4_RIGID
Transform1
SixDOF5
SW2020_Aluminium_25T_Servo_Horn_10_RIGID

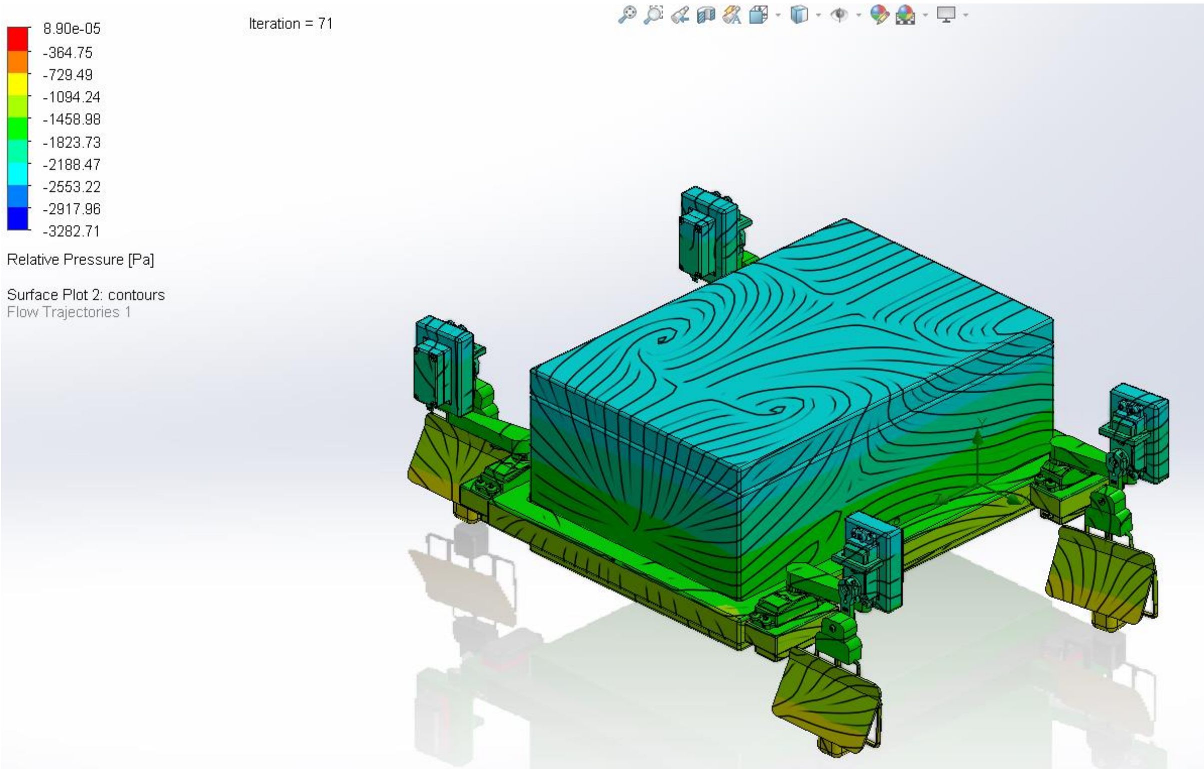

Transform2
SixDOF
SW2020_DS3225MG_Servo_25Kg_4_8_6_8V_10_RIGID
Cylindrical11
Transform5
SixDOF2
Mirrortop_mot_hold_2_5_RIGID
Cylindrical28
oval_head_am_9_RIGID
Cylindrical6
oval_head_am_12_RIGID
Cylindrical5
oval_head_am_11_RIGID
Cylindrical4
oval_head_am_10_RIGID

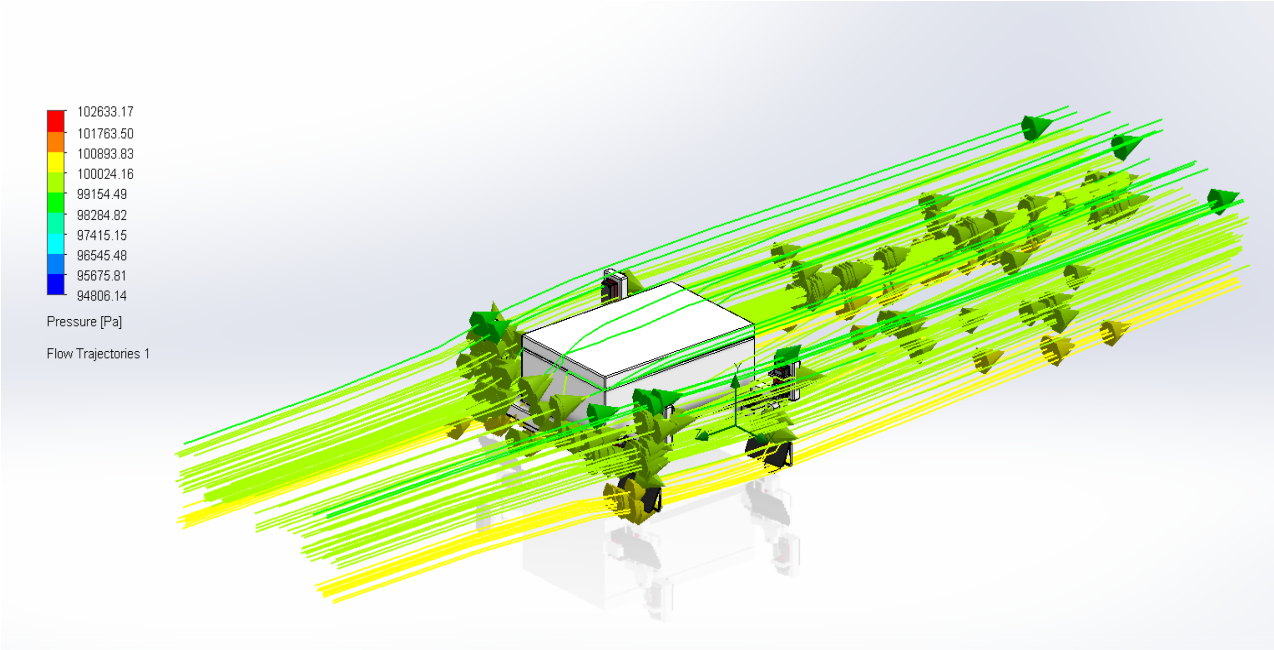
APPENDIX I: Flow Simulation Results






3.679e-04
1.317e-04
-1.045e-04
-3.407e-04
-5.769e-04
-8.131e-04
-0.001
-0.001
-0.002
-0.002
Velocity (Z) [m/s]
Global Coordinate System
Surface Plot 1: contours
Flow Trajectories 2


Iteration = 71
8.90e-05
-364.75
-729.49
-1094.24
-1458.98
-1823.73
-2188.47
-2553.22
-2917.96
-3282.71
Relative Pressure [Pa]
Surface Plot 2: contours
Flow Trajectories 1


102633.17
101763.50
100893.83
100024.16
99154.49
98284.82
97415.15
96545.48
95675.81
94806.14
Pressure [Pa]
Flow Trajectories 1

APPENDIX J: Codes

```
#include<Servo.h>

const int num_of_motors  = 3;

Servo motor[num_of_motors], motor4;

int p,n, i=0;

int onstate=0;

int turn = 0;


void setup() {

  for (i  = 0; i < num_of_motors; i++) {

    motor[i].attach(9  + i);

  }

  motor4.attach(6);

  Serial.begin(9600);

}


void loop(){


 if (Serial.available())

 {

  char data=Serial.read();

  data == '1' ? onstate = 1 : onstate = 0;

 }


  if (onstate && turn == 0)

  {

    for (p=0;p<90;p++)

    {

      n = 90 - p;
```

```
      motor[0].write(p);

      motor[1].write(n);

      motor[2].write(p);

      motor4.write(n);

      delay(5);

      }

      turn  = 1;


  }

  else if (onstate && turn == 1) {

    for (p=90;p>=1;p--)

    {

      n = 90 - p;

      motor[0].write(p);

      motor[1].write(n);

       motor[2].write(p);

        motor4.write(n);

         delay(5);

      }

    turn = 0;


  }

  else if (!onstate)

  {

    //motor.write(p);

  }


}
```

APPENDIX K: Team Roles

Project Leader: Precious Philip-Ifabiyi

Designers: Jamal Khader, Muhammad Lasisi

Materials specialist: Jonathan Olukare

Analyst: Joseph Adweka

Technician: Precious Philip-Ifabiyi

APPENDIX L: 3D Printing G-CODE

Because of the length of the G-codes, the codes are part of the files submitted with the project document.