MECH 3401 – Mini Design 2

Energy Conversion Through Renewable Alternative - Final Design Report (Tutorial 8 Group 1)

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Abstract

The energy crisis has continued to worsen in third-world countries and the financial separation between these countries and first-world countries is continuing to grow. These third-world countries lack the financial and natural resources to deal with the energy demands of their growing populations. These regions require a device which is able to harness energy without taking up large amounts of space to be implemented to fuel these growing communities. One of the most suitable implementation candidates is ocean-based solar panel systems. These devices use the sun's energy to fuel society over water, meaning that the open land can then be used for societal expansion allowing such countries to develop further. This report outlines the engineering design process of a water-based solar panel solution to be used in these developing countries. This write-up includes various potential designs, design improvements, relevant design calculations, design manufacturing as well as optimization and testing. The expectation is that the design will be able to harness the sun's energy to a high enough degree of efficiency such that enough power can be generated to power itself and society.

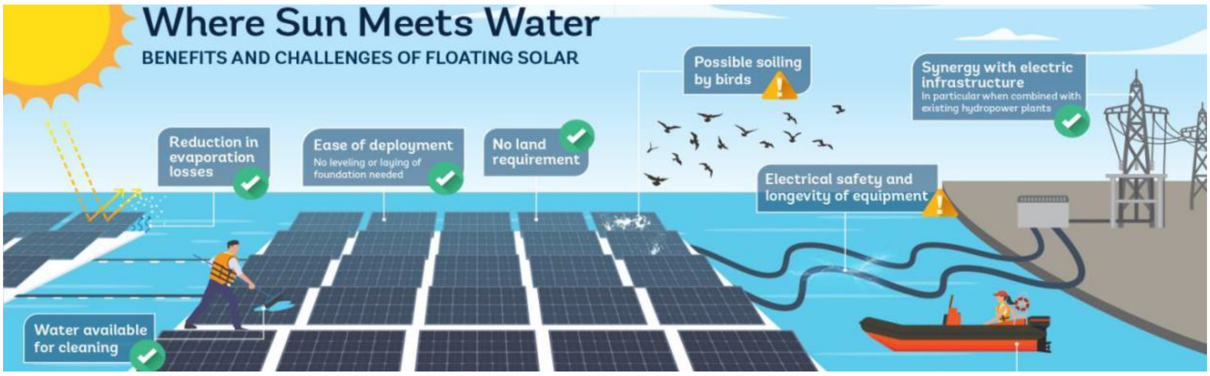
Problem Background and Context

Introduction

With the human population continuing to increase exponentially, society has struggled to meet the energy demands of its occupants leaving millions of people without an adequate energy source needed for survival. This ongoing problem has become such a large-scale issue to the point where 10% of the world's population lacks access to energy for a prolonged period of time (Cozzi 1). In addition to this, space, and financial resources available for societal expansion have further restricted the government from the large-scale implementation of energy plants which may be used to combat this ongoing energy crisis. With the number of individuals without energy increasing yearly, the implementation of a solution which is affordable, sustainable, and reliable is needed urgently before the scale of the ongoing energy crisis worsens. A strong solution would allow for large amounts of energy to be conserved and used in these third-world countries allowing its occupants to gain access to the energy needed for survival.

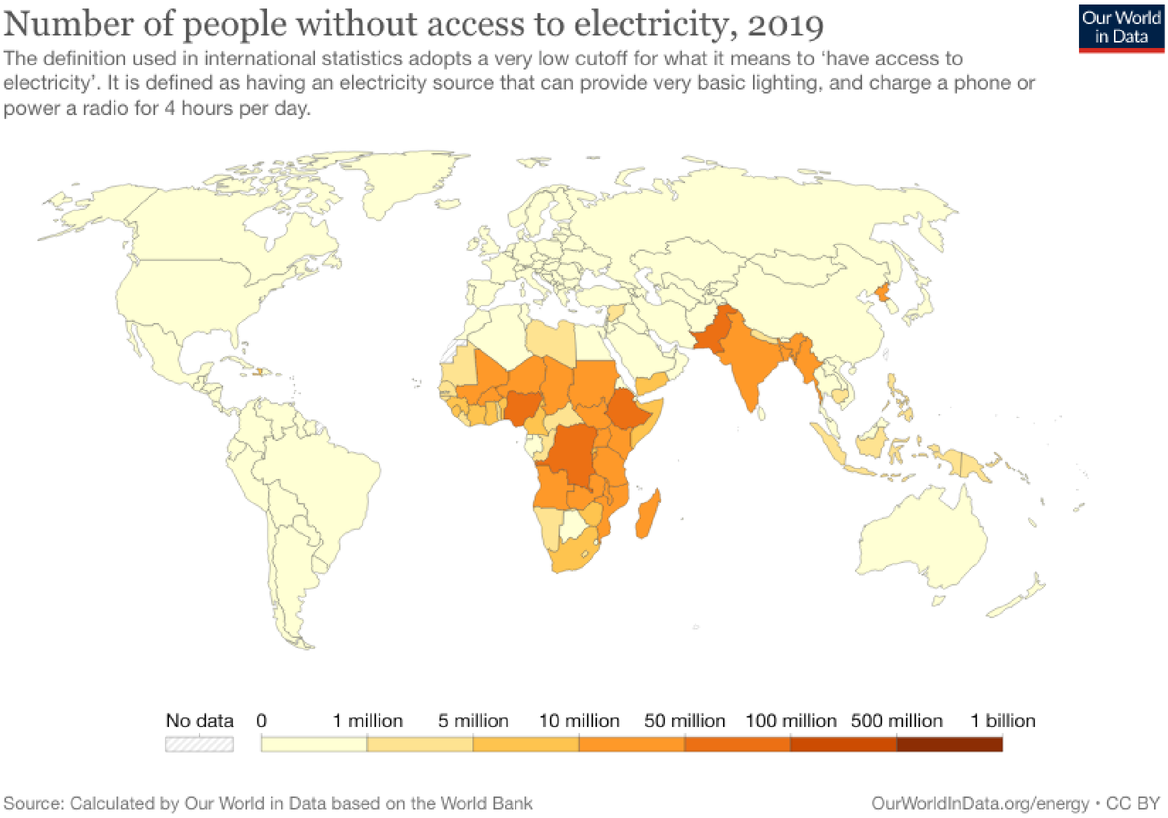
Design Background

One of the most suitable candidates for potential implementation into these areas of interest is solar panels. Solar panels are one of the few energy sources that are capable of meeting the criteria needed for a successful solution. These sources of energy are very versatile and can be water-based as well, meaning more space can be saved allowing for more land to be used for societal expansion. By implementing water-based solar panels to resolve the ongoing energy crisis, a mechanism that allows for stable flotation will be required to manufacture before design implementation. Aside from the benefits of saving space for the usage of society, water-based solar panels also have several other benefits that would allow for a strong, effective, and efficient solution. As water carries its own cooling properties, air currents which flow over the water would assist in cooling down the panels which help with the efficiency and lifespan of the device. Solar panels usually work better when they are cooled as it reduces hazards such as overheating and corrosion allowing for a much more long-term solution (Baker 2). It also keeps the land more conserved for other structures which is beneficial in areas with a high demand for infrastructure or those undergoing large population growth. In terms of the location of the third world country where the design is going to be implemented, these areas usually have a much larger frequency for natural disasters including earthquakes, landslides, and wildfires. Adding a water-based solution would reduce the damage potential of the mechanism making it a much more long-term solution. The water-based solar panel solution presents a cheap and reliable solution, suitable for the given task at hand. (Baker 2).



Implementation Context

For the implementation of this project, the primary area of interest would be areas around the world which lack the resources to provide energy for its community. This would primarily target coastal regions of Africa where enough water is available to implement the ocean-based solar panel system. These would include countries such as Nigeria, Kenya, and Tanzania. These countries lack the resources needed to implement large-scale energy-based programs due to poor economic stability, lack of natural resources available and environmental conditions. Implementing the water-based solar panel solution does not require major resources for implementation, it is not as costly as other energy projects such as coal and hydro plants and is able to reach full functionality with the given environmental conditions. This implementation is required due to the increase in the financial gap between first and third-world countries making it a challenge for the government to adequately provide for its residents. This overall makes it much more difficult to preserve life due to insufficient energy which is typically used for societal needs, including healthcare and communication.



2.0 Stakeholder Analysis

For the implementation of such a design to be considered a success, it is important that the numerous stakeholders involved in the implementation of the project are satisfied to ensure that the design meets the implementation stage of the project. The various stakeholders as well as their interest, influence, attitude and ranking within the project as evaluated in Table 1 below.

Stakeholder	Needs and Interest	Project Influence	Attitude	Importance Ranking
Government (Environmental, economic, and social regulators)	Ensure that the project follows respective national guidelines in terms of social, economic, and environmental impacts.	Determine that the project is following legal specification and decide whether that project can be initialised. This stakeholder can also become a potential funding source for the project.	Impartial in decision making as this entity is interested in making sure rules are followed appropriately. Views on the project will become favourable if positive outcomes are achieved.	2
Project team	Create an effective mechanism to provide electricity in a sustainable way for those who need it.	The team members are the project managers and will investigate and employ others to fulfil the project requirements.	Effective leadership from the team must be transmitted to other stakeholders of the project to guarantee success in the project.	1
Local community	This is the target user of the project. They demand availability of electricity in their households.	They will dictate how much electricity is needed and if the project parameters would have any negative impact on their lives.	Supportive as the implementation of the project should initiate energy distribution.	3
Manufacturers & Local Utility companies	Receive monetary benefits from providing the team with the needs for a successful project.	Facilitate distribution of materials required in the project. These will be essential to decrease the timeline of the construction phase.	Neutral as their sole purpose in this project is to provide help in terms of logistics.	4
Contractors	Ensure the project is completed under the determined timeline. Receive instruction on product creation through schematics	Has an advisor role in the project. This stakeholder provides tools to the project team to optimise the timeline of the design process.	Interested in the project as their job is to guarantee time efficiency in the development phase of the project.	6
External Investors (UN Capital Development Fund, Work Bank, International Monetary Fund)	Make sure that the money they invest on the project provides any sort of positive outcome to them. This comes from marketing benefits, sponsorship, or monetary payback.	Improve the quality or quantity of the material the team will receive a higher amount of funding to invest more high-end materials.	Interested as the money being provided to the project will benefit in different aspects.	5

To better accommodate the needs of the various stakeholders involved in the implementation of this project, it is also very important that each of their importance is ranked to ensure that the most important stakeholders have the highest degree of satisfaction. Based on the ranking above, the project team was the highest rank. This is due to their importance in implementation as the design both starts and ends with this stakeholder. Next is the government as this stakeholder will oversee all operations and can approve and reject the design implementation. For implementation to take course, the government must be satisfied. The third most important is the local community. As these devices are being designed to meet their energy demands, it is important that their needs are met for a successful solution to take place. This is followed by manufacturers and investors. These parties provide the project with material and financial benefits so they must be accommodated to ensure their constant contribution to the project. Though contractors are important, they are not prevalent after the design is created and they don't have a major influence on decision-making. This is because they usually receive financial or monetary benefits from working on the project.

It is also essential that the process in which stakeholders are informed is evaluated to ensure succession. This can be computed through the usage of a stakeholder engagement analysis and Power/interest grid shown in the tables below.

Stakeholder	**Unaware**	**Resistant**	**Neutral**	**Supportive**	**Leading**
Government			X		
Project team					X
Local community				X	
Utility companies and Manufacturers				X	
Solar Panel Manufacturers				X	
Contractors				X	
External Investors				X	

Keep Satisfied	**Manage Closely**	**Monitor**	**Keep Informed**
• Government	• Project team • Local community • Solar panel manufacturers • External Investors	• Local utility companies	• Contractors

Design Objectives

The goal of this design is to assist the residents of third-world countries in achieving a sustainable and long-term energy solution to fuel society for the foreseeable future. In order to better understand the needs that the design needs to accomplish during implementation, design objectives can be split into primary and secondary objectives to evaluate the importance of different aspects which will go into the design. The primary objective of this project is to design and construct an IoT-based floating Sun Tracking Solar panel configuration that will provide individuals in third-world countries with a stable energy source. The primary target stakeholder which this design is being implemented for is the residents of these developing countries. For this objective, the solar panel configuration must be able to maximise its sun absorption by keeping the panels perpendicular to the sun's rays at any given time. The assembly must also be able to deliver and store the energy in the battery facility to which the configuration will be connected. Lastly, the base of the design must be sturdy enough to keep the entire mechanism at full efficiency to ensure that energy is being collected to the highest degree of effectiveness. By effectively achieving this design objective the general reason for the implementation would be satisfied.

In addition to this primary objective, there are also numerous secondary objectives which could be implemented into the design to meet the needs of various secondary stakeholders making the overall design more suitable for multiple parties involved in the design process. For this design, it is important to be considerate about the materials used within the mechanism to ensure that the design can last for a longer period, lowering the repair costs for the design team. In other words, the durability of the solution needs to be maximized. This could include using corrosion-resistant material for the base or using hydrophobic material on the solar panels to ensure that they adhere to design specifications for a longer period. Fewer repairs mean more money saved for the design team after initial implementation. In the instance that a repair is needed, it is also important that the mechanism has ease of accessibility in terms of repairs. This design objective would allow the contractors and local utility companies to fix the assembly much faster and more efficiently in the event there are damages. This could be done by adding various sensors to the design to indicate if there are any part failures, or by creating a simplistic design which is easy to repair. Another design objective would be to minimize environmental impact to ensure that the local wildlife can continue to thrive without habitat loss or disruption. This would mean using materials that are not toxic to aquatic life and ensuring that the mechanism itself does lead to any type of pollution during its usage. Furthermore, it is important that the government approves the assembly to ensure that it is able to become fully operational. This would mean submitting adequate paperwork and ensuring that that design meets the bylaws and regulations that each country has for ocean-based structures. Lastly is to consider the local residents. It is important that the residents are accounted for not only through supplying energy but also the living conditions. It is important that the general mechanism does not disrupt the community. This can be done by making the assembly function silently to ensure that society is able to function without disruption. This would mean using motors in the design that do not emit large amounts of noise when the solar panel assembly is rotating towards the sun. It is important that these secondary objectives are fully implemented into the design to ensure the satisfaction of the various stakeholders involved in the project.

Before the design stage of the project, the demands of the various stakeholders need to be analysed and assessed to ensure that certain aspects of the design meet what is wanted from them. This allows for stakeholder satisfaction throughout the project's duration. Table 4 below illustrates the design requirements that need to be adhered to for the project to meet its stakeholder needs.

Requirement Type	Requirement	Source	Validation Approach and Timing
Functional	Convert sunlight into usable energy	• Local communities • Design Team • Manufacturers • Contractors	Will be validated once the design is created. The last check will occur after implementation in complete
Functional	float over the water (base density less then 997 kg/m^3)	• Local communities • Design Team • Contractors	Will be validated once the design is created. The last check will occur after implementation in complete
Performance	Solar Panel Efficiency - Polycrystalline mini-solar panels (15-20%)	• Local communities • Design Team • Manufacturers	Solar panels will be tested when acquired from the manufactures and last test will be after implementation
Performance	Motor Noise Suppression (Under 24 dBA)	• Local communities • Manufacturers • Contractors	Will be validated once the design is created. The last check will occur after implementation in complete
Interface	Sensor Input (Ultraviolet, Infrared or LDR sensor)	• Manufacturer • Design Team • Contractors	Sensors will be tested when acquired from the manufactures and last test will be after implementation
Interface	Positional Rotational Servo Motor (2-3 DC or AC Servo Motors)	• Manufacturer • Contractor • Design Team	Motors will be tested when acquired from the manufactures and last test will be after implementation
Regulatory	Water Licensing and Rights Guidelines	• Government • Design Team • Contractor	Guidelines must be evaluated before the design is constructed. Last check will be right before implementation completion
Regulatory	Environmental Regulations	• Government • Design Team • Manufacturer	Guidelines must be evaluated before the design is constructed. Last check will be right before implementation completion
Economic	Cost Efficient Design (under 200 dollar)	• Investors • Design Team • Contractors • Manufacturers	Budget will be managed prior to material purchasing. Last check will be completed after the design is constructed
Functional	Solar panel rotation mechanism	• Design Team • Manufacturers • Contractors	Will be validated once the design is created. The last check will occur after implementation in complete
Interface	Power supply provided by solar energy (18650 lithium-ion rechargeable cell)	• Design Team • Manufacturers • Contractors	Solar panels will be tested when acquired from the manufactures and last test will be after implementation

Design Constraints

To better understand the potential designs which could arise from this project, design constraints must be appropriately evaluated. This is to ensure that the various designs created during the conceptual design process of the project meet the mentioned constraints and can physically be implemented in the chosen environment. These potential constraints include technical, cost, regulatory or user limitations, implied by the conditions and environment that the mechanism is subject to function. Constraints can be separated into three major categories, technical constraints, budget constraints and environmental constraints. Technical constraints are limitations imposed on the design due to technical-related factors including available technology, software limitations and component quality. Budget constraints are limitations imposed on a financial level that limit the resources readily available for the project design. Environmental constraints are limitations posed by the environment of the implementation.

All constraint types must be evaluated to ensure that the chosen design can be implemented without issue.

Technical Constraints

In terms of technical constraints, there are various technical aspects which are limited by the design team. Firstly, the primary power source of this mechanism must be entirely automated. This would mean that the various solar panels, motors, and sensors need to be able to function on their own with little to no human interaction. This implies that all sensors and motors must be pre programmed before design implementation. The design team is also limited to the usage of solar panels from the manufacturer (as listed in the course outline) and the solar panel must not only provide power to the storage facility but also power itself to operate the various parts it's composed of. In terms of the technical constraints held by the manufacturer, the design is limited to the usage of a 150 mm x 75 mm Polycrystalline mini-solar panel with a power grade of 12 volts. The power supply and sensors are limited to a 18650 lithium-ion rechargeable cell and an IoT Arduino Uno kit. It is important that these technical constraints are met to create a suitable design going forward.

Budget Constraints

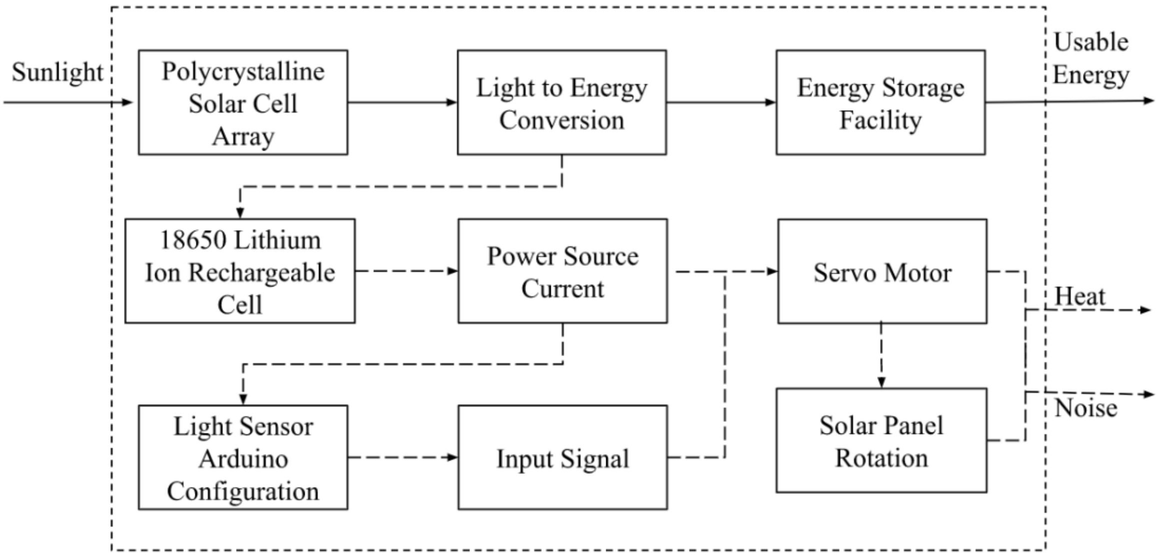
For budgeting-based constraints, it is important that the materials that go into this project can meet the financial constraints provided to the design team by the various sponsors on this project. According to the sponsors, 200 dollars are reserved for the purchasing of materials for this design. This money will go directly to the manufacturing of the base and rotation mechanism of the assembly. This will include the servo motor, gear assembly for the rotation mechanism and the general structure of the design. The Arduino kits and solar panels are available to be loaned when making a prototype design for this mechanism. It is important that a bill of materials is kept during the design process to ensure that these constraints are adhered to.

Environmental Constraints

Due to the selected environment in which the proposed solution is to be implemented in, it is important that the design can successfully operate with no issues under such conditions. For the prototype, the floating mechanism will be subjected to a small ruffle of water waves of a frequency of 2 Hz and an amplitude of 1-2 cm. This test would validate similar environmental conditions to that of the targeted area. The mechanism must be able to withstand this test for the design to reach 12 the complete implementation process. For a successful design to take place, all the above constraints must be adhered to in order to continue to the conceptual design stage of the project.

Functional Structure Diagram

A functional structure diagram provides a visual representation of the way in which various functions within a given product are depicted. These diagrams help illustrate how the many different interactions take place between the different mechanical elements within the design. The diagram is used to help the project team understand and improve their organisational structure, work processes, and decision-making processes. For this project, the function structure diagram is used on the solar panel configuration and rotational mechanism to review the various inputs and outputs of the parts used in the system. The figure below illustrates the functional structure diagram which will be used in the conceptual design phase further down the line.



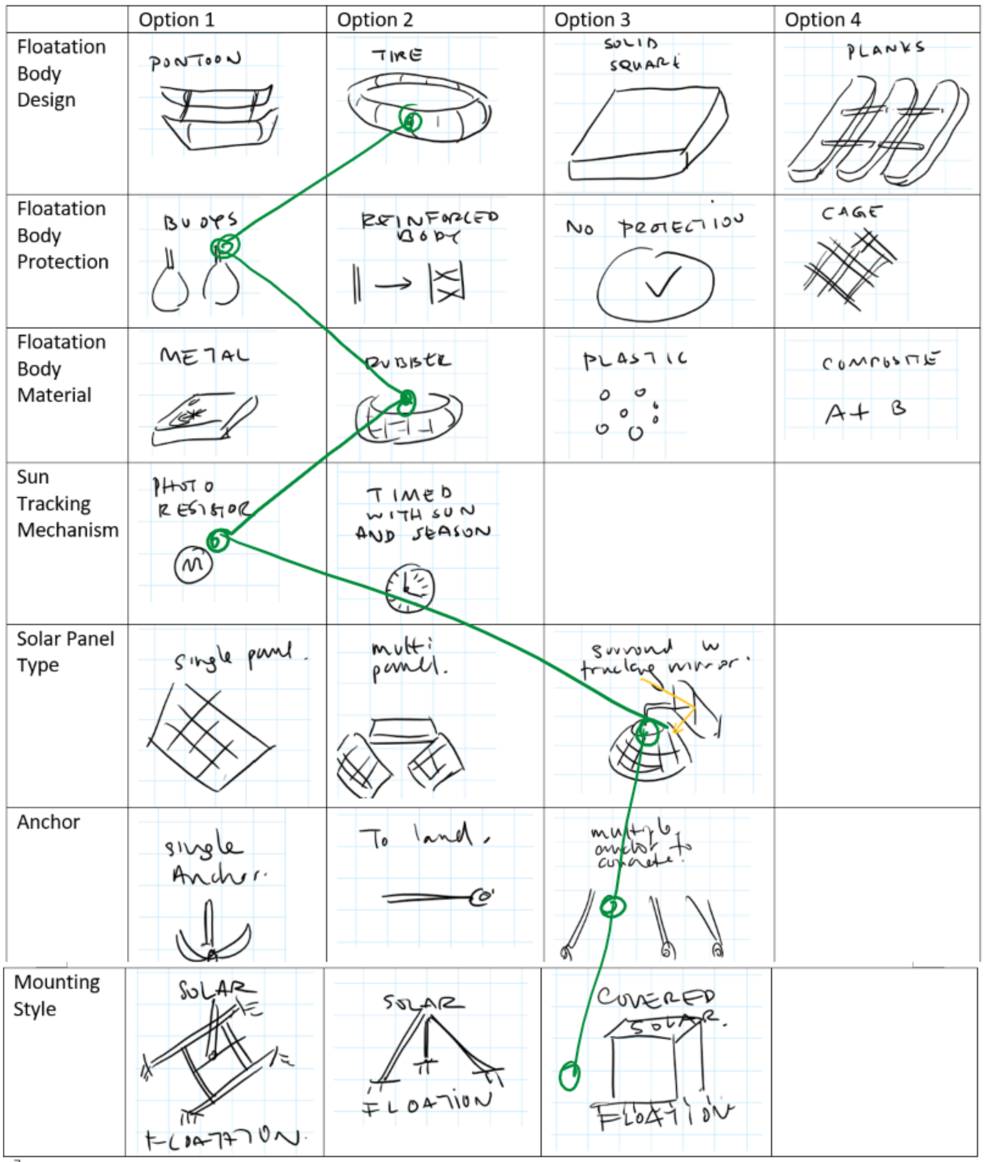
The functional structure diagram for this project only has one input. This is because one of the design constraints was for the design to be fully automated, meaning that no human interaction is required for this design. This means that there are not any input signals required for complete functionality. This mechanism has two main goals based on the functional structure diagram, one is to deliver power to the energy storage facility to provide usable energy to the community and two, to provide itself with energy for the rotating mechanism. These two functionalities come together to form the final design mechanism.

For the production of useful energy, the Polycrystalline Solar Cell Array absorbs light to begin the energy conversion process. These solar panels typically absorb light at 13-16% efficiency. It's through these solar panels that light can then be converted into electrical energy due to the chemical reaction between the solar cells and light, which cause electron displacement and ultimately creates electrical energy. This electrical energy is then sent to an energy storage facility where the energy will be stored for societal usage down the line. This would allow access to useful energy which is one of the outputs of the functional structure diagram. This energy storage system would lead to local communicates being able to acquire the energy they require to live fulfilling lives.

In terms of the self-automated section of the functional structure diagram, this section is much more complex in the general design structure. Similar to the useful energy-storing mechanism, the Polycrystalline Solar Cell Array absorbs light allowing for the conversion of sunlight to usable electrical energy. However, instead of being sent to the energy storage facility, the energy collected by the solar panels is instead stored in a 18650 Lithium-Ion Rechargeable solar cell which will be used to send a power source current to the various mechanical components which need the energy to function. This power source current is sent to both the servo motor and the light sensor Arduino configuration. With a now viable voltage source, the sensor can now function accordingly to assist in the rotation of the solar panel configuration. Based on where the highest intensity of light is being emitted from, the light sensor is able to create an input signal based on the preprogrammed software used during the design phase. This input signal is then sent to the various servo motors which rotate the solar panel configuration to the area of the highest light intensity. The mechanical parts which move in this design, unfortunately, create noise and heat, due to the various energy losses which occur during this process. By fully understanding this functional structure diagram, potential designs can be created that follow a similar process to achieve the end goal. This is done while meeting the various constraints and requirements put in place by the various stakeholders in this project.

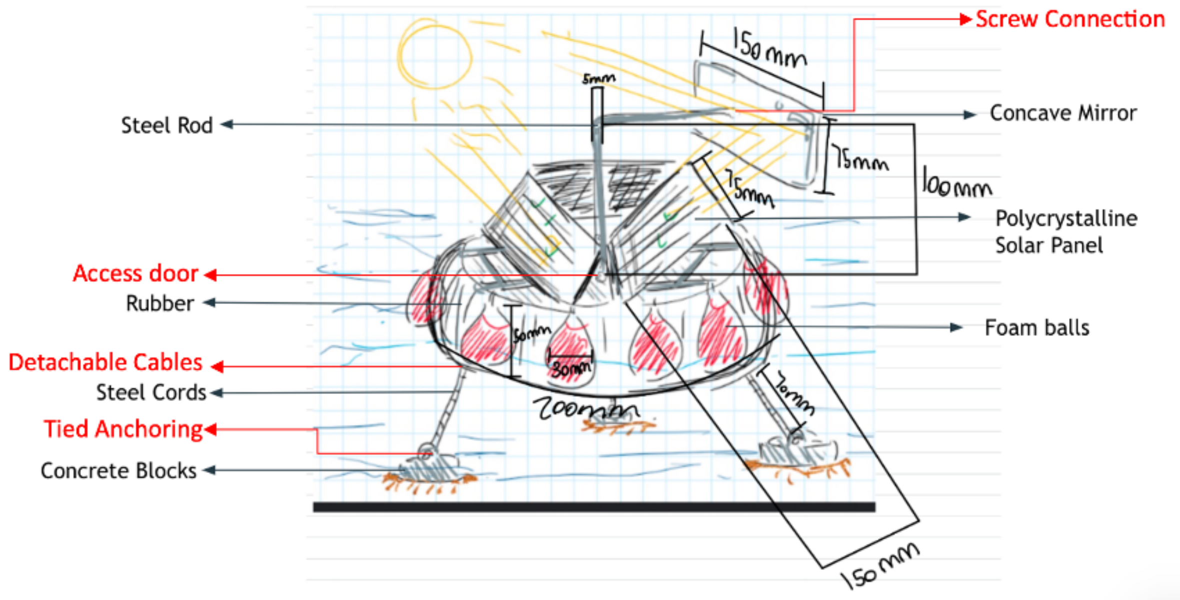
Morphological Chart

Morphological charts are decision-making tools used to systematically analyze and organize potential design solutions for a given project solution. This is done through a graphical representation of the relationships between various design components allowing for various parts of the design to be broken down into smaller, more manageable parts. The morphological chart provides a structured approach to ideation and helps engineers to explore a wide range of possible solutions and to evaluate their design potential and setbacks. The morphological chart shown below shows the various design components a successful solution may be made of to solve the task at hand.



3.0 Preliminary Design

The primary objective of this project is to create a floating device that autonomously tracks the sun and achieves the best efficiency and generation of energy. Initially, the design was going to incorporate a dual axis tracking system however, this was changed to single axis as per the confirmation of requirement from the director of the project (Professor Hassan). Therefore, the goal for our team became to maximize solar energy conversion with IoT features, staying within budget, and having a long-term cost saving target for the purpose of scaling this project to supply communities of different magnitudes. As the budget for this project was $200, our team decided to maximize this budget in a way that can maximize solar absorption by using multiple solar panels. By being more creative in the process, this would allow for long term reduced cost as it would not be necessary to have two separate units in order to increase energy production by two. Labor and cost of materials would be saved if this project was to be scaled. The solar panels are set up in 3 and angled so that it would receive the highest amount of solar energy year-round. The sun tracking component is in the form of a mirror that would rotate and reflect sunlight to the side which is not facing the sun. With this design, the sun will provide energy to almost all three solar panels at any given time. A circular base was chosen in order to increase stability and also to create a surface that would be friendlier to colliding objects. Furthermore, the circular shape is the more efficient shape for the 3 solar panel configurations. Buoys would surround the floating structure to protect the device and anything that would collide with it. The base of this flotation device would have 3 cords which would be tied to concrete blocks that are buried into the lakebed. This will increase the stability of the device while preventing the device from capsizing if winds get too strong. Lastly, there will be a frame laying over the floating base which will support the solar panels and mirror and situated at the center of the frame, would be the electrical components such as the Arduino, battery, wires, servo motor and other components needed for this project.



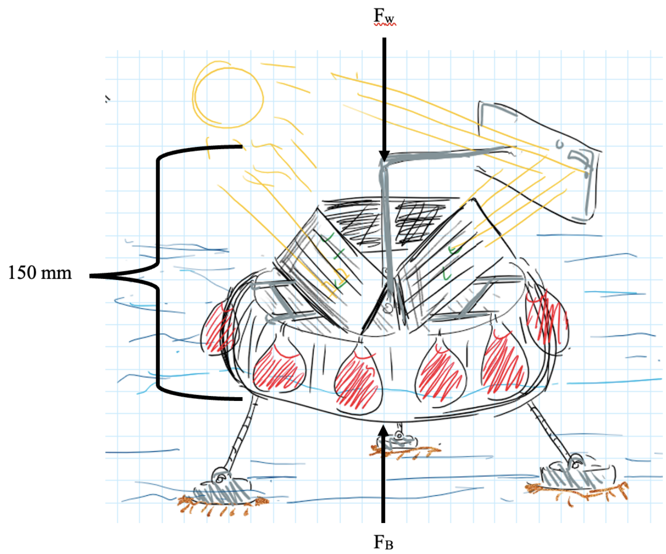
Based on feedback from the contractor and the design matrix, the design can further be optimized using aspects from the other designs used in the selection process. The various red arrows shown in figure 2 show the various annotations made towards the selected design in order to assist in maintainability and assembly. For maintainability, by adding an access door, the ability to access the circuit is much easier allowing for the design to undergo maintenance in a much more safe and effective method. In terms of assembly the main issue with this design were the various fixed or welded joints throughout the design. To accommodate for this, a combination of screw and joint detachment components have been incorporated into the design. This would make the design not only easier to assemble, but easier to maintain when part replacement is required.

Design Calculations

In order to better understand the various conditions that the design needs to meet for complete implementation, it is necessary that calculations are computed to ensure the final design's success. These calculations will be taken into account to optimize the various lengths and measurements used throughout the design process. This will also better prepare the design for the selected design environment

Buoyant Force

Among the most important forces needed to be taken into account is the buoyant force. For the mechanism to float accordingly, it is essential that the buoyant force can withstand the gravitational force allowing it to stay above water level. For this analysis, it will be assumed that the model is modeled after a spherical element with a 150mm diameter. Additionally, it will be assumed only half of the design's base will be submerged in water during operation. For the analytical analysis a gravitational force and density of 9.81 m/s^2 and 997.77 kg/m^3 will be used respectively. Based on the Buoyancy calculation, the expected mechanism weight can also be calculated



$$V_{mechanism} = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{0.15}{2}\right)^3 = 0.0017671\ m^3$$

$$Submerged\ Ratio = \frac{r_{submerged}}{r_{total}} = \frac{25mm}{150mm} = 0.1666\overline{6}$$

$$V_{submerged} = V_{mechanism} \cdot Submerged\ Ratio = 0.0002945243\ m^3$$

$$F_B = \rho_w g V_{submerged} = 2.88284\ N$$

Weight

$$W = F_B \rightarrow mg = F_B$$

$$2.88284N = m(9.81)$$
$$m = 0.29386\,kg$$
$$m = 294\,g$$

Drag Forces

To ensure that the design is able to function at the specified wind current, it is essential that the various components with the design are able to withstand the drag of both winds and water currents. For this analysis, it was assumed that the wind speed is uniform and 1 dimensional. In addition to this to simplify the analysis, it was assumed that the mechanism has a similar drag coefficient to that of a sphere with a 150mm radius, meaning that a drag coefficient of 0.47 will be used for analysis above and below the water. The radius can be reduced for the water drag calculations to only account for the submerged area of the design. To take into account the worst possible scenario, the radius will be divided by a factor of 2.

Air Drag:

$$\text{Sphere: } C_D = 0.47 \qquad \rho_{@273k} = 1.293\,kg/m^3$$
$$Average\ velocity\ of\ wind\ on\ earth = 5\,m/s$$
$$F_D = \frac{1}{2}\rho V^2 C_D A$$
$$F_D = \frac{1}{2}(1.293)(5)^2(0.47)\pi(\frac{150}{1000})^2$$
$$F_D = 0.5369\,N$$

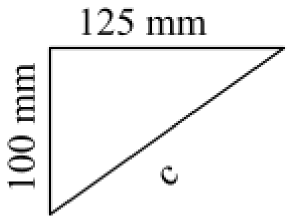
Water Drag:

$$\text{Sphere: } C_D = 0.47 \qquad \rho_{@273k} = 997\,kg/m^3$$
$$Expected\ speed\ of\ currents = 5\,m/s$$
$$F_d = \frac{1}{2}\rho v^2 C_d\,A$$
$$F_D = \frac{1}{2}(997)(5m/s)^2(0.47)\pi(\frac{75}{1000})^2$$
$$F_D = 103.5\,N$$

Note: These are the upper and lower limit drag forces that the design may experience. Though these conditions are unlikely, it is essential to design for the work case scenario to assure that the design always functions.

Focal Point & Radius Of Curvature

The main difference between the chosen design and traditional designs is its innovative method of driving efficiency higher using a mirror. This means that the reflection of light also needs to be taken into account to ensure that the mirror actually does have an effect on the efficiency of. To do this, the focal length and radius of curvature need to be found. If we ensure that the focal length is the distance between the mirror and solar panels, a radius of curvature can be found which would measure the concavity needed to achieve the highest light intensity at the selected point. For this analysis, it will be assumed that light is perpendicular to the mirror and that they travel in rays. Furthermore, it is expected that no refraction is to occur through the solar panel and mirror surfaces.



$$a^2 + b^2 = c^2$$

$$c = \sqrt{100^2 + 125^2}$$

$$c = 160.078\, mm \rightarrow Focal\ Length$$

Radius of curvature: $\frac{1}{f} = \frac{2}{C}$

$$\frac{1}{160.078} = \frac{2}{C}$$

Radius of curvature = 320.156 mm

<u>Light Intensity & Efficiency</u>

To accumulate the highest possible efficiency, it is important that the light intensity to meet the highest possible efficiency is met. This would ensure that the mirror does make a difference when focusing light on to the solar panel.

$$Light\ intensity = \frac{power}{area}$$

$$Light\ intensity = \frac{2}{(0.15 \cdot 0.075)}$$

$$Light\ intensity = 177.7\ W/m^2$$

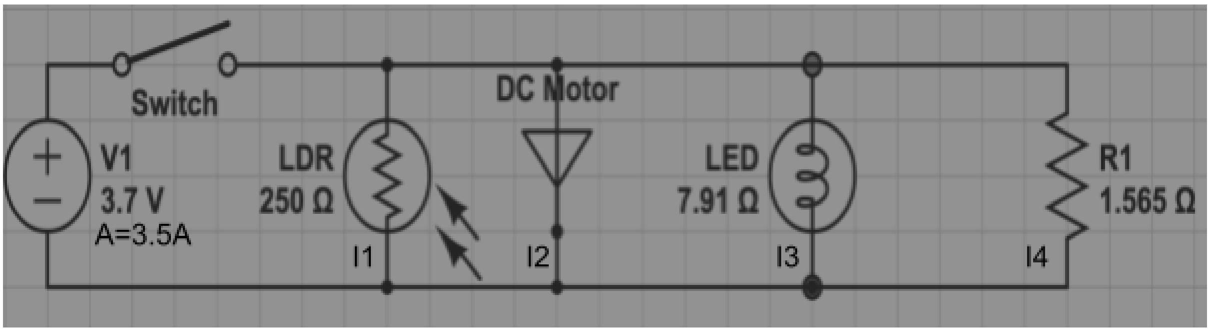
Efficiency $= \frac{Power_{max}}{Area \cdot 1000} \cdot 100$

$$= \frac{2}{(0.15 \cdot 0.075) \cdot 1000} \cdot 100$$

=17.7%

<u>Electrical Analysis</u>

In addition to the various mechanical based calculations associated with this design, electrical circuit analysis should also be conducted to ensure that the lithium ion battery meets the voltage requirements of the various sensors and electrical parts throughout the circuit. In addition to this, the voltage must be in accordance with the voltage rating associated with the part. For this analysis, electrical insulations will be neglected. It will also be assumed that the various parts are always functional with the specified voltage. It is to be noted that these calculations are subject to change based on the kit provided by the contractor. This would imply that the internal resistances are subjected to change during the configuration process. In addition to this, arduino specifications are unknown, so they have been shown using a 1.565 ohm resistor. Additionally, the voltage and amperage rating of the battery was found in accordance to specifications found through online sources. The arduino can be used in parallel and series, but the optimal decision must be conducted through experimental analysis to evaluate the major benefits and drawbacks of each option.

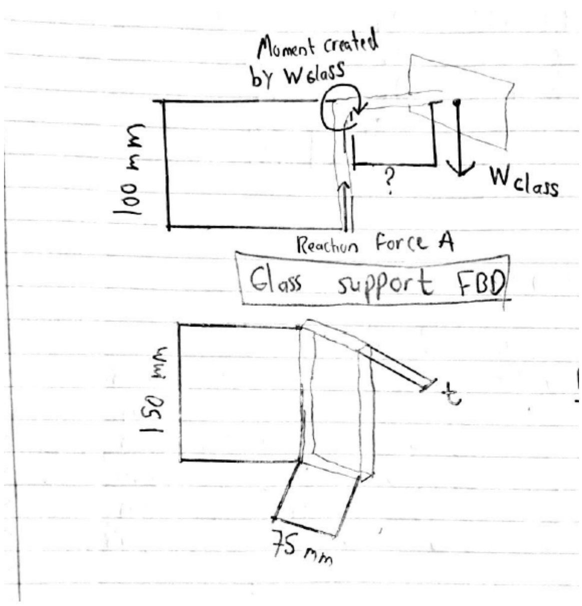


$$I_1 = \frac{3.7}{250} = 0.0148A \quad I_2 = \frac{3.7}{4} = 0.925A \quad I_3 = \frac{3.7}{7.91} = 0.468A$$

$$I_4 = \frac{3.7}{1.565} = 2.364A$$

Stress Analysis

Another crucial mechanical aspect considered in the calculations are the stresses found on the mechanism. It was identified that the principal force causing stresses on the design is the weight of the mirror. The weight of the mirror was compared by selecting three arbitrary thicknesses (1 mm, 2 mm, and 3 mm). In order to counter this force, a reaction force will be applied by the steel rod, which will result in normal stress. The distance between the mirror and curvature of the rod will result in the existence of a moment. This moment will cause bending stress of the rod that, if not addressed appropriately, can jeopardise the reliability of the mechanism.



$V_{Mirror} = Length * Width * Thickness$

$V_{Mirror} = 0.15 * 0.075 * 0.001$

$= 0.00001125\, m^3$

$W_{Mirror} = M_{Mirror} * g = 0.2746\, N$

$\sigma_{Bending} = (Moment * Radius\ of\ rod)/Moment\ of\ Inertia$

$\sigma_{Bending} = (0.027 * 0.0025)/(\frac{1}{3} * 0.028 * 0.1^2)$

= 0.73 Pa

$M_{Mirror} = \rho_{Glass} * V_{Mirror}$

$M_{Mirror} = 2500 * 0.00001125\, m^3$

$= 28\, grams$

$Moment = 0.2746 * 0.1 = 0.027\, Nm$

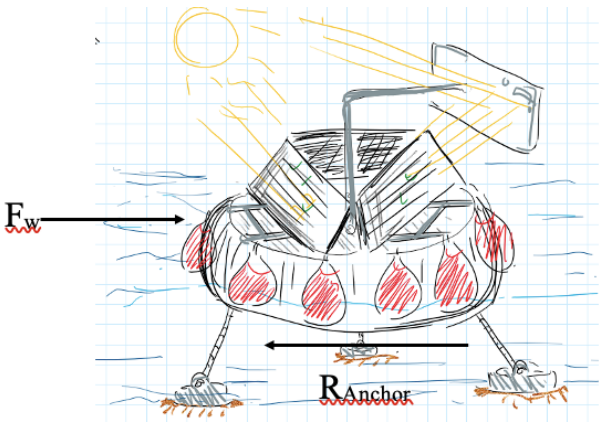
$\sigma_{Normal} = Reaction\ Force * Area$

$\sigma_{Normal} = 0.2746/(\frac{\pi * 0.005^2}{4})$

= 14 Kpa

Wave Calculations

In addition to the drag force created by the water, the forces exerted by the current also pose a major threat to the design which could potentially cause flipping and complete design failure. It is essential that wave oscillations are taken into account when analyzing such a design. For this, it will be assumed that the wave function is constant throughout. Additionally, the object will be considered to be stationary, and half the base will always be submerged during this process throughout this analysis.



$$Velocity = Frequency * Wavelength$$

$$Velocity = 2 * 0.02 = 0.04\, m/s$$

$$Amplitude = 2\, cm$$

$$Time\ Period = \frac{1}{Frequency} = \frac{1}{2}$$

$$Time\ Period = 0.5\, seconds$$

$$Angular\ Frequency = \frac{2\pi}{T} = \frac{2\pi}{0.5}$$

$$Angular\ Frequency = 12.57\, rad/s$$

$$Wave\ Function = y(t) = 0.02 sin(12.57t)$$

Based on the wave function the maximum and minimum wave size is 2 cm and -2cm respectively. This means that the base needs to be large enough such that no water is able to enter the interior space. If half the base is to me submerged, for safety measures, the base needs to be at least 8 cm high while accounting for the fact that half of the base is submerged. Based on the wave function, a graphical representation can be presented to better understand wave behavior. This function is shown below

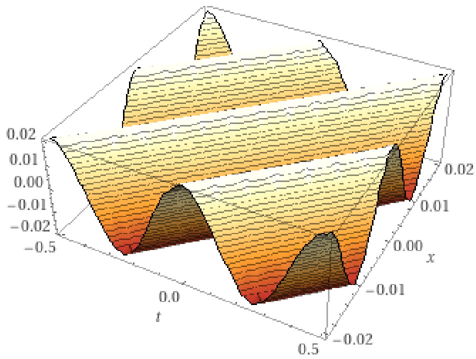


Figure 4: 3D plot of wave created by fan

To better understand the needs and expected materials needed for this project to continue through the engineering procedure, analyzing cost effective materials for potential usage is proven beneficial. It is essential that the various components are in agreement to the calculations computed above to achieve an optimal design. For buoyancy, an off the shelf material that could be a potential solution to addressing the buoyant force required is rubber. Rubber has a low density allowing it to stay afloat without risk of sinking while being durable enough to withstand currents and drag forces. As the base has the most weight of the design, having a low density is proven beneficial. Specifically, a floating ring can be utilized for the base due to these properties. For the buoys, using styrofoam would allow for strong impact resistance while maintaining the density restriction opposed by the buoyancy calculation.By using small waterproof styrofoam spheres, this can be accomplished to a high degree of effectiveness allowing for a safe design. In terms of the mirror holders, this part needs to be sturdy enough to hold the mirror up all the time. This would mean a high strength material is required for this to work. Products similar to metal straws hold high potential in meeting the measurements of this section of the design. For the mirror itself, it would need to be able to withstand the drag force while being lightweight to ensure that the holder is capable of keeping the part in the suited position. For the mirror the best off the shelf material is that of a car rear view mirror. Its concavity would allow for an increase in light intensity while being lightweight and fitting the design parameters required for the selected ones. Though this component selection is not finalized, analyzing off the shelf alternatives is essential for the design progress.

Safety Optimization

As engineers play such an important role in serving society, it is important that the various designs produced are safe enough for implementation. The goal for the various risks that exist within the design is to negate them using the various safety oriented design techniques. Doing so will eliminate the risks associated with the design and allow for no risk in the process. For this design, the most concerning risk is the possibility of contact between the various electrical components and surrounding water. When water interacts with electricity, electrons are able to flow through it through conduction. As water is a great conductor, electrons will flow throughout at very high rates. This is an issue because the various wildlife or people within the mechanism's environment pose the risk of electrocution when water contacts the circuit. To eliminate this, the safe-life avoidance technique can be used by sealing the battery and electrical components within a sealed container. Doing so will eliminate the risk for the remainder of the product life. In addition to this, it is important that the design is tapered to the environmental conditions of the area implementation area. This means that the design would need to withstand the environmental conditions of the area as well as influences from man-made contraptions nearby. By adding a combination of buoys and LEDs, the design would be able to withstand impact with other objects such as boats and other waste carried by the current, while warning seafarers using the LED during times of poor visibility In addition to sealing the circuit components to prevent damage, a switch can also be added to limit damage to electrical components during failure. This switch can also aid in the maintenance possessed in order to eliminate the current when modifications need to be done on the circuit. This would make the design more maintainable and safe. Lastly is the risks associated with corrosion and oxidation. Corrosion is not only a risk for the structural integrity of the design, but also the safety of the environment. Corrosion has the potential to create harmful chemical reactions and impurities in the environment, disrupting the environment's functions. To account for this, the base will be made of rubber. Rubber has excellent corrosion resistance while being very cost effective making it an excellent material selection for the design.

Safety Inspection and Maintenance

In addition to designing to negate the risks associated with the design, routine safety checks also need to be conducted to assure that the design is up to standard. In terms of maintenance, the expectation is that the various tests are done once a week for the first month to assure that the design is functional, and then on a monthly basis after that. Doing so will allow for the design to run at full efficiency during the design's lifespan. This is the service time for typical aquatic vehicles, so it would be beneficial if the design follows similar procedures. For electrical expectation the main tests will be conducted on the circuits, this includes voltage tests, resistor inspections, sensor inspection and battery maintenance. If the circuit doesn't function to standard, the entire design would not function properly, so it is of utmost importance that the circuit is maintained. For mechanical tests, the main focus will be the various joints, dc motors, and rotating mechanisms. These are important for the functionality of the mirror itself. As mechanical components are associated with the most movement within the design, they have a higher chance to fail meaning that they need to be checked annually. The material inspection focuses on checking for corrosion and physical damage. This would include the various solar panels, base, links, and anchors in the mechanism. This would aid in the design keeping afloat and ensuring that the risk integrated safety measures remain fully functional during its usage.

Description of Final Design

Figure displays most of the components in the CAD build. The dimension of critical components such as the rotating mirror arm, weight and size of the device were validated by the calculations in section 'Design Calculations'. The concavity of the mirror shown at the back of figure 4 can be found in the aforementioned section. The three cords attached to the bottom of the base are removable for the purpose of ease of usage and maintainability. The three concrete blocks tied to those cords are buried into the water bed and are designed to keep the device stable in high wind and wave events. There are 6 collars evenly spaced and fixed onto the floating base. On top of each of the collars are rings that are used to secure the buoys as well as any future purposes.

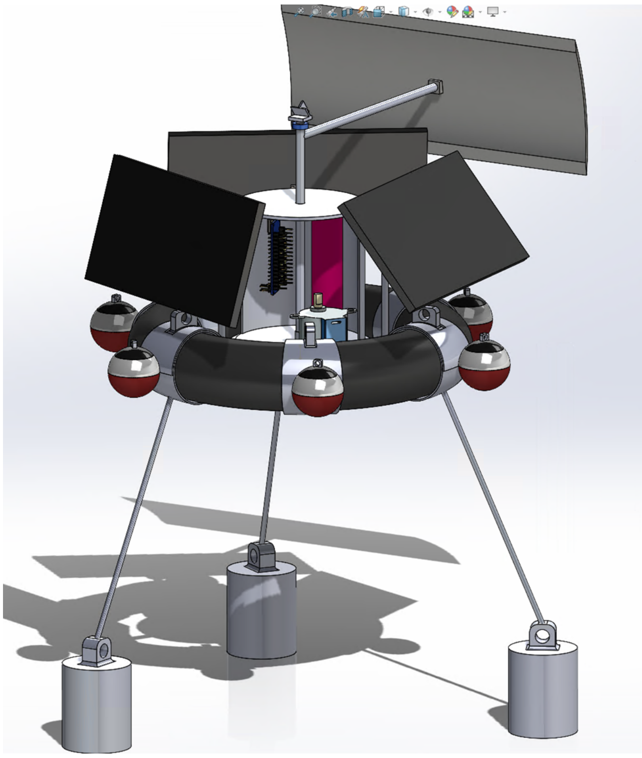


Figure : Detailed CAD model

The frame that supports everything above the base is shown in figure 5. The frame's outer section is made up of three half collars with cutouts that sit securely on top of the rings located on the existing three of the six collars affixed onto the main base. This allows for ease of assembly and minimizes the amount of fastening and/or welding required. From the outer collars, three bars extend and merge at the center with a base that can support the core housing. In Figure 4, the core casing is sunken as the frame was designed to lower the center of gravity for increased stability of the device.

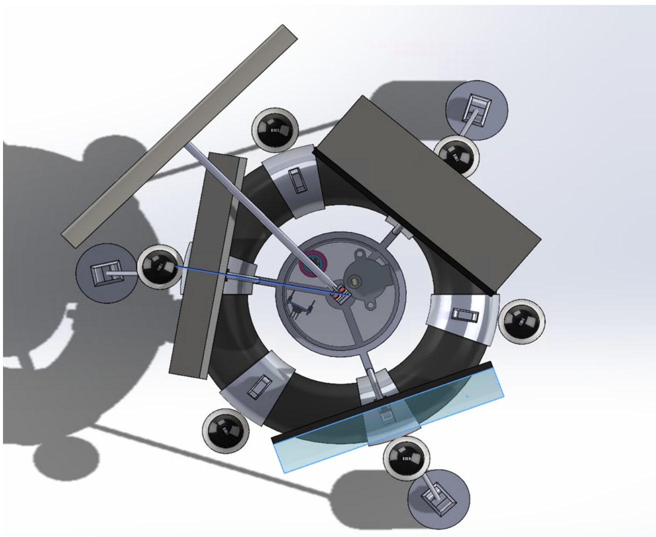


Figure 5: Top view of design

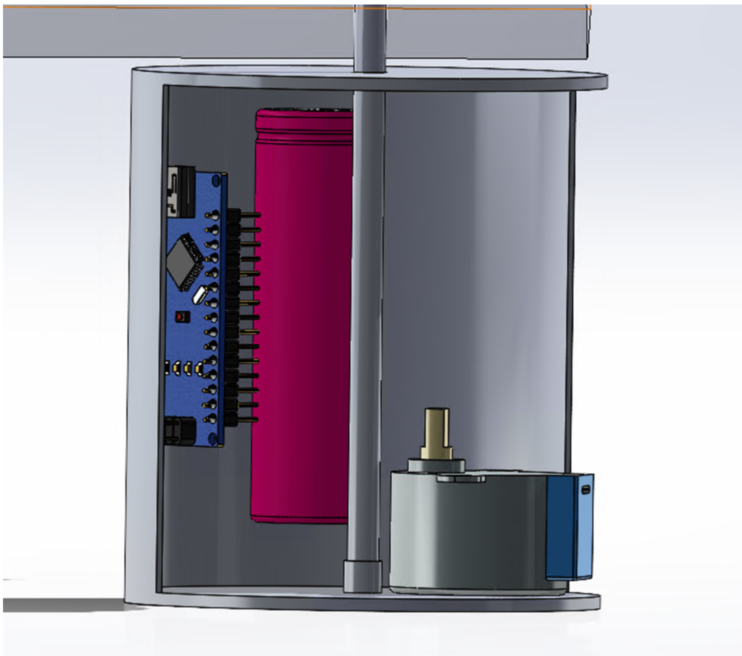


Figure 6: Internal Components

The core casing has been designed to fit the primary electronic components- the Arduino computer, an 18650 battery and a servo motor. The size of this design considers the need for extra components to be put in as well as access for maintenance. As this system will require IoT functionality, a number of sensors and components will comfortably fit into this casing to support these functions. The picture features the core casing when it is open. In its closed state, it will be completely sealed with a sliding cylindrical door. This has also been designed in consideration for when the project is to be scaled for a large size where it would then be a necessity for accessibility and maintainability to and for this core.

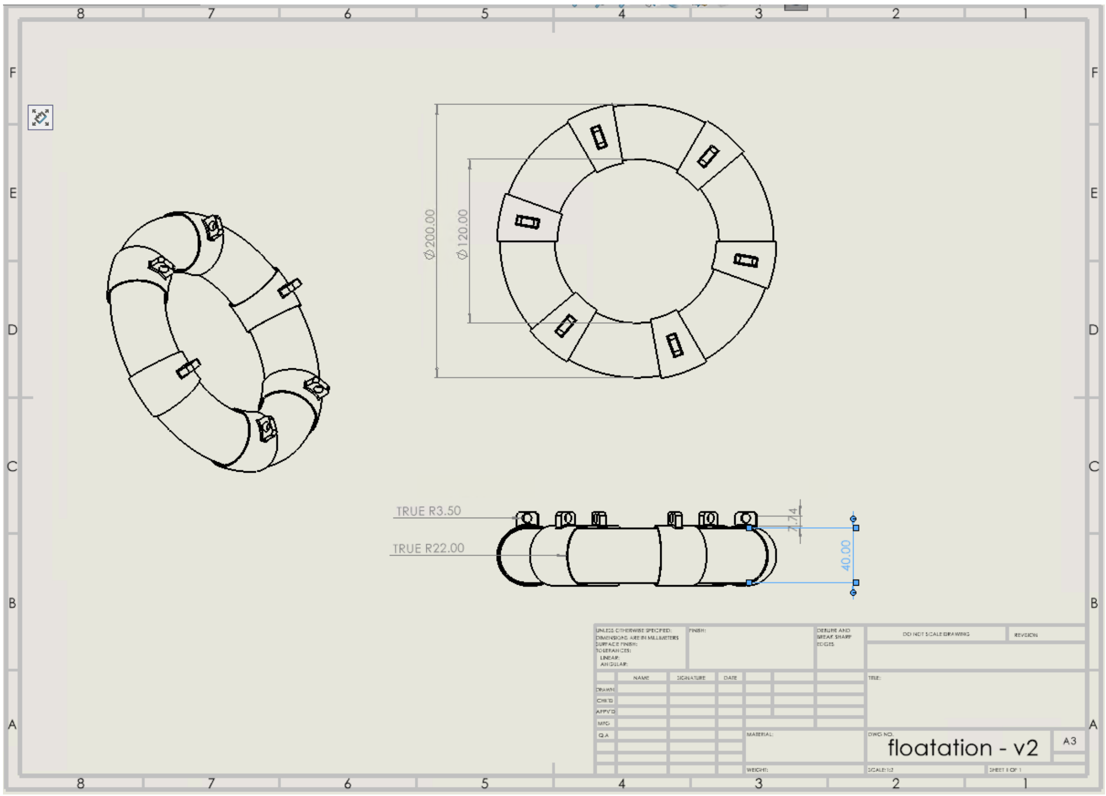


Figure 7: Drawing of Floating base with Dimensions

The base shown in figure 7 has been sized in order to fit the components required for this project as well as the complying with the required buoyancy calculated 'Design Calculations'

Figure 7 is an image of the bend of the mirror arm. Fixed atop of this is the photosensitivity sensors for the purpose of solar tracking and right below it is a circular LED light which serves as a signal for watercraft operators to steer clear of during low light situations.

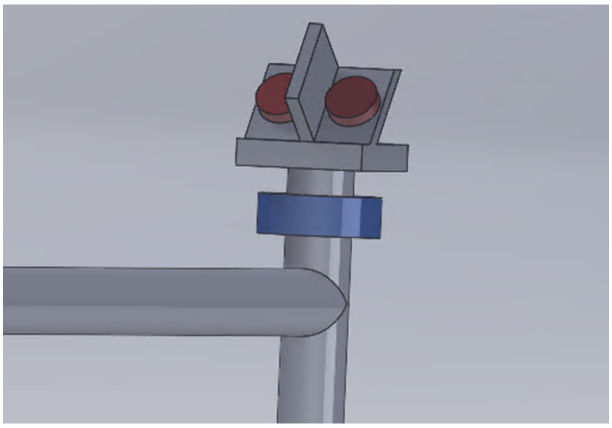
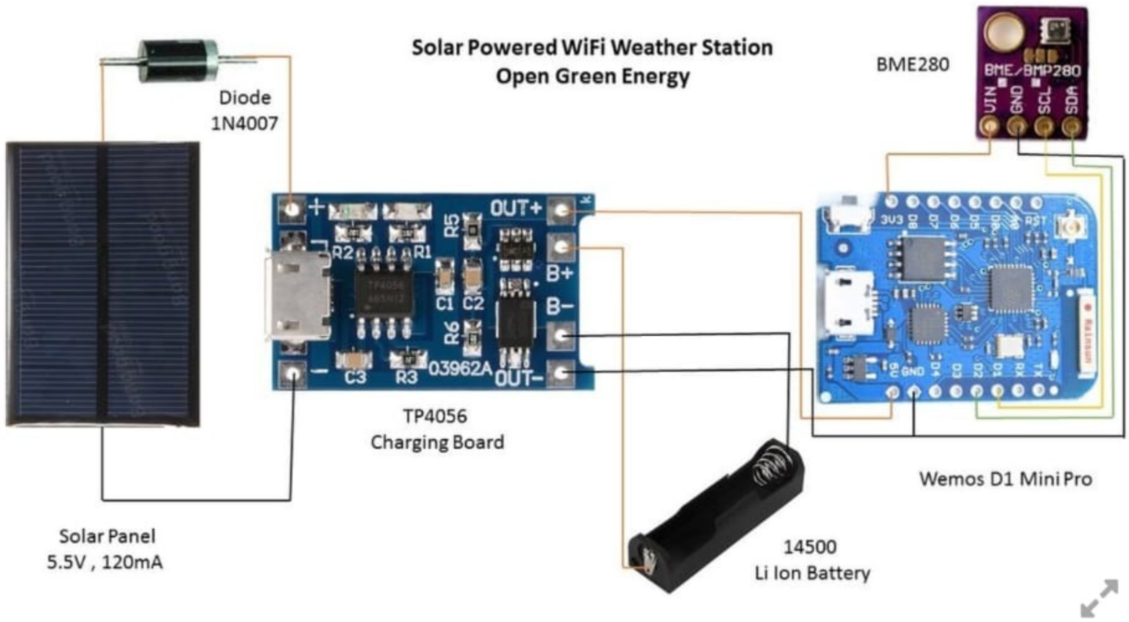


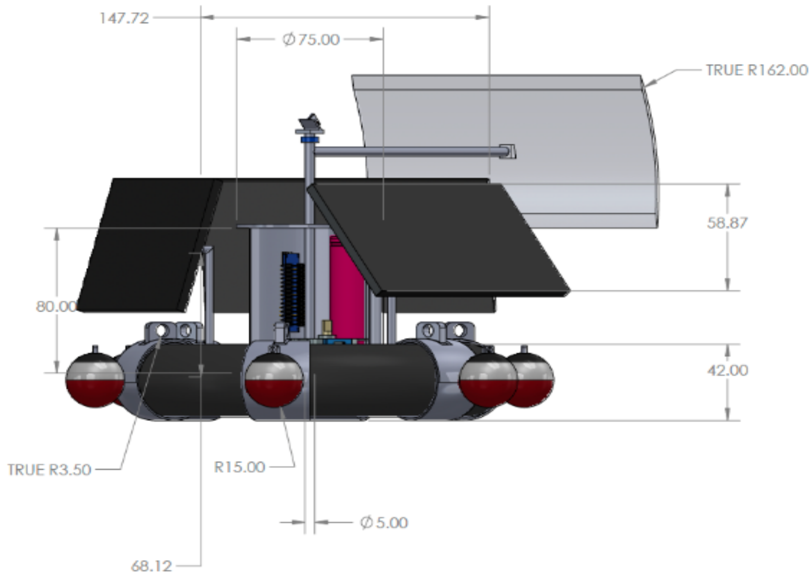
Figure 9: LED & LDR Placement

The completed design The final design was created by the team going through the design process throughout the semester, the design can be seen below on **figure**. In order to meet function expectations, changes were made in order for the prototype to better achieve the goals and objectives in which it was designed for.

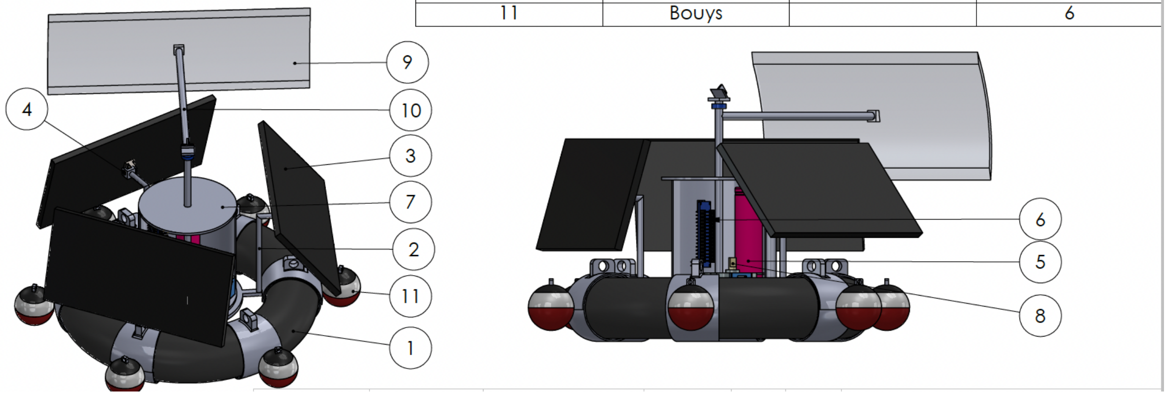
The expectation is that the design will be able to rotate the mirror to always face the solar panel system. This will be done by mounting the mirror holder onto a DC motor which will rotate based on the readings of the LDR sensors displayed in **figure**. The motor will rotate in the direction of the LDR sensor with the higher reading in an attempt to allow both sensors to reach an equilibrium point. Once the LDRs both have a similar reading the motor will stop rotating. This will allow for all of the solar panels to receive light even if one is facing a different direction. In terms of electrical functionality, a TP4056 charging board was used in order for charging to occur between the Solar Panel and the battery as well as the arduino board. This would ensure that no current travels backwards towards the solar panels which would result in a short circuit. Figure _ below shows the electrical system expected to be used for this project.



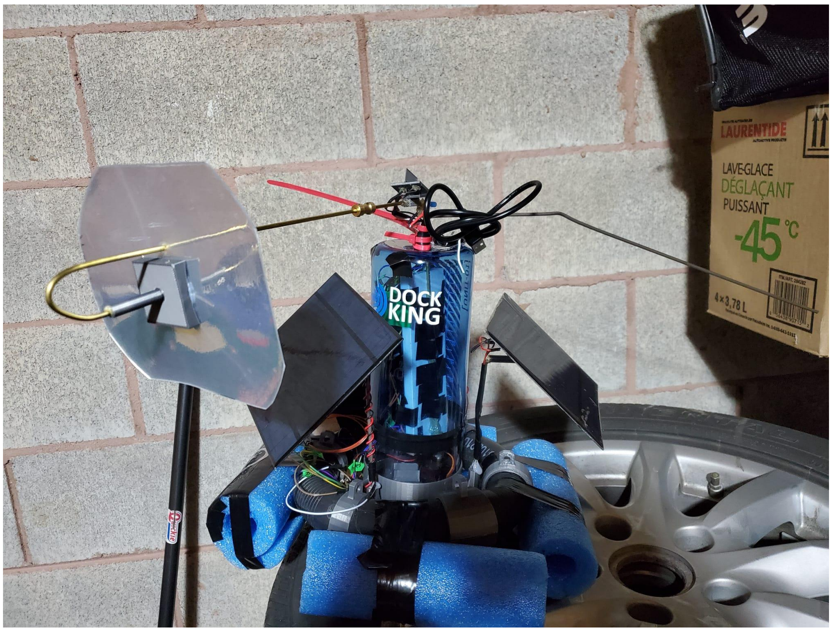
A complete overview of the design parameters as well as bill of materials was compiled using SolidWorks which can be found in **figure _ and _ respectively.** In terms of materials, it is expected that most of the components in the base are made of ABS 3D printer filament. This would include the base plate, component casing, mirror and collars. The floating base will be made of styrene butadiene rubber, a common material found in tires which has a very high buoyancy. The Buoys will use styrofoam balls as their primary material. These materials have good impact absorption making them ideal for collision protection. The solar panel and mirror supports will both be made of AISI 304 steel. This material has a high strength with low ductility allowing it to hold the parts up without any kind of deformation over a long period of time



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	Floatation Device		1
2	Solar Panel Holder		3
3	Solar Panels		3
4	Solar Panel Pins		3
5	Lithium Ion Battery		1
6	Arduino Board		1
7	Base Plate Cover		1
8	DC Motor		1
9	Concave Mirror		1
10	Mirror Holder		1
11	Bouys		6



Overall the design managed to reach full scale production and did function as expected, however, various changes needed to be made to the design due to adjustments and part availability. In terms of functionality, the design was able to function in accordance to its expectation, with the mirror being able to rotate based on LDR readings. The final manufactured design is shown in figure _ below.

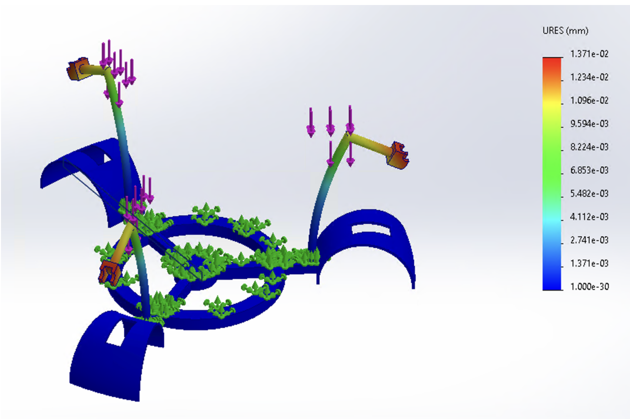


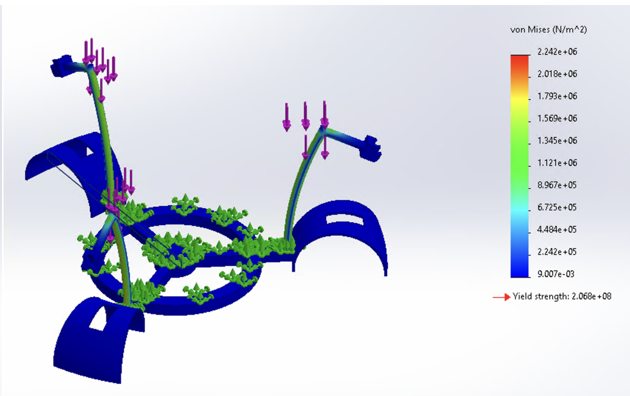
Final Design Testing and Results

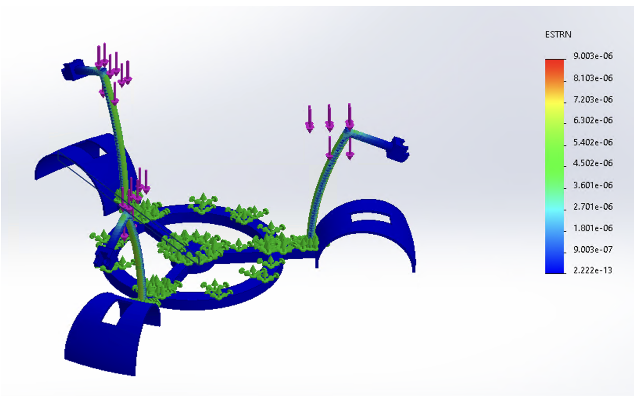
In order to ensure that the design is able to function under the expected environmental conditions, it is essential that various tests are conducted to ensure the design's success. The testing procedure will be conducted using Solidworks simulation analysis to ensure that the various components of interest are up to standard. These components are those which undergo extensive force such as the base plate, and parts which have a large bending moment such as the mirror and solar panel holders. Each component will have a weight equivalent to the gravitational load applied to it, as well as the maximum rotational speed equivalent to that of the expected motor speed.

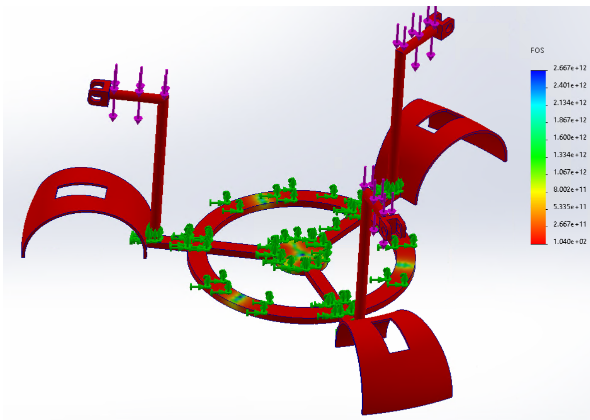
Solar Panel Arms

The first area of interest is the solar panel arms. These arms are relatively thick and provide support to the solar panel assembly to assure that these devices are adequately held up. With their orientation in this design they are pron to a bending moment which can cause mechanical defects over time To set up this simulation a fine mesh was used to achieve the most accurate results. In addition to this, a downwards force equivalent to the weight of the solar panels was applied onto the supports. As the area of interest was specifically these arms alone, the base plate was set as fixed to ensure no force was transferred to this section allowing for a finite element analysis to be conducted on the arm. For this analysis AISI 304 steel was used to gather appropriate material properties. In terms of results, it was found that the mechanism far exceeds the strength and tensile threshold making it very safe for design usage to take place. With a max displacement of under 1mm, this demonstrates how sturdy the design is to the gravitational force exerted on it by the solar panels. In terms of calculation comparison, the yield strength far exceeded that in which it was calculated. This was likely due to the material selected when simulation took place. For the calculations phase, plastic was used as it was assumed that this part would be 3D printed. In terms of factor of safety, it was found the value exceeded 100. Though very high, this was expected as the weight of the solar panel was approximately 100 grams. Though optimization could have been done to save material, the possibility of acquiring a holder which is less than 5mm in diameter is very low. Furthermore, it is important to note that currents of 1-2cm in amplitude are expected, however, in reality the conditions are much more severe and designing in accordance to the 1-2 cm wave oscillation would mean that the design could fail in higher frequency or taller wave oscillations. Figure _ to _ show the various simulations conducted on the solar panels arms.



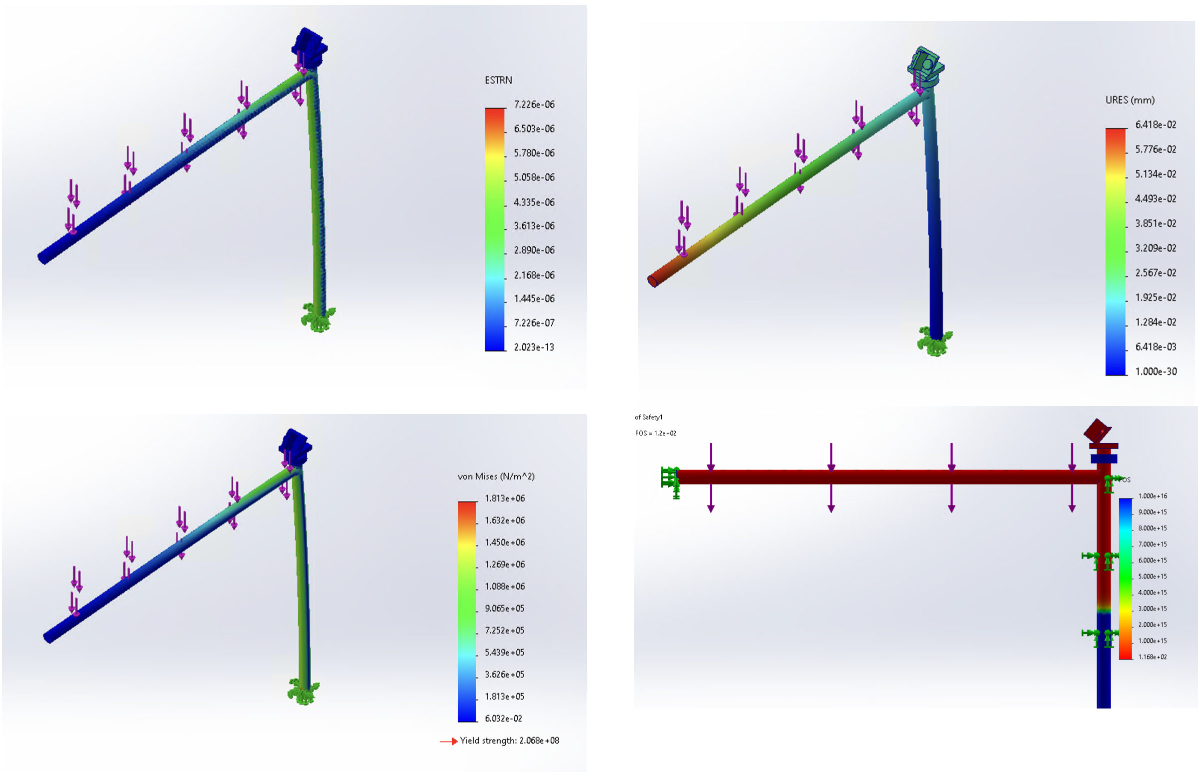






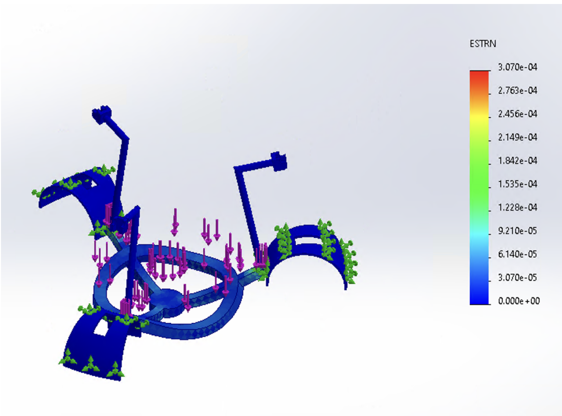
Mirror Arms

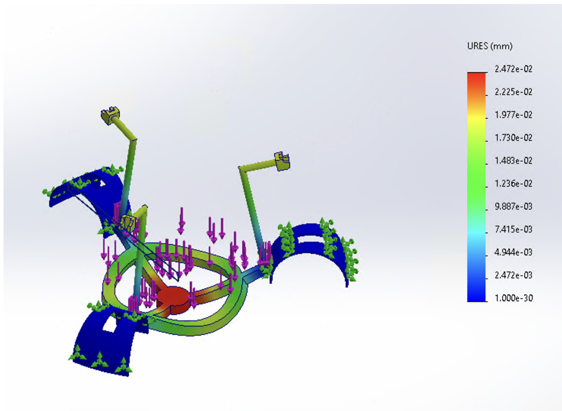
The second area of interest is the mirror arm. These arms are relatively thin with a 2mm diameter and provide support to the mirror assembly to assure that these devices are adequately held up. With their orientation in this design they are pron to a bending moment which can cause mechanical defects over time To set up this simulation a fine mesh was used to achieve the most accurate results. In addition to this, a downwards force equivalent to the weight of the mirror was applied onto the supports. As the area of interest was specifically the upper portion of the arm, the lower base was set as fixed to ensure the forces would not just translate the entire body. For this analysis Brass was used to gather appropriate material properties. In terms of results, it was found that the mechanism far exceeds the strength and tensile threshold making it very safe for design usage to take place. With a max displacement of under 1mm, this demonstrates how sturdy the design is to the gravitational force exerted on it by the mirror. In terms of calculation comparison, the yield strength far exceeded that in which it was calculated. This was likely due to the material selected when simulation took place. For the calculations phase, plastic was used as it was assumed that this part would be 3D printed. Similar to the solar panel arm, the factor of safety for these components equates to about 100. However, through testing it was found that by altering the diameter of the mirror holder the displacement along the tip ends up being much higher. Considering the mechanism is quite small in size, even a displacement of 1 millimetre can provide a critical point for failure. Though the FOS was quite high, it serves for maximum stability while lowering the risk of any mechanical failure.

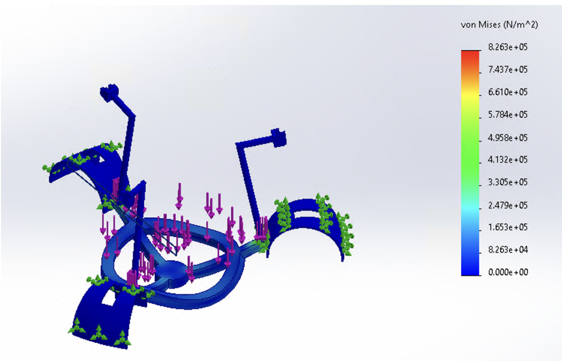


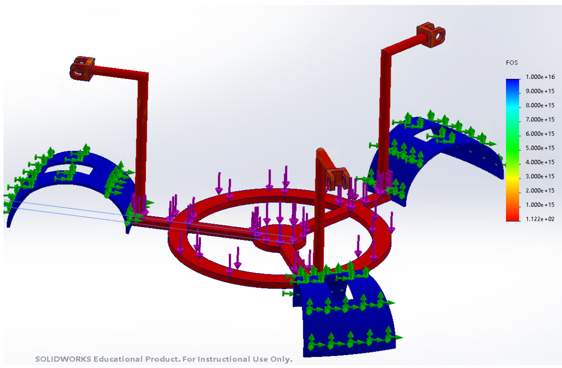
Base Plate

The last part on the design for the simulations was the bass where most of the components will be concealed in an enclosure including the breadboard, arduino, motor, battery, wires and also the mirror arm. Having all this weight on top of the base in the middle, simulations had to be taken into account as we did not want the design to fail when having all this weight on top of the base. This is the part of the mechanism which will hold the most weight so it is essential that this component meets mechanical standards. For this analysis, a downwards force of 2.98N was applied to the op of the base plate. This value represents the estimated weight of the entire mechanism. In terms of fixtures, the metal collars were set to fixed as these parts of the base plate will be attached to the floatation device which is among one of the most sturdy parts of the design. By keeping these points fixed all of the force would stay on the base plate and would not be distributed to other bodies. This helps the design prepare for the worst possible case scenario when making a simulation. In terms of materials, ABS was used as this part was expected to be 3D printed. ABS is among the most common 3D printer filaments so choosing it allowed for the most realistic results. In terms of results it was clear that the base plate far exceeded expectations and also has a displacement of less than 1mm. With a high von mises stress and low tensile stress, this shows that the base design is very suitable for this application. In terms of calculations, it was originally assumed that AISI 304 steel would be used for this component as well, but for convenience ABS was used instead. This would imply that the values which were achieved from calculations were much higher then what was simulated due to the difference in material properties. In terms of factor of safety, this component ends up being over 100 as well. Though optimization could have been computed for this component as well, the main issue that arises there is that even the slightest bend in the base plate can cause complete failure. This can be seen within the other simulations where slight bends can cause parts like the solar panel arms to bend inwards. This would mean that it is important that the displacement is minimised as failure in this part can ruin the entire design.









Floatation Testing

In order to ensure the design's success, it is essential that the design is able to function over long periods of time without the risk of topping or sinking. To do this, the preliminary design was tested in open water conditions. Unfortunately, due to numerous design adjustments which occurred because of part availability the initial design did not float. These changes included the material of the solar panel arms and mirror arms which were expected to be used of AISI 304 steel, however due to part availability the mirror arm was made of brass instead, which did provide adequate stability for the mechanism. Furthermore, the casing was switched from ABS 3D printer filament to Polyethylene terephthalate, which is a plastic used for water bottle manufacturing. This adjustment increased the overall weight of the design meaning that the base needed to be adjusted as well in accordance to the new casing, This resulted in the addition of Polyethylene foam which was added using Pool Noodles. This foam allowed the mechanism to float due to its high surface area to weight ratio. These changes can be seen in accordance to figure_.

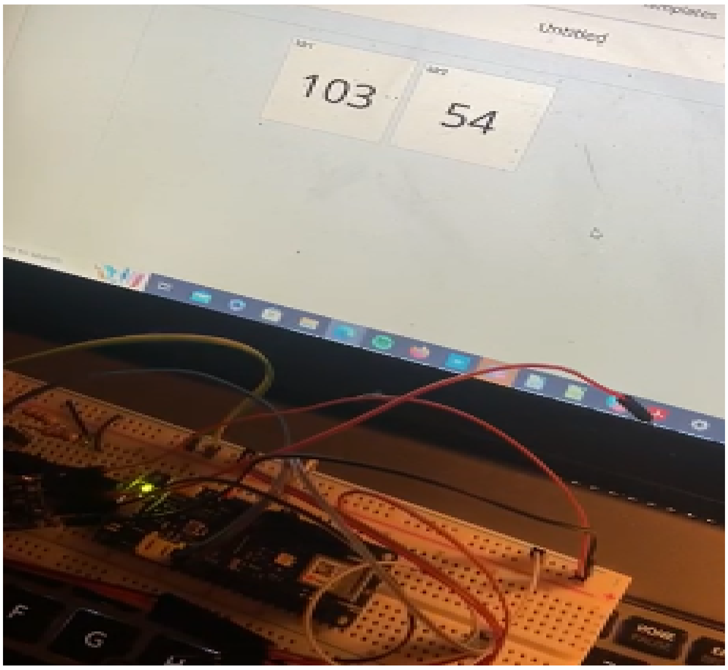
Electrical Testing

To make sure that the design is fully functional from an electrical standpoint, it is essential that both the electrical systems and arduino code are compatible with the mechanical systems embedded within the design. It is also important that the electrical systems within the design are thereroe tested to ensure complete design functionality. To do this, an arduino widget will be used to display LDR reading to ensure sensor operation is possible. As these photoresistors are the main driving component of the mechanism it is essential that these electrical components are fully capable of tracking light. These LDRs must work in coincidence with the motor which also needs to rotate based on the LDR readings. To do this, these components can be isolated and tested to ensure complete functionality. While testing the motor, it was also found that the motor is able to fully function based on the imputed arduino code. This would mean that all electrical systems are up to standard so the mechanism would be ready for large scale production.

3.3 Project Reflection & Evaluation

Due to the complexity of the design, the building process of the mechanism resulted in a challenging phase in the project due to miscalculations, unforeseen conceptual mistakes, and equipment errors. In terms of mechanical mistakes, the main component proved to be challenging was the servo motor. When the mechanism was subjected to the initial testing phase, the motor speed was inconsistent as there were occasions where the torque generated was either insufficient to move the mirror or excessively high which almost caused failure on our steel rod structure. The reason for this malfunction was deduced to be prompted by an error in the circuit. Since the motor was fed with an irregular amount of the power (as the arduino board voltage and battery voltage are not the same), this device was not able to function in a consistent manner. Another mechanical shortcoming that was faced during the building phase was the entanglement of wires when the mechanism started moving. In order to fix this, a rotating mechanism was implemented on the mechanism in order to prevent any wires from breaking.

In terms of electrical components, the biggest challenges faced was establishing a successful compatibility between the arduino IoT cloud and the board. Due to the lack of knowledge on the nature of the software, external assistance was required in order to create the IoT cloud, as well as making sure the arduino board was linked with the cloud. Smaller electrical difficulties that occurred in the project were: loose wiring and LED shortage. In order to secure the wiring system,a combination of male to female wire connections were implemented. Additionally, thicker wires were used in the soldering process in order to reduce the amount of moving parts in the design. In the case of LEDs, resistors were added in order to create a controlled threshold of voltages that would cause the LED to either turn on or off. This way, there was no need to purchase more LEDs since the inventory available was enough for the requirements of the project.



[1]

Although the project was able to satisfy the requirements and constraints established, there is a considerable amount of improvement that can be made onto the design. One aspect that can be improved is the planning phase of the design. Most of the time was dedicated to discussing how the mechanism will function rather than focusing on building procedure of the design. Another aspect that should be considered was the number of testing iterations performed. The number of tests was insufficient, therefore, it was not possible to monitor in more detail which components are not functioning in an optimal manner and have enough time to optimise that specific section. Finally, the material selection can be improved as well since components such as servo motors, mirror or wire types can be modified in order to obtain a more effective design.

3.4 Summary

The prototype testing was successful as all design requirements were met with a remainder from the budget that can be used to either improve the design or to further promote the affordability of the design. Firstly, the prototype was able to float with no issues even with the simulated wind blowing across it and it was able to successfully track the light so that the mirror is facing the solar panel(s) that would not be receiving direct sunlight. As the build and function of the prototype was very similar to the CAD model that was created from the decision matrix, the stakeholders will be pleased that not much has deviated from the model that was dependent on their needs and requirements. As shown in the FEM analysis from solidworks, the critical components that support the weight demonstrate factor of safety that are greater than 100 which means that components can be slimmed down in terms of materials or performance components can be maximised for the purpose of generating more electricity, increasing solar efficiency or even increasing overall robustness of the structure in case of stronger winds or unexpected forces that may compromise the system.

[1] IoT dashboard. The readings displayed are voltages detected by the LDR sensors.

By having an extensive roadmap on how to solve a problem, and by considering the same problem not as a singularity but a multifaceted, web of different components that involved different people, this project was able to reach targets that were more than satisfactory. The engineering approach was applied many times over as the original design needed different iterations during the planning stage and the building stage. Although many iterations and trouble shooting sessions occurred, the project upheld the promises and standards set by the stakeholders and the project requirements.

Appendix A: Arduino IDE Code

Solar_Tracking

```
//Include the servo motor library
#include <Servo.h>
//Define the LDR sensor pins
#define LDR1 A0
#define LDR2 A1
//Define the error value. You can change it as you like
#define error 50
//Starting point of the servo motor
int Spoint =  90;
//Create an object for the servo motor
Servo servo;

void setup() {
//Include servo motor PWM pin
  servo.attach(7);

//Set the starting point of the servo
  servo.write(Spoint);
  delay(15);
  pinMode(13, OUTPUT);
}

void loop() {
//Get the LDR sensor value
  int ldr1 = analogRead(LDR1);
//Get the LDR sensor value
  int ldr2 = analogRead(LDR2);


//Get the difference of these values
  int value1 = abs(ldr1 - ldr2);
  int value2 = abs(ldr2 - ldr1);

//Check these values using a IF condition
  if ((value1 <= error) || (value2 <= error)) {

  } else {
    if (ldr1 > ldr2) {
      Spoint = --Spoint;
    }
    if (ldr1 < ldr2) {
      Spoint = ++Spoint;
    }
   servo.write(Spoint);
   delay(80);
  }
    if (ldr1<=100 && ldr2<=100){
      digitalWrite(13, HIGH);
    }
    else {
      digitalWrite(13, LOW);
    }


//Write values on the servo motor

}
```

Appendix B: Arduino IoT Cloud Code

```
#include "thingProperties.h"
#include <Servo.h>
//Define the LDR sensor pins
#define LDR1 A0
#define LDR2 A1
//Define the error value. You can change it as you like
#define error 30
//Starting point of the servo motor
int Spoint =  90;

//Create an object for the servo motor
Servo servo;
void setup() {
  // Initialize serial and wait for port to open:
  servo.attach(7);

//Set the starting point of the servo
  servo.write(Spoint);
  delay(20);
  pinMode(13, OUTPUT);
Serial.begin(9600);
```

```
 initProperties();

 // Connect to Arduino IoT Cloud
 ArduinoCloud.begin(ArduinoIoTPreferredConnection);

 /*
    The following function allows you to obtain more information
    related to the state of network and IoT Cloud connection and errors
    the higher number the more granular information you'll get.
    The default is 0 (only errors).
    Maximum is 4
*/
 setDebugMessageLevel(2);
 ArduinoCloud.printDebugInfo();

void loop() {
 ArduinoCloud.update();
 // Your code here
  ldr1 = analogRead(LDR1);
//Get the LDR sensor value
  ldr2 = analogRead(LDR2);
```