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TAYLOR'S UNIVERSITY

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1.0 INTRODUCTION

With pollution on the rise during this day and age, the application and usage of renewable energy sources have been prioritized as an alternative source of power. This is due to the fact that current sources of energy used such as petroleum emit harmful gases as its by-product. This in turn damages the quality of air and the environment itself. Therefore, efforts have been made by countries all over the world to use renewable energy sources such as wind and wave energy to act as the primary source of power for everyday life.

Under the Malaysian Government's Feed-in Tariff (FiT) system, a local electricity company, Tenaga Nasional Berhad (TNB) Energy Services has taken a step forward into the application and usage of renewable energy by outsourcing their solar farms to private companies. A good example of this would be a solar farm run by a partner company called Fortune 11 Sdn. Bhd. **[3]** Both parties practise a buyer-supplier relationship to provide electricity generated from the solar farm for commercial use. This project is located in Sepang, Selangor and is the first solar farm with single-axis system. More details on Fortune 11 solar farm will be discussed in *Background/Report of Fortune 11 Solar Farm* section. **[1]**

However, TNB has faced issues on the maintenance side of the solar farm. This is mainly caused by the cleaning procedure of the solar panels themselves. **[1]** According to IR Muhammad Rhaiz Abdul Aziz from TNB, the maintenance of the panels is not only very time consuming (manual labour) but also can be costly if automatic cleaning machines were used. This is due to the substantial amount of panels that need to be cleaned. In addition, a large amount of water is required to do the cleaning. Thus, water wastage is a possible occurrence. **[1]**

Nonetheless, the maintenance of these panels is essential to ensure the efficiency of solar energy that is being converted to electrical energy. **[1]** Based on a statement by the TNB representative, the conversion of energy drops by a rate of up to 30 % due to the panels being dirty. A study conducted by Google at their solar farm in Mountain View, California further proves and emphasizes on the cleanliness of solar panels in farms. Results obtained showed panels that were well maintained over a 15-month period were able to produce double the output of electricity that was initially expected. **[2]** The study also proved that using rain as a natural way of cleaning the panels was not as efficient as cleaning them professionally.

Although using rain saves cost and labour, professional cleaning of the panels yielded 12 % more output as oppose to those cleaned by rain water. **[2]**

With maintaining the solar panels set as a top priority, TNB have looked around for alternative methods of cleaning their panels. Examples of professional methods include Heliotex technology, electrostatic cleaning and robotic cleaners. **[3]** All available methods will be further explored in the *Literature Review* section. However, these methods have one thing in common; they would cost a large amount of initial investment by TNB. For the company to turnover an acceptable profit margin, solar energy has to be widely used across the country and even so, the amount of time needed for that to happen may be long. The cost may not be be covered and instead cause a loss for the company.

Therefore, IR Muhammad Rhaiz has requested our team to come up with a locally designed and built automated robotic cleaning system that can satisfy the required needs for maintaining a large scale solar farm and also cost efficient. The project given to our team is divided into 2 parts. The first part which will be focused on planning and designing the system within a time period of 14 weeks was completed in the previous semester (MEGP 1). Based on the CDIO method, this is called the Conceive (C) and Design (D) stage of the project. **[6**] In this semester, the team will move on to actually building, testing and making sure that the system is able to function according to the requirements set within a time period of 14 weeks. This is known as the Implement (I) and Operate (O) stage of the project. Therefore, our team will be using the appropriate and necessary methods in this stage of CDIO to try and completely build the proposed prototype in addition to making it fully functional.

1.1 BACKGROUND OF TNB SOLAR FARM

In Malaysia, the local electricity company, Tenaga Nasional Berhad (TNB) Energy Services has taken a step forward into the application and usage of renewable energy by constructing a large scale solar farm. **[4]** This project is located in Mukim Tanjung 12, Sepang and has been in operations since 23rd November 2018. It is the largest solar farm in the country to date with an area of 98 hectares. **[4]** The farm uses 230000 solar panels to generate 50 MWac of electricity to the national power grid. That value has since increased to 73.2 MWac in the month of December 2018 which is in line with the Malaysian Government's aim of promoting the use of clean and renewable energy sources. **[4]** The solar farm project was won by TNB's subsidiary company, TNB Sepang Solar Sdn. Bhd., in a Government led Large Scale Solar (LSS) auction in 2017. **[5]** Another subsidiary of TNB, TNB Engineering Corporation Sdn. Bhd. acted as the EPC partner for the project.

Figure 1: TNB's Solar Farm located at Sepang

However, TNB has faced issues on the maintenance side of the solar farm. This is mainly caused by the cleaning procedure of the solar panels themselves. **[6]** According to IR Muhammad Rhaiz Abdul Aziz from TNB, the maintenance of the panels is not only very time consuming (manual labour) but also can be costly if automatic cleaning machines were used. This is due to the substantial amount of panels that need to be cleaned. In addition, a large amount of water is required to do the cleaning. Thus, water wastage is a possible occurrence. **[6]**

Nonetheless, the maintenance of these panels is essential to ensure the efficiency of solar energy that is being converted to electrical energy. **[5]** Based on a statement by the TNB representative, the conversion of energy drops by a rate of up to 30 % due to the panels being dirty. A study conducted by Google at their solar farm in Mountain View, California further proves and emphasizes on the cleanliness of solar panels in farms. Results obtained showed panels that were well maintained over a 15-month period were able to produce double the output of electricity that was initially expected. **[2]** The study also proved that using rain as a natural way of cleaning the panels was not as efficient as cleaning them professionally. Although using rain saves cost and labour, professional cleaning of the panels yielded 12 % more output as opposed to those cleaned by rainwater. **[2]**

Figure 2: Google's Solar Farm in California

With maintaining the solar panels set as a top priority, TNB has looked around for alternative methods of cleaning their panels. One example of a professional method is by using Heliotex technology. **[3]** This is a viable option as it not only cleans the panels professionally but also does it automatically without the need for human labour. Besides that, electrostatic cleaning is also an efficient method of cleaning the panels. Nicknamed 'Harvesting Electricity', this method uses electrostatic charges on transparent sheets of glass or plastic placed on top on panels to detect dust levels and activate cleaning mode when necessary. **[3]** Another method is by using robotic cleaning solutions. This method cleans solar panels automatically based on the specific instructions programmed into the 'robot' (machine). **[3]**

Figure 3: Robotic Cleaning Method

Figure 4: Heliotex Technology

However, each method mentioned had one thing in common. They all would cost a large amount of initial investment by TNB. For the company to turnover an acceptable profit margin, solar energy has to be widely used across the country and even so, the amount of time needed for that to happen may be long. The cost may not be covered and instead, cause a loss for the company. Therefore, IR Muhammad Rhaiz has requested our project team to try and come up with a locally designed and built automated robotic cleaning system that is not only able to satisfy the required needs for maintaining a large scale solar farm but also is cost-effective. The task given to the team is divided into 2 parts. The first part has a time period of 14 weeks for planning and designing the system. Based on the CDIO method, this is called the Conceive (C) and Design (D) stage of the project. **[6]** Therefore, our team will be using the appropriate and necessary methods in this stage of CDIO to try and come up with a solution for the issue at hand. The team has also proposed a potential collaboration with Karcher Malaysia as they are well known for their cleaning expertise. All further progress will be recorded by the team from time to time.

1.1.1 TNB's Future Plans

As a company that acts as the main supplier of power to the entire country, TNB has taken the initiative to begin using renewable energy to generate power for the nation. Although coal and fuel are still major sources of power, TNB has plans to increase the use of renewable energy in the near future. In March 2019, TNB's green solutions were displayed at the Asean Super Mechanical & Electrical Engineering Show at the Malaysian International Trade and Exhibition Centre (MITEC). **[7]** Some of its subsidiary companies were showcased there. One example was GSparx Sdn. Bhd. This company offered end-to-end solutions with zero upfront payments from its clients. Services such as consultation, monitoring and maintenance were offered without any costs involved. **[7]** A statement by GSparx's head of marketing, Nor Ziha Zainol Abidin, says that the company's current focus is on solar PV rooftops. In the future, GSparx plans to come up with battery storage solutions and many more.

A premium alternative to the PV panels provided by GSparx is actually a roof with a solar thin film built in. This product technology is provided by Tenaga Switchgear. **[7]** The chief of business development, Umar Ridzuan Hawari said that this alternative product has two functions. It not only generates power but also provides the usual protection against external environmental elements. He also stated that the tiles come with a home energy storage system. This system consists of a liquid-based battery system (like the voltage-regulated acid battery) which is not only safer but also does not heat up much. **[7]**

Figure 5: Umar (centre-left) explaining to Works Minister, Baru Bian (centre-right) about Solar Roof Tiles

Besides these companies, another green subsidiary, TNB Engineering Corporation Sdn Bhd (TNEC) focuses on large scale solar farm setups in addition to district cooling systems (DCS). **[7]** Head of Project Development and Implementation, Rizuan Eusoff said in a statement, *"Basically our major businesses are district cooling systems plants and large-scale solar installation." "District cooling plants, like the one at KLIA2, is a centralised air conditioning plant that supplies chilled water to the whole KLIA2 airport development. A district cooling plant with thermal energy storages is able to reduce the electricity cost compared to conventional plant."* **[7]**

Figure 6: Rizuan Eusoff at MITEC

TNEC provides the full range of services related to DCS. He also added that TNEC spearheaded the construction of 2 large scale solar farms in 2018 which are, the well-known 50 MWac capacity farm, TNB Sepang Solar in Selangor and the 29 MWac capacity farm, Leader Solar Energy in Sungai Petani, Kedah. A brand new 30 MWac solar farm located in Bukit Selambau, Kedah is under construction and shall be completed by 2020. **[7]**

In fact, the solar farm project in Bukit Selambau only got approved recently. The project got the 'Green Light' after TNB's unit, TNB Bukit Selambau Solar Sdn. Bhd. (TBSS) secured a financial close for the project worth RM 144 million with MUFG Bank (M) Bhd. **[8]** The bank has agreed to provide all the funding and capital required by the project. TBSS was awarded the project by TNB's Energy Commission through a competitive bidding system. A statement by TNB noted that the solar farm would have a generation capacity of 30 MW with a direct current installed capacity of 45 MWp. **[8]** TNB further stated that all of its solar farms further reinforces their commitment and aspiration towards the application and expansion of the use of renewable energy in Malaysia. 20 % of the country's electricity is targeted to be produced by renewable energy sources by 2030. This is a major increment from the current value of 2 % according to The Energy, Science, Technology, Environment and Climate Change Ministry. **[8]**

1.2 BACKGROUND/REPORT ON FORTUNE 11'S SOLAR FARM

Since TNB's Solar Farm is unavailable for public access due to an unfinished entrance road, TNB's IR, Mr. Rhaiz and our module coordinator/ lecturer, Dr. Faizal have requested for us, Team Solar Fam to focus our project on TNB's partner's solar farm run by a local company known as Fortune 11. **[9]** Hence, on the 29th of April 2019, we made a site visit to their solar farm located in Sepang, Selangor to gather more insight on the current state of the farm and the issues that they face with cleaning the solar panels available there.

Figure 7: Fortune 11's Solar Farm at Sepang, Selangor

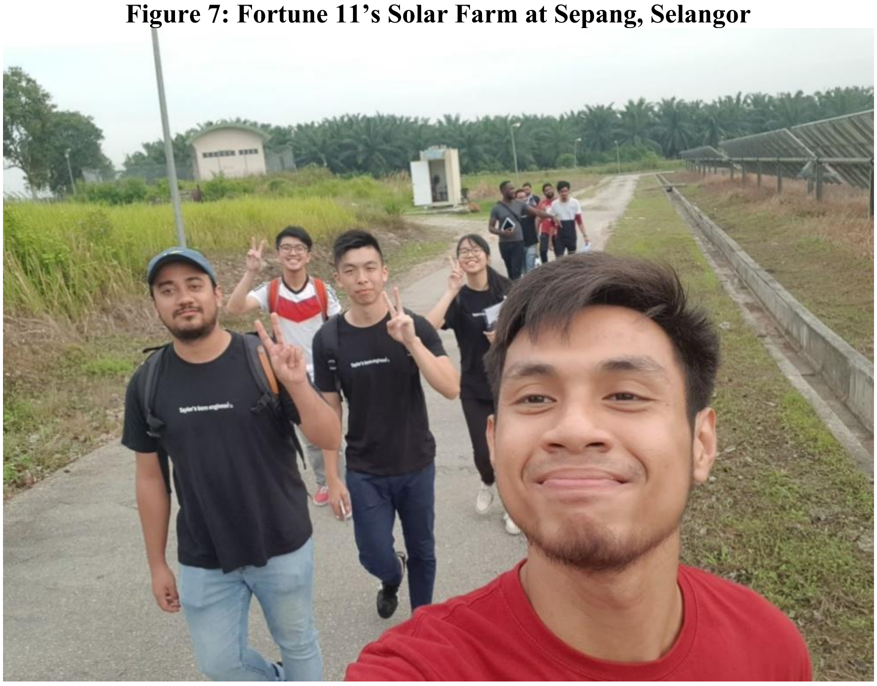


Figure 8: Team Picture at the Solar Farm

Our lecturer, Dr. Faizal also took the time off to tag along with the team for the site visit. At the farm, we managed to meet up with Fortune 11's Head of Operations & Maintenance, En. Idham along with the farm's caretaker, En. Johari. **[9]** Since they both have a first-hand experience of maintaining the solar panels on the farm, our team prepared a questionnaire prior to our visit for them to answer. This was to allow the team to gain more information on the farm and the cleaning methods currently used on the solar panels.

<u>LIST OF QUESTIONS FOR TNB</u>

1. Type of solar panel TNB used (lifetime)
2. Size of panel (Dimensions/Weight)
3. Specification of solar panels (electricity generated)
4. How they clean it /problems faced cleaning
5. How often?
6. How they detect and know when to clean the solar panel
7. Cost of cleaning & labour / no. of workforce required
8. Types of dirt (bird shit or dust, leaves)
9. Pics & vids of worker cleaning the panels
10. How they know if it's clean enough (if got graph, numbers/ figures as proof)
11. Confirm number of panels
12. Expectation from TNB/ budget given for Team solar fam
13. Max weight / force applied can be on top of panel

From our meeting and interview with Mr. Idham and Mr. Johari, we managed to gain a lot of information about the solar farm. Firstly, the solar farm is 20 acres in size and contains 17120 solar panels. **[9]** The solar farm has a plant capacity of 5 MWh and it is able to generate up to 20 MWh of electricity per day. The electricity generated is then converted to have an AC output for distribution to TNB and other customers that they have. **[9]** The solar panels used by Fortune 11 are from a local manufacturer known as MEMC Electronic Sdn. Bhd. (formerly known as SunEdison Sdn. Bhd.) **[9]**


Figure 9: MEMC brand Solar Panels used by Fortune 11

In addition to these, 3 types of solar panels are used on the farm. **[9]** They vary in terms of power output by each panel. The difference in power is as shown below:

- 290 W
- 295 W (Average power output of each panel)
- 300 W

The panels are also arranged in a way whereby there are 40 panels in a set and there are 4 sets in a row. **[9]** The sets of panels have an estimated gap of 1.12 m in between them. This, according to Mr. Idham, is to allow for the circulation of air to occur. This is especially crucial during windy periods and heavy downpour as the panels are prevented from falling over and being blown away with the help of the air gaps. **[9]** Furthermore, the solar panels have an automated moving feature (single-axis system) that allows the panels to move in the direction of the sun. This is possible due to the panel's movement path being pre-programmed using a programmable logic controller (PLC) system.

The location of this solar farm is isolated and the solar panels are fixed higher from the ground. Hence, it suffers from fewer types of contaminants (mainly dust, mud and bird droppings) as compared to other solar farms that are close to areas prone to contaminants such as rubbish dump sites.

Regarding the cleaning methods used for the solar panels, our questions were answered by Mr. Johari, who is the lead caretaker of the farm. We found out that the most common method of maintaining the panels is by using natural rain water. **[10]** According to Mr. Johari, this technique is used because there are no extra cost and labour involved. If the panels were not able to be cleaned by rain, then a couple of workers needed to use a mop and water to further clean the panels (manual method). No nylon material and soap or chemical cleaning solution is used due to concerns of potential damage to the solar panels. Although these are not the best maintenance methods for solar panel efficiency, they are used regardless due to the fact that advanced solar panel cleaning methods are very expensive. **[10]**

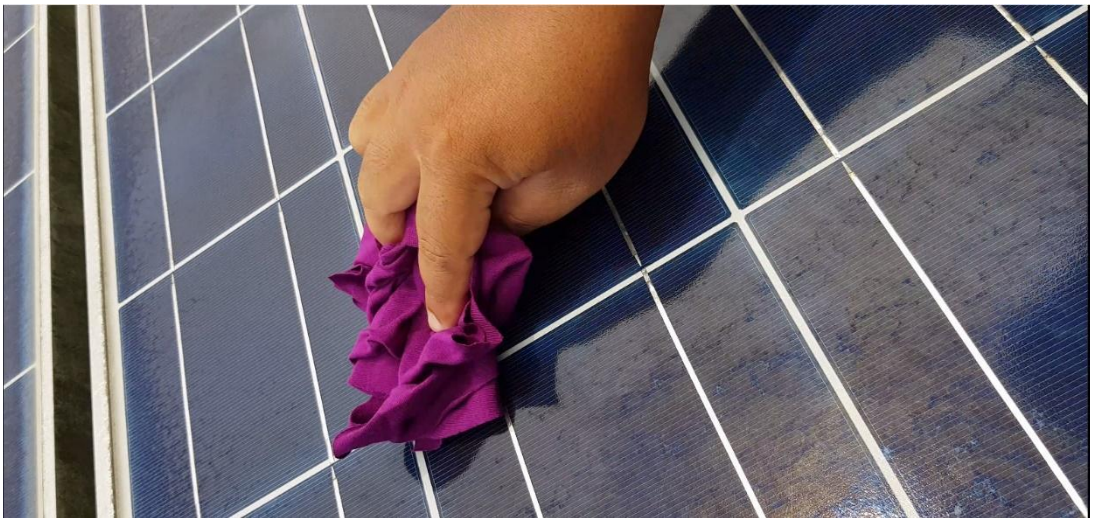


Figure 10: Manual Cleaning Method of Solar Panels at the Farm

If there are insufficient rainy periods, then the manual method is used to clean the panels once a month. **[10]** Mr. Johari also stated that the cleanliness and condition of the solar panels are visually monitored. This is due to the absence of an automated tracking and inspection system. The cost, based on monetary value and time, of having daily inspection and cleaning of panels is as shown in the table below. **[10]**

Table 1: Estimated Cost of Using Fortune 11's Method of Maintaining Solar Panels (Based on Time)

Number of Workers	10
Total Number of Solar Panels	17120
Number of Available Working Days per Week	5 days
Standard Working Hours per Day	9 hours
Total Working Hours per Week	45 hours per week
Cleaning Method Used	Manual (Water, soap, brush/ mop)
Time to Clean & Inspect 1 Panel	1 minute 15 s
Number of Solar Panels in a Set (Row)	40
Amount of Panels Cleaned & Inspected by 10 Workers in 5 minutes	40 (4 panels per worker)
Number of Panels Cleaned & Inspected per Hour	480 Panels per Hour
Number of Panels Cleaned and Inspected per Working Day	4320 Panels per Day
Total Time Required to Clean & Inspect All Panels (1 cycle)	4 days
Number of Cleaning Cycles in a Month	5 cycles

Table 2: Estimated Cost of Using Fortune 11's Method of Maintaining Solar Panels (Based on Monetary Value)

Total Cost of 10 Worker's Salary per Month (5 working days, 4 weeks per month)	RM 12000 per Month
Total Cost of Soap per Month	RM 4708
Total Cost of Water per Month	RM 19509.45
Total Cost of Brushes per Month	RM 1712
Total Cost of Mops per Month	RM 170
Total Monthly Cost (Expenditure)	RM 38059.45

Based on the table, it can be seen that the cost is extremely high for daily cleaning and inspection of solar panels. To avoid losses, Fortune 11 prefers the current method of solar panel maintenance being used. **[10]** However, the current method decreases solar panel efficiency in the long run.

Therefore, TNB's IR, Mr. Rhaiz has requested for us to focus our project on solving this issue. The expectation is for us to build an autonomous solar panel cleaning robot that is:

1. Effective and efficient
2. Lightweight and easy-to-use
3. Low cost and maintenance
4. Adaptable to shifting arrangements of solar panels
5. Flexibility in cleaning various types of contaminants
6. Has its own dirt tracking system **[11]**

The product of our project will be tested out on Fortune 11's farm first before getting approval from TNB themselves.

Figure 11: Team Picture with IR Mr. Rhaiz, Mr. Johari and Mr. Idham

1.3 COLLABORATORS

As stated in the team's final report from Semester 5 (MEGP 1), the team intended to collaborate with Karcher Cleaning Systems Malaysia to successfully build this project. This is because Karcher is well-known for their cleaning systems and products. Therefore, the team felt that by collaborating with Karcher, more in depth knowledge about various cleaning systems could be obtained and this in turn will benefit the team when working on this project. With this intention in mind, the team drafted necessary letters and documents to make this collaboration happen. However, there was no response or reply from any of Karcher Malaysia's superior officers last semester.

Nonetheless, the team did not want to give up easily. Hence, the team had a meeting with Karcher Malaysia this semester to discuss the potential collaboration plans. The team was asked to draft new documents and letters because Karcher was under new management. So, the team obliged and did the necessary paper work. Unfortunately, there was still no reply after a month of waiting. Thus, the team decided not to wait any longer as the time delayed may cause the project to not be completed.

As the team was surveying and buying materials, the team found a company named Rajini Welding Works. After several meetings and consultations, both parties agreed to collaborate on the project. Even though this company was not a cleaning system provider, Rajini Welding Works did assist the team in improving and finalizing the design of the prototype. The collaboration overall was a successful one as the team obtained a multi-functional frame for the solar panel cleaning robot. Further details of this collaboration and the 'behind the scenes' work done by both parties will be discussed in the implementation section of this report.

Figure 12: Team Consultation with Rajini Welding Works

2.0 OBJECTIVES

In the previous Final Report for MEGP 1, the team had gathered information and covered all possible questions regarding the challenge. This aids in designing a solution that addresses all the root causes the first time around or with as little changes needed.

The Ishikawa Diagram technique involves classifying the potential causes of an issue in order to pinpoint its root cause. This diagram also helps us to organize the causes systematically and act as a guide for us to create solutions.

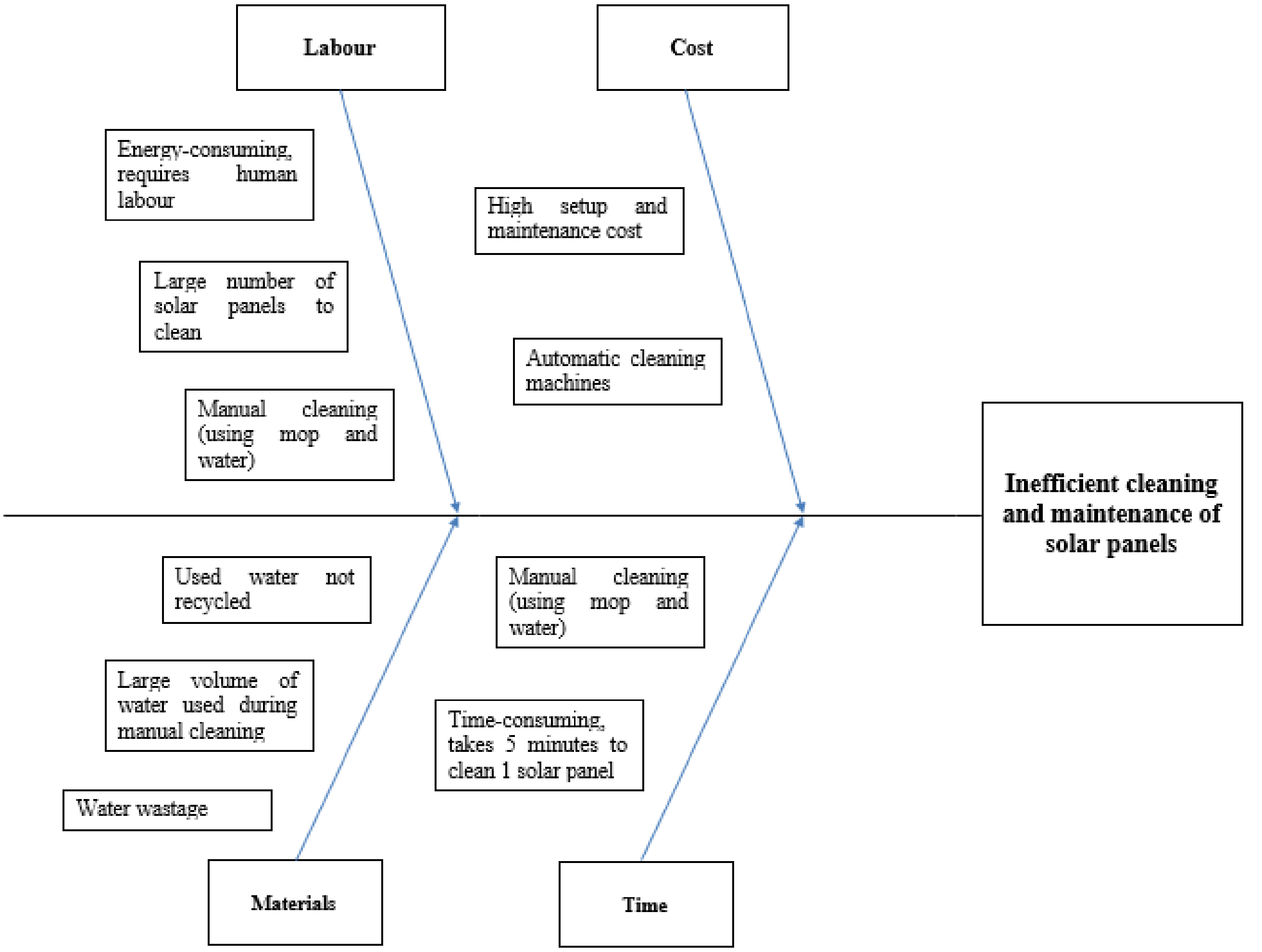


Figure 13: Ishikawa Diagram

Based on **Figure 13** and also referring to the section *Background/ Report on Fortune 11 Solar Farm*, the objectives are:

1. To create an autonomous solar panel cleaning robot which is:
    - Effective and efficient
    - Lightweight and easy-to-use
    - Low cost and maintenance
    - Adaptable to shifting arrangements of solar panels
    - Flexibility in cleaning various types of contaminants
    - Has its own dirt tracking system

2. To complete the construction of the final working product by Week 14 of Semester 6.

3.0 ENGINEERING ANALYSIS

During MEGP 1, team Solar Fam utilised five methods of analysis to compare the 3 different designs and ultimately pick the most ideal design among the 3. The methods used are as follows:

- Cost Analysis
- Business Value Analysis
- ANSYS Analysis
- Solidworks Analysis
-

3.1 ANSYS Simulation for Stress

3.1.1 Solar Panel

The Solar panel is mounted onto a frame where the supports are attached to it. The material of the frame is made from aluminium alloy which has the yield strength of 50 MPa and its ultimate strength amounts up to 90 MPa. When an estimated force of 1962 N (200 kg) is acting on the panel frame, a stress of about 10.5 MPa is exerted on the panel. It can be illustrated through the pictures as shown below.

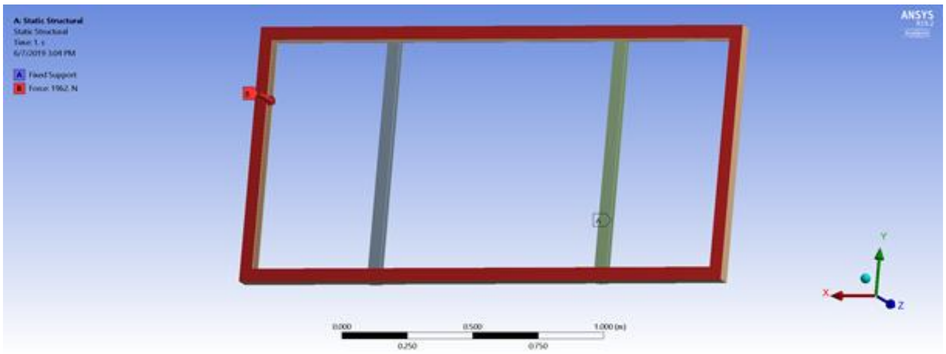


Figure 14: Force applied on the solar panel frame

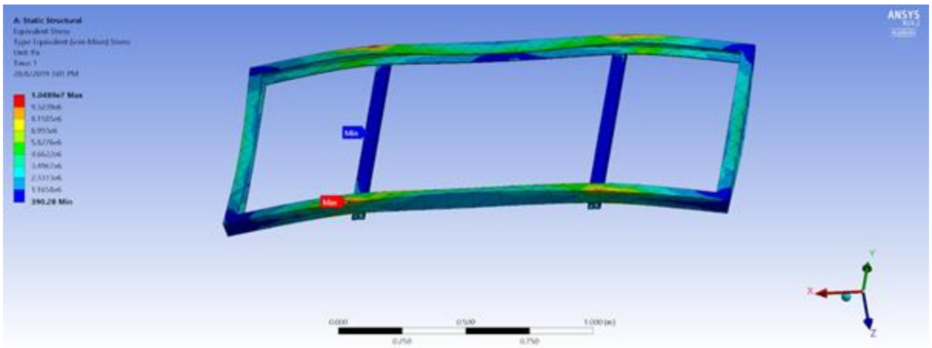


Figure 15: ANSYS Stress analysis of solar panel frame

3.1.2 Design 2 (Wet Dry)

With an initial estimate of 40 kg allocated for design 2 (wet dry), the weight of the machine is divided among the 2 bars and would result in the stress shared between the 2 bars. By setting the locks at the edges set as the fixed support, the 40kg weight divided into 2 which is translated to about 196.2 N of force per side. The stress calculates to about 9.59×10^5 Pa or 0.96 MPa.

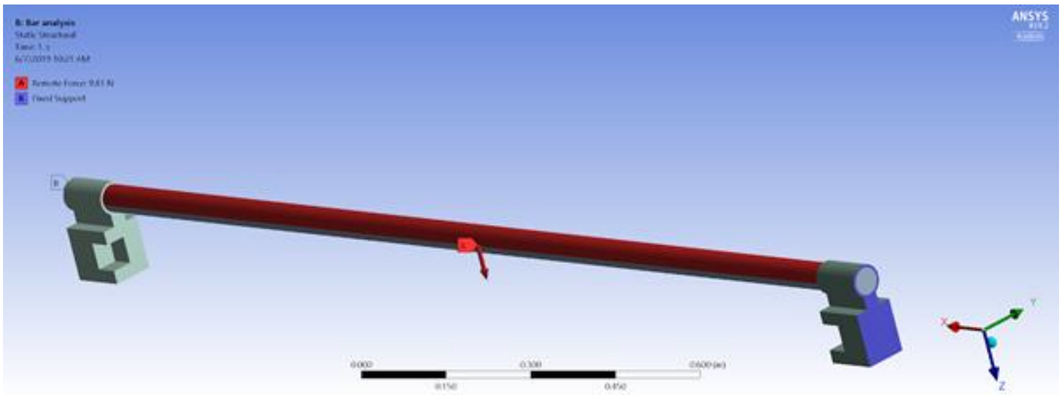


Figure 16: Setup of the ANSYS Stress test for design 2

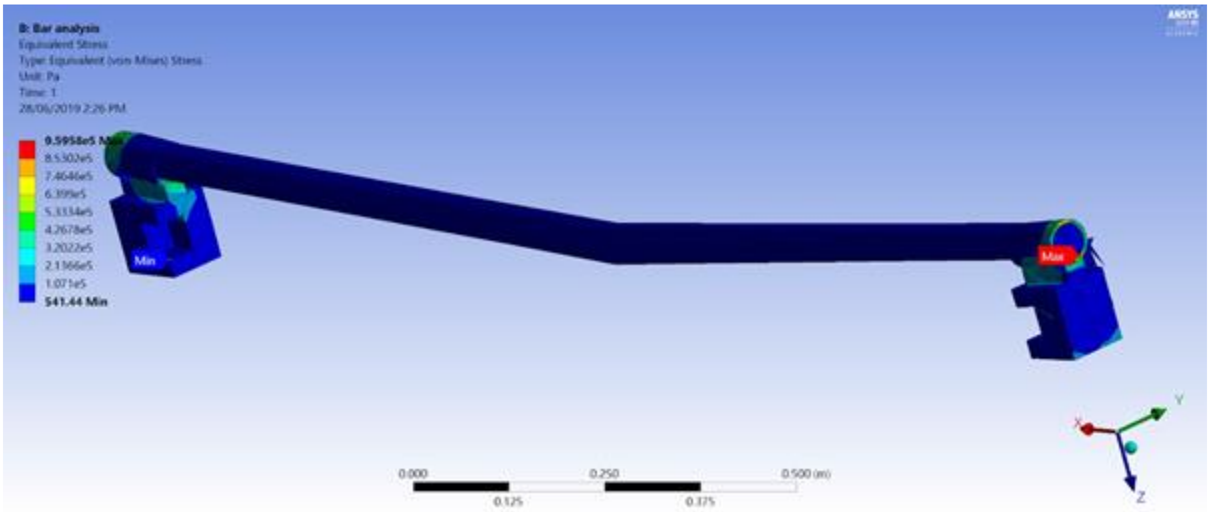


Figure 17: ANSYS Stress analysis of Design 2 bars

Table 3: ANSYS Stress analysis data

Design	Dry	Wet Dry	Ultrasonic	**Solar Panel & Frame**
Estimated Weight	20kg	40kg	25kg	**25kg**
Estimated Stress	6.55x10^5 Pa	9.59x10^5 Pa	8.19x10^5 Pa	**1.05x10^7 Pa**

Since the stress and weight of design 2 does not exceed the stress limit of 1.05×10^7 Pa, deformation will not occur on the solar panel frame and damage the solar panel.

3.2 Solidworks Simulation Analysis

After running ANSYS simulations for design 2, the team used Solidworks simulations to roughly simulate how maintenance is done for a solar panel. Design 2 only takes roughly 45 seconds to clean a single panel which would mean that a whole row of 20 panels. Based on the theory that with less moving parts or links suchs as binary, ternary and quaternary links, it lesser amount of power is needed for movement as well as lesser amount of maintenance is required for the overall design in Design 2. **[12]** Grubler’s equation is used to find the numbers of links within a body which calculates the degrees of freedom. **[13]**

$$F = 3(n-1) - 2j_1 - j_2$$

F = Mobility or number of degrees of freedom

n = Number of links including frame

j_1 = Joints with single or one degree of freedom

j_2 = joints with two degrees of freedom

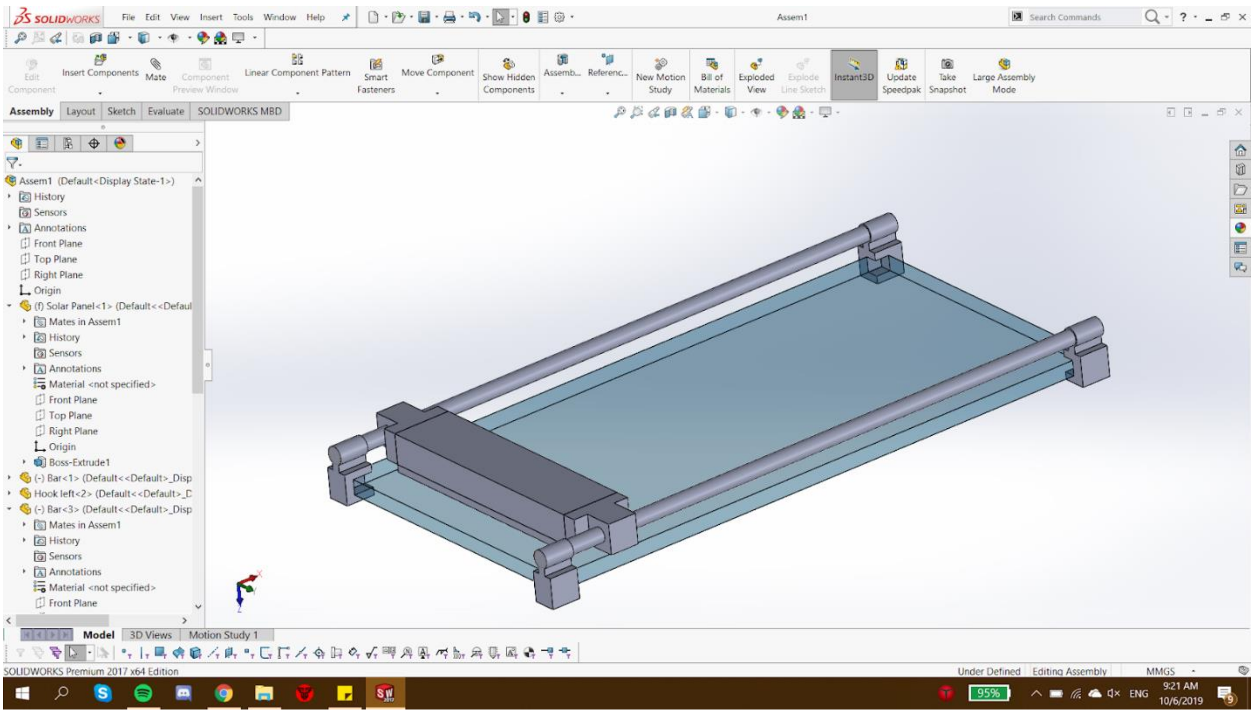


Figure 18: Solidworks of Design 2

3.3 Cost Analysis

When a business makes an expenditure or an investment, there are a few factors that come into play. These factors include prospective revenue brought in by the product, price of the product and net profit or loss from acquiring the product. Price is described as the value of expenditure in the form of money spent on things such as labour, equipment and rent in order for a business to function to its full capability. **[14]** Net profit or loss is the measure of a business' earnings after all operating expenses, interest and taxes have been deducted from the business' total revenue. **[15]** Loss is when the business' spending outweighs its total revenue. Moreover, revenue can be defined as the total income of a business. **[16]** The formula used to calculate either profit or loss is as follows:

$$\text{Total Revenue - Total Cost} = \pm\text{ve Value Profit or Loss}$$ **[16]**

The purpose of making a cost analysis is to show if the design would profit a business or even bring a business loss. We gathered information on how Fortune 11 maintained their solar panels which was just natural rain water. **[17]** Bird droppings were stubborn to remove which would entail manual labour by using a mop/brush with some soap and water.

Table 4: Cost of Using Fortune 11's Method of Maintaining Solar Panels (Based on Time)

Number of Workers	10
Total Number of Solar Panels	17120
Number of Available Working Days per Week	5 days
Standard Working Hours per Day	9 hours
Total Working Hours per Week	45 hours per week
Cleaning Method Used	Manual (Water, soap, brush/ mop)
Time to Clean & Inspect 1 Panel	1 minute 15 s
Number of Solar Panels in a Set (Row)	40
Amount of Panels Cleaned & Inspected by 10 Workers in 5 minutes	40 (4 panels per worker)
Number of Panels Cleaned & Inspected per Hour	480 Panels per Hour
Number of Panels Cleaned and Inspected per Working Day	4320 Panels per Day
Total Time Required to Clean & Inspect All Panels (1 cycle)	4 days
Number of Cleaning Cycles in a Month	5 cycles

Example Calculations for Table

Total working hours per week = 9 hours × 5 days

= 45 hours per week

Time to clean & inspect 1 panel per worker = 1.25 minutes

In 5 minutes, number of panels cleaned and inspected per worker = $\frac{5\ minutes}{1.25\ minutes\ per\ panel}$

= 4 panels

Amount of panels cleaned & inspected by 10 workers in 5 minutes = 10 workers × 4 panels

= 40 panels

Number of panels cleaned & inspected per hour = $\frac{60\ minutes}{5\ minutes} \times 40\ panels$

= 480 panels

Number of panels cleaned & inspected per working day = 480 panels × 9 hours

= 4320 panels

Total time required to clean & inspect all panels (1 cycle) = $\frac{17120\ panels}{4320\ panels\ per\ day}$

= 3.96 days

~ 4 days

Number of cleaning cycles in a month = $\frac{20\ working\ days}{4\ days\ per\ cycle}$

= 5 cycles per month

Figure 19: Cost of using Fortune 11's Method of Maintaning Solar Panels (Based on Time), Split into 6 Types of Costing

a) Worker Cost

Cost per Worker	RM 60 per Day
Cost of 10 Worker's Salary per Day	RM 600 per Day
Total Cost of 10 Worker's Salary per Month (5 working days, 4 weeks per month)	RM 12000 per Month

b) Soap Cost

Amount of Soap Used per Cycle	171.2 kg
Amount of Soap Used per Month (5 cycles)	856 kg
Cost of Soap (4 kg Packet from Lazada)	RM 22
Total Cost of Soap per Month	RM 4708

c) Water Cost

Amount of Water Used per Cycle	1712 *l*
Amount of Water Used per Month (5 cycles)	8560 *l*
Cost of Water per *l* **(Based on SYABAS Rates for Commercial Use) [31]**	RM 2.07 per first 35 *l* RM 2.28 above 35 *l*
Total Cost of Water per Month	RM 19509.45

Figure 20: Cost Calculation

d) Brush Cost

Amount of Brushes Used per Cycle	171.2
Amount of Brushes Used per Month (5 cycle)	856
Cost of Brushes (From Lazada)	RM 2 per Brush
Total Cost of Brushes per Month	RM 1712

e) Mop Cost

Number of Mops Used per Cycle	2.4
Number of Mops Used per Month (5 cycle)	17
Cost of Mops (From Lazada)	RM 10 per Mop
Total Cost of Mops per Month	RM 170

f) Total Cost

Total Monthly Cost (Expenditure)	RM 38059.45

Figure 21: Cost Calculation

Example Calculations for Table

a) <u>Worker Cost</u>

Cost per worker = RM 60 per day

Cost of 10 workers per day = RM 60 × 10 = RM 600

Cost of 10 workers per month = RM 600 × 20 = RM 12000

b) <u>Soap Cost</u>

1 small scoop of soap = ~ 100 grams

100 grams of soap can clean 10 panels

So, 100 panels require = 100 grams × 10 panels

= 1000 grams/ 1 kg of soap

Amount of soap required to clean all panels (1 cycle) = $\frac{17120\ panels}{100\ panels}$ × 1 kg

= 171.2 kg of soap

Amount of soap required for 5 cycles = 171.2 kg × 5 cycles = 856 kg

Cost of 4 kg soap from Lazada = RM 22

Total cost of soap per month = $\frac{856\ kg}{4\ kg} \times RM\ 22$ = RM 4708

c) <u>Water Cost</u>

1 l of water can clean = ~ 10 panels

10 l of water can clean = 10 panels × 10 l = 100 panels

Amount of water required to clean all panels (1 cycle) = $\frac{17120\ panels}{100\ panels}$ × 10 l

= 1712 l

Amount of water required for 5 cycles = 1712 l × 5 cycles = 8560 l

Figure 22: Cost Calculation

Cost of Water per l (Based on SYABAS) = RM 2.07 per first 35 l, RM 2.28 above 35 l

Cost of water for first 35 l = RM 2.07 × 35 = RM 72.45

Cost of water above 35 l = (8560 l – 35 l) × RM 2.28 = RM 19437

Total cost of water per month = RM (72.45 + 19437) = RM 19509.45

d) <u>Brush Cost</u>

1 Brush can clean 100 panels

Amount of brushes required to clean all panels (1 cycle) = $\frac{17120\ panels}{100\ panels} \times$ 1 brush

= 171.2 brushes

Amount of brushes required for 5 cycles = 171.2 brushes × 5 cycles = 856 brushes

Cost of 1 brush from Lazada = RM 2

Total cost of brushes per month = RM 2 × 856 brushes = RM 1712

e) <u>Mop Cost</u>

*mop used for panels placed at high/ hard to reach positions

1 mop can clean 5000 panels

Amount of mops required to clean all panels (1 cycle) = $\frac{17120\ panels}{5000\ panels} \times$ 1 mop

= 3.4 mops

Amount of mops required for 5 cycles = 3.4 mops × 5 cycles = 17 mops

Cost of 1 mop from Lazada = RM 10

Total cost of mops per month = RM 10 × 17 mops = RM 170

f) <u>Total Monthly Cost</u>

RM (120 + 1712 + 19509.45 + 4708 + 12000) = RM 38049.45

Figure 23: Cost Calculation

Now that the team had Fortune 11's monthly cost and revenue, we then calculated the monthly net profit and profit margin of the company.

Net profit = Total Revenue – Total Cost

= RM 326400 – RM 38049.45

= RM 288350.35

$$\text{Profit Margin} = \frac{Net\ Profit}{Total\ Revenue} \times 100\ \%$$

$$= \frac{RM\ 288350.35}{RM\ 326400} \times 100\ \%$$

= 88.34 %

We then evaluated our design based on the costs needed. From there, we calculated the potential net profit or loss that the design could make established on the continuous revenue attained by Fortune 11.

3.3.1 Design (Wet Dry)

Table 5: Bill of Materials of Proposed Design

Bill of Material						
No.	Material	Description	Vendor	Unit Price (RM)	Quantity	Total (RM)
1	Aluminium Frame (8m total)	0.13 m x 0.13m x 0.3 m RM 10 per 0.3m = RM 270	Lelong	Rm10/0.3m	8m	RM270
2	Stainless steel body	0.5 m x 0.3m x 0.0005 m = RM 136.55 x 2 = RM 273.10	Online shop	Rm26.20/rod	2m	RM52.40
3	Electrical Cable (5m)	Old project or shopping	Taylors lab/ shopee	Rm 2 per 15cm x 10pc	40	Rm 8.00
4	12V DC motor (x2)	Pudu shop = RM 23	Vendor	RM23/pc	2	RM46
5	Roller Brush	RM 3.34 per pc	Alibaba	RM3.34 per pc	1	RM3.34
6	Vacuum	Karcher Malaysia	Karcher	RM 600 per pc	1	RM600.00
7	Sprinkler system (x2)	Low Pressure	Lelong	RM15 per set	2	RM30
8	Castor wheel (x2)	4.6 cm diameter RM 16 per 4pc= RM 8	Lelong	RM4 per pc	2	RM8
9	Rubber Lip	Wiper	Karcher Malaysia	RM 20 per pc	2	RM40
10	Arduino	Motherboard	Cytron	RM96 per pc	1	RM96
11	Battery	12V Lipo	Cytron	RM12.50 per pc	1	RM12.50
12	Lock	Online shop	Lelong	RM 4 per pc	4	RM16.00
Grand Total (RM)						**RM1,182.24**

Table 6: Bill of Materials for Monthly Maintenance of Proposed Design

Part	Quantity	Unit Price	Total Cost
Roller Brush	2	RM 3.34	RM 6.68
Oil/ Lubricant for Motor (From Lazada)	1 bottle	RM 115.00	RM 115.00
Vacuum Service (After 1 year warranty by Karcher)	Once Monthly	RM 40	RM 40
Rubber Lip (After 1 year warranty by Karcher)	2 pieces	RM 47.29	RM 94.58
Water (Able to be recycled)	214 *l*	RM 2.07 per first 35 *l* RM 2.28 above 35 *l*	RM 480.57
Soap (Able to be recycled)	21.4 kg	RM 5.5 per kg	RM 117.70
Grand Total			**RM 854.53**

Table 7: Bill of Materials of Final Design

No.	Material	Description	Vendor	Unit Price (RM)	Quantity	Total (RM)	Project Total (RM)
1	Wiper Washer	Water Sprinkler	Meter Trading	28	1	28	28
2	arboy Wiper 12"	Rubber Lip	Meter Trading	13	1	13	41
3	Mega Ch340G	Arduino Mega	QQ Trading	60	1	60	101
4	Optical Dust Sensor	Dust Sensor	QQ Trading	50	1	50	151
5	Arduino Motor Shield	Motor Shield	QQ Trading	15	1	15	166
6	Bluetooth Module HC-05	Bluetooth Module	QQ Trading	25	1	25	191
7	Jumper M-F 12cm	10 pc Jumper M-F 12cm	QQ Trading	1.8	1	1.8	192.8
8	Jumper M-M 12cm	10 pc Jumper M-M 12cm	QQ Trading	1.8	1	1.8	194.6
9	Jumper M-F 20cm	10 pc Jumper M-F 20cm	QQ Trading	2	1	2	196.6
10	Jumper M-M 20cm	10 pc Jumper M-M 20cm	QQ Trading	2	1	2	198.6
11	Lipo Battery	Lipo 11.1V 8C 2200 MAh	QQ Trading	62	1	62	260.6
12	Metal Shaft	Metal Shaft (8mm x 400mm)	QQ Trading	14	2	28	288.6
13	Disc Screw Coupling	Shaft Connector (6mm for 8mm Shaft)	QQ Trading	10	4	40	328.6

14	DC Gear motor	Gear Motor (12V 500RPM 37mm)	QQ Trading	43	4	172	500.6
15	Ultrasonic sensor HC SR04	Ultrasonic sensor HC SR04 DC 5V	QQ Trading	6	2	12	512.6
16	Breadboard 400	400 pin Breadboard 8.3*5.5cm	QQ Trading	6	1	6	518.6
17	Pensonic Vacuum	WetDry Vacuum 1200W	HLK Chain Store	226	1	226	744.6
18	Shellac	Shellac	Dian Be Hardware	8.9	1	8.9	753.5
19	Metal wire	Wire Rope (4 m)	Dian Be Hardware	4	1	4	757.5
20	Metal frame	Robot metal frame	Rajini metal works	800	1	800	1557.5
Grand Total (RM)							**1557.5**

Table 8: Bill of Material for Monthly Maintenance for Final Design

Part	**Quantity**	**Unit Price**	**Total Cost**
Oil/ Lubricant for Motor (From Lazada)	1 bottle	RM 115.00	RM 115.00
Vacuum Service (After 1 year warranty by Karcher)	Once Monthly	RM 40	RM 40
Rubber Lip (After 1 year warranty by Karcher)	2 pieces	RM 47.29	RM 94.58
Water (Able to be recycled)	214 *l*	RM 2.07 per first 35 *l* RM 2.28 above 35 *l*	RM 480.57
Soap (Able to be recycled)	21.4 kg	RM 5.5 per kg	RM 117.70
Grand Total			**RM 847.85**

In order for this design to be able to clean all the solar panels for 5 cycles monthly, each row of solar panel has to have one autonomous solar panel cleaning robot of this design. However, since this design is able to move by itself or by human assistance, 20 of this design will be sufficient to get the job done. This is because after 20 rows are cleaned, the robots can be moved to clean the remaining 20 rows. Hence, the total monthly cost calculation are as follows:

Total monthly cost for Proposed Design:

= (20 x Cost to build 1 unit) + (20 x Maintenance of 1 unit)

= (20 x RM 1182.24) + (20 x RM 854.53)

= RM 40,735.40

Total monthly cost for Final Design:

= (20 x Cost to build 1 unit) + (20 x Maintenance of 1 unit)

= (20 x RM 1557.50) + (20 x RM 847.85)

= RM 48,107.00

The cost of the final design has increased due to aesthetic purposes to make the product neater and more compact. Thus, increasing the final product price to RM 1,557.50. Knowing that the price has increased, the profit margin will lower as compared to the profit margin for the proposed design, However, the difference is minimal. With the cost attained, the potential monthly net profit for the respective proposed design and final design are as follows:

Net Profit for Proposed Design:

= Total Revenue – Total Cost

= RM 326,400 – RM 40,735.40

= RM 285,664.60

Profit margin for Proposed Design:

= (Net Profit ÷ Total Revenue) x 100%

= (RM 285,664.60 ÷RM326,400) x 100%

= 87.52%

Net Profit for Final Design:

= Total Revenue – Total Cost

= RM 326,400 – RM 48,107.00

= RM 278,293.00

Profit margin for Proposed Design:

= (Net Profit ÷ Total Revenue) x 100%

= (RM2 78,293.00 ÷ RM 326,400) x 100%

= 85.26%

3.3.2 Conclusion from Cost Analysis

From the evaluation carried out, it can be seen that the increase in price due to aesthetics had a very minimal impact on the profit margin. Therefore, the final design has the best profit margin.

3.4 Business Value Analysis

Business value has a variety of definitions and meanings, but it can be generalised as the net benefit to the client of a project that is in terms of either being monetized or de-monetized. **[18]** In this case, the client is Tenaga Nasional Berhad. Business value can also establish the welfare of the company in the future. Hence, this analysis will cover the de-monetized benefits in the first half and the monetized benefits in the second half.

A drop of 30% in energy conversion can occur due to the dirty panels. **[19]** This occurs due to the build-up of contaminants that creates an opaque layer on the surface of the solar panels which in turn reduces the total of light reaching the solar cells. The current method being used by the workers at Fortune 11 is to clean the solar panels by using natural rain water which is ineffective due to the fact that rain is unpredictable and rain is unable to remove stubborn stains. In addition, rain water also contains dust particles that can attach to the solar panel surface after it evaporates.

During the dry season where rain water is lacking, the panels are cleaned manually with a mop or brush with soap and water. Even though this method is inexpensive, it is ineffective because it is time consuming and requires a lot of human effort. There is also a risk of mishaps especially when the solar panels are installed at a certain stature. This method also yields a lot of water wastage since a large amount of water is needed to wash away soap from the surface of the solar panels. In addition, manual cleaning has the possibility to decrease the solar panel efficiency as humans do apply equal amounts of pressure on the solar panel surface when cleaning with a mop or brush. Too high of a pressure can cause damage to the surface of the solar panel. **[20]** Any erroneous movements can cause abrasions or scrapes on the exterior of the solar panel which in turn affects the effectiveness of the solar panel.

When it comes to professional cleaning, this technique can yield up to 12% more production as compared to those cleansed by rain water or manually. Henceforth, the proposed resolution was an autonomous solar panel cleaner. This technique requires minimal labour which only requires the user to mount/dismount the robot onto each solar panel row. Thus, the risk of accidents is significantly lesser. The overall cleaning time is cut down since the robots work on all solar panel rows concurrently and have perpetual rates during cleaning. Water usage is also reduced in comparison to manually cleaning the solar panel.

Both the proposed and final designs are both equipped with cleaning equipment that can eradicate any stubborn stains without putting high pressure on the surface of the solar panel. In addition, both designs are able to adapt to the shifting angles of the solar panel tables at Fortune 11's solar farm. With the addition of a dust sensor for both designs, visual inspections can be eliminated.

Another pros is the business value gain (monetized) of the proposed and final design. Whether or not the business of a company or organisation is sustainable in financial terms is an important aspect to consider. Following a previously taken module, Business Skills for Engineers, taught by Dr. Felicia Wong Yen Myan, the team was able to obtain formulas for business vaule gain and annual savings which are then applied to both the proposed and final design.

3.4.1 Sample Calculations for Monthly/ Annual Expenditures

Manual Cleaning

Labour Cost	= RM12,000.00
Maintenance Cost	= Soap Cost + Water Cost + Brush Cost + Mop Cost
	= RM 4 708 + RM 19 509.45 + RM 1712 + RM 170
	= RM 26,099.45
Total Monthly Expenditure	= Labour Cost + Maintenance Cost
	= RM 12,000.00 + RM 26,099.45
	= RM 38,059.45
Total Annual Expenditure	= Total Monthly Expenditure x 12 Months
	= RM 38,059.45 x 12
	= RM 457,193.40

Proposed Design

Manufacturing/Implementation Cost = RM1,182.24

Maintenance Cost = RM 854.53

Total Expenditure for First Month = (20×Cost to build 1 unit) + (20 × Maintenance of 1unit)

= (20 x RM 1,182.24) + (20 x RM 854.53)

= RM 40,735.40

Total Annual Expenditure = (Total expenditure for first month) + (Total expenditure for the remaining 11 months

= (RM 40,735.40) + (20 units x RM854.53 x 11 months)

= RM 40,735.40 + RM 187,974.60

= RM 228,710.00

Final Design

Manufacturing/Implementation Cost = RM 1,557.50

Maintenance Cost = RM 847.85

Total Expenditure for First Month = (20 x Cost to build 1 unit) + (20xMaintenance of 1 unit)

= (20 x RM 1,557.50) + (20 x RM 847.85)

= RM 48,107.00

Total Annual Expenditure = (Total expenditure for first month) + (Total expenditure for the remaining 11 months

= (RM 48,107.00) + (20 units x RM 847.85 x 11 months)

= RM 48,107.00 + RM 186,527.00

= RM 234,634.00

3.4.2 Sample Calculations for Business Value Gain

Proposed Design

Table 9: Business Value for Proposed Design

	Conventional Method	Proposed Design
Total Annual Cost	RM 457,193.40	RM 228,710.00

Business Value Gain = Annual cost of conventional method – Annual cost of Proposed Design

= RM 457,193.40 – RM 228,710.00

= RM 228,483.40

Final Design

Table 10: Business Value for Final Design

	Conventional Method	Final Design
Total Annual Cost	RM 457,193.40	RM 234,634.00

Business Value Gain = Annual cost of conventional method – Annual cost of Final Design

= RM 457,193.40 – RM 234,634.00

= RM 222,559.40

Sample Calculations for Annual Savings

Proposed Design

% Savings per annum = (Business Value Gain ÷Cost of Conventional Method)

= (RM 228,483.40 ÷ RM 457,193.40) x 100%

= 49.97%

Final Design

% Savings per annum = Business Value GainCost of Conventional Method

= RM222,559.40RM457,193.40x 100%

= 48.68%

3.4.3 Sample Calculations for Return of Investment (ROI)

Proposed Design

Return of Investment, ROI = (Investment ÷ Business Value)

= RM 228,710.00 ÷ RM 228,483.40

= 1.001 x 365 days

= 365.4 days

Final Design

Return of Investment, ROI = (Investment ÷ Business Value)

= RM 234,634.00 ÷ RM 222,559.40

= 1.045 x 365 days

= 381.4 days

3.4.4 Business Value Summary

Table 11: Comparison of Proposed and Final Design

	Conventional	Proposed Design	Final Design
Monthly Labour Cost (RM)	RM12,000.00	-	-
Monthly Manufacturing Cost (RM)	-	RM1,182.24	RM1,557.50
Monthly Maintenance Cost (RM)	RM26,099.45	RM854.53	RM 847.85
Total Monthly Expenditure (RM)	RM38,059.45	RM40,735.40	RM48,107.00
Total Annual Expenditure (RM)	RM457,193.40	RM228,710.00	RM234,634.00
Business Value Gain (RM per year)	-	**RM228,483.40**	**RM222,559.40**
Annual Savings (%)	-	49.97%	48.68%
Return of Investment (Days)	-	365.4 days	381.4 days

Based on **Table 11**, the business value gain for the proposed design may be higher than the business value gain for the final design, but the difference is minimal as it may take only 2 weeks longer for the return of investment.

4.0 ENGINEERING DRAWING

In the initial stages of the design process, Solar Fam came up with 3 separate sketched designs namely traditional, wet dry and ultrasonic methods. All 3 sketches were converted to 3D drawings with the help of the Solidworks software. At the end of MEGP 1, the team voted to go with design 2, wet dry method. Moving on to MEGP 2, during the team's attempt to tackle the project goals and expectations, the design of our project had been tweaked and modified to come up with practical solutions in order to keep the robot's functionality while trying to keep within the limited budget and technological limitations. This can be seen by the changes from the proposed design 2 to the final design of Solidworks.

Design 2 is a wet dry design because it utilises the wet dry cleaning method. This design has a frame which holds on to the solar panel and for guidance of the machine. It also has a machine part which will house the microcomputer.

The cleaning machine is equipped with a water sprinkler at the front to eject small dosages of soap - water mixture. A motor controlled rotating cylindrical helix brush located behind the sprinklers will scrub the dirt and dust off the panel surface. A built in vacuum located in the cleaning machine will suck up the dirt on the solar panel from the vacuum hole placed strategically after the brush. A rubber lip is attached at the rear end and the sides of the machine to prevent dirt, dust and water from spilling out at the sides and direct it to the vacuum hole.

The frame consists of two components mainly the bar and lock whereby the lock is latches on the edge of the solar panel and steadies the bar in place. The rubber wheeled rollers placed underneath the machine helps to facilitate the movement of the machine across the surface of the solar panel. The arms at the side are clamped onto the bar so that it moves in the lateral direction and to let the machine stay on its path.

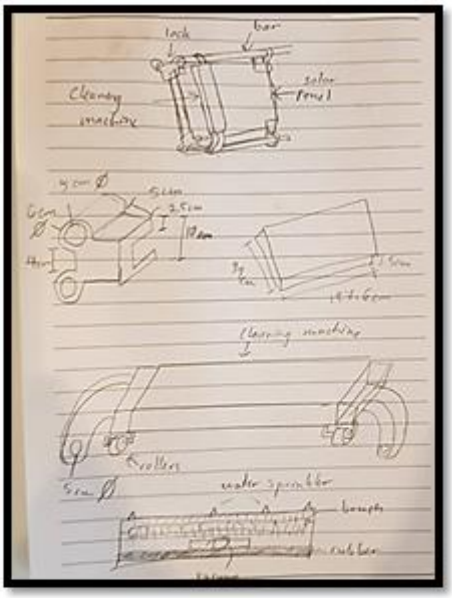


Figure 24: Initial sketch of Design 2 (wet dry) inspired by car wipers

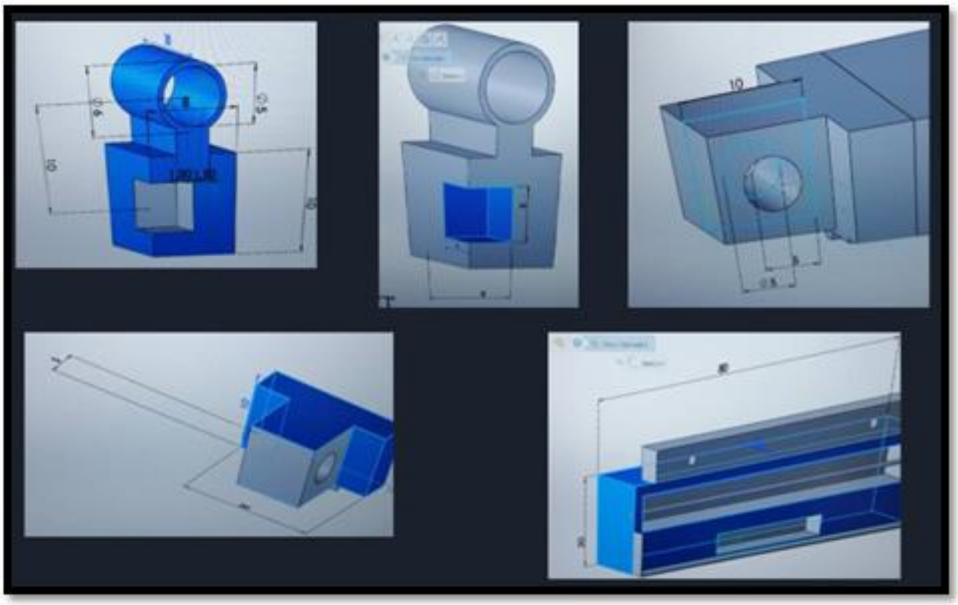


Figure 25: Converting 2D sketch to 3D Solidworks for Wet Dry design 2

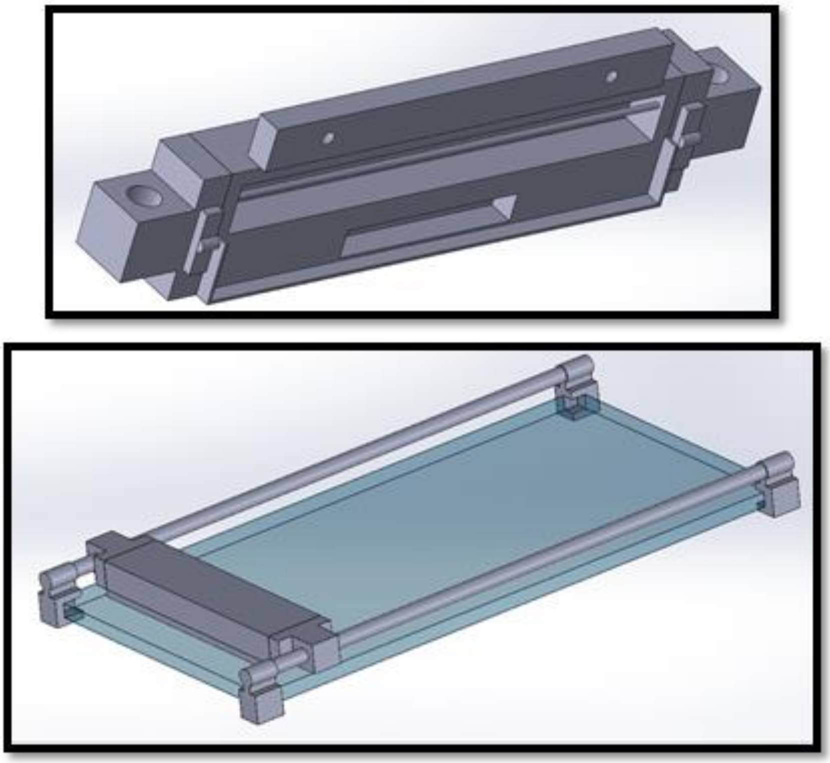


Figure 26: Proposed design 2 (wet dry) at the end of MEGP 1

Figure 27: Small scale 3D printed prototype of the proposed design

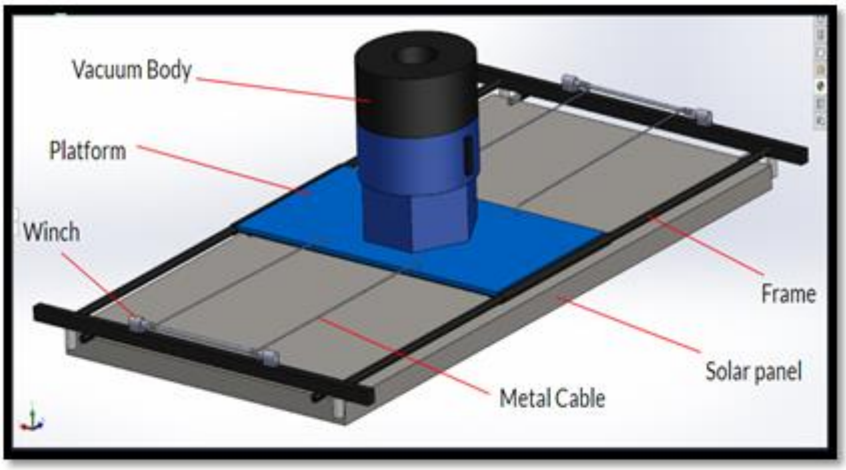


Figure 28: Final solidworks design ready for building

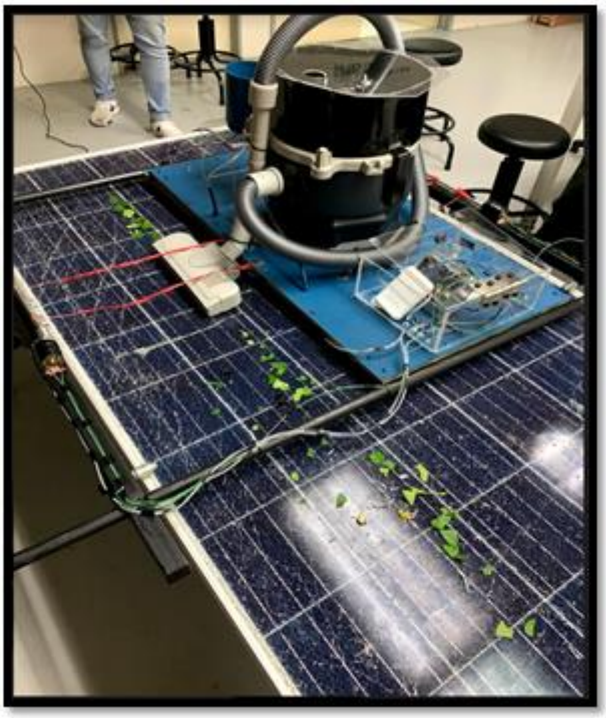
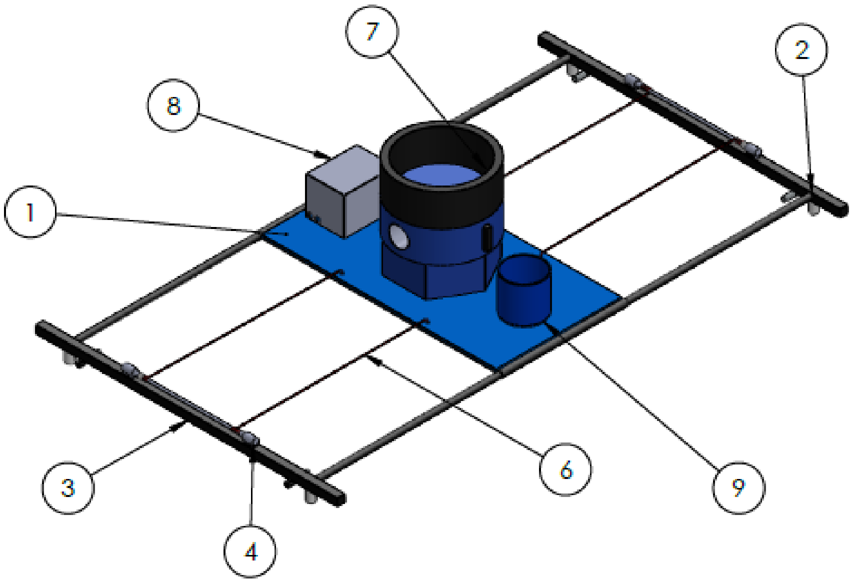


Figure 29: Complete prototype ready for presentation

Bill of Material



ITEM NO.	PART NUMBER	Material	QTY.
1	Frame platform	Wood	1
2	Frame Shaft	Steel	2
3	Frame Bar	Steel	2
4	Winch Motor	Iron	2
5	Castor ball	Iron	4
6	Cable	Steel	2
7	Vacuum body	Plastic	1
8	Home Box	Perspex	1
9	Container	Plastic	1

Figure 30: Bill of Material of Prototype

Prototype Specifications

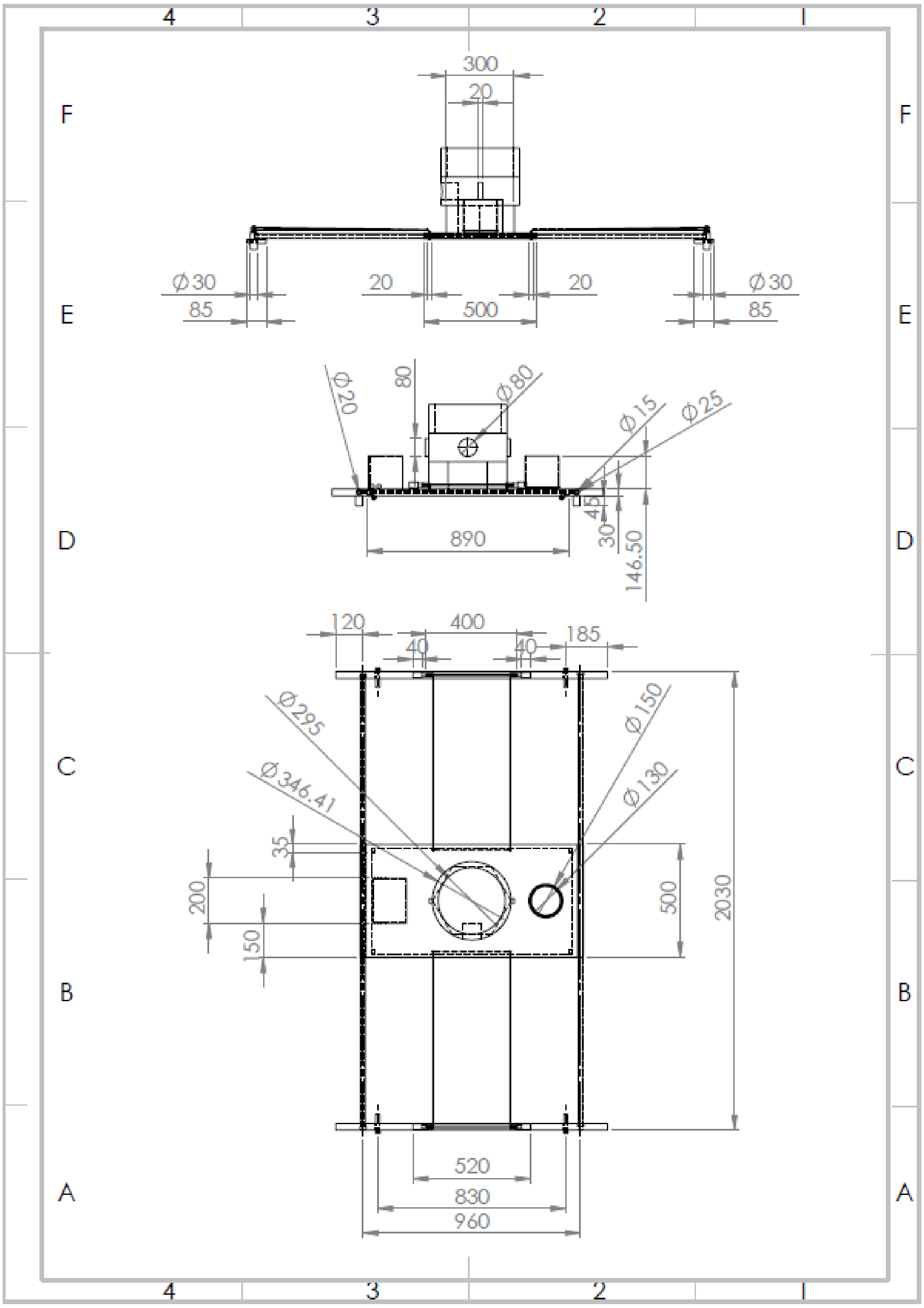


Figure 31: Prototype Specifications

5.0 IMPLEMENTATION

5.1 Purchasing

5.1.1 Electronic Components

Between two vendors, the types and availability of the required electronic components as well as their prices were surveyed and compared. As a result, the team selected QQ Online Trading and purchased the following:

- Arduino Mega
- Dust sensor
- Motor shield
- Bluetooth module
- 11.1 V lipo battery
- Metal shaft
- Shaft connectors
- 12 V gear motors
- Jumper wires
- Ultrasonic sensors
- Breadboard

Figure 32: Surveying items and prices at Smart Ace Trading

Figure 33: The team purchasing items from QQ Online Trading

5.1.2 Vacuum Cleaner

Initially, the brands, specifications and market prices of various wet/dry vacuum cleaners were surveyed online. Since the team prioritised cost, Pensonic wet/dry vacuum cleaner was chosen. With its market price in mind, the team surveyed prices of the mentioned brand between five physical vendors. Upon comparison, the team purchased the item from HLK Electrical Appliances for a lower price than the expected amount.

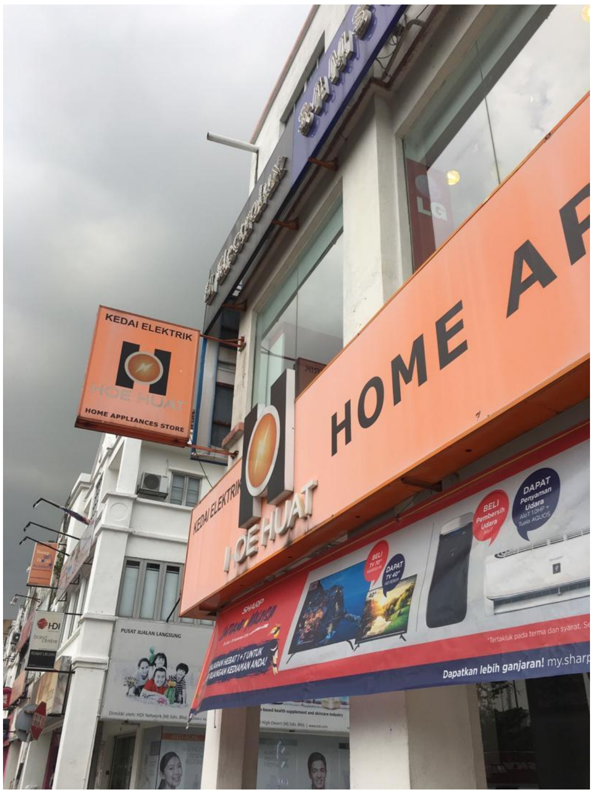


Figure 34: Stores we surveyed prices at; (left) Hoe Huat and (right) Onking

Figure 35: Stores we surveyed prices at; (left) Hoe Huat and (right) Onking

Figure 36: Surveying price at HLK (left) and enquiring about prices in One Living (right)

Figure 37: Purchasing vacuum from HLK after comparing prices

5.1.3 Frame / Exterior

Previously, the team had intended on self-constructing the frame of the robot which would move across the solar panel. Upon surveying the prices of metal rods from several equipment and hardware vendors, the team reconsidered. Factors such as the team's level of expertise in welding, time constraint and sky-high prices of raw metal all were all accounted for, which lead to the decision of engaging the services of Rajini Welding Works Sdn. Bhd. After thorough discussion with the owner Mr Rajini, the team made minor modifications and improvements to the design. Both parties mutually agreed on the design specifications, total cost and timeframe for completion of the frame. The main materials involved in the fabrication of the frame consist of steel bars, rods, wheel bearings and rollers.

Figure 38: Surveying vendors

Figure 39:Fabrication of frame by Rajini Welding Works

5.1.4 Miscellaneous

For the cleaning mechanism, accessories such as sprinklers and wipers were purchased from Meter Trading Co. Sdn. Bhd. Besides, shellac and metal rope were purchased from Dian Be Hardware.

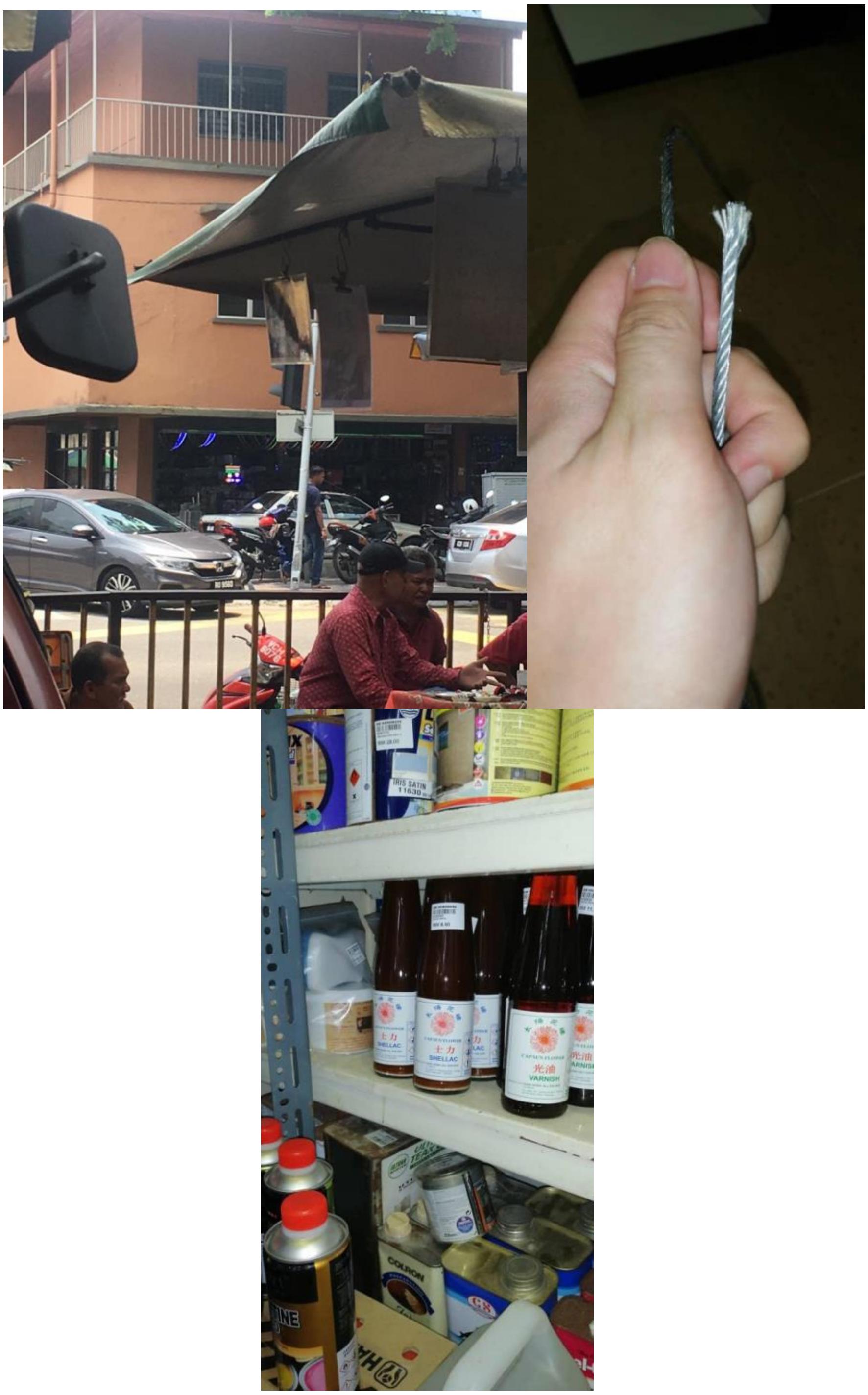


Figure 40: Obtaining items

5.2 Construction and Assembly

5.2.1 Motion system

The team started off by consulting Mr Rajini regarding the proposed design. A few recommendations were given to improve the design, such as by including the metal bearings to smoothen the motion of the frame on the solar panel. Besides, he suggested to use circular hollow rods to implement the extendable feature. Meanwhile, adjustments were made to the Solidworks model based on the recommendations. Referring to the sample solar panel provided in the laboratory, its dimensions were obtained so that the frame measurements could be based upon them.

Figure 41: The team at Rajini Welding Works Sdn. Bhd.

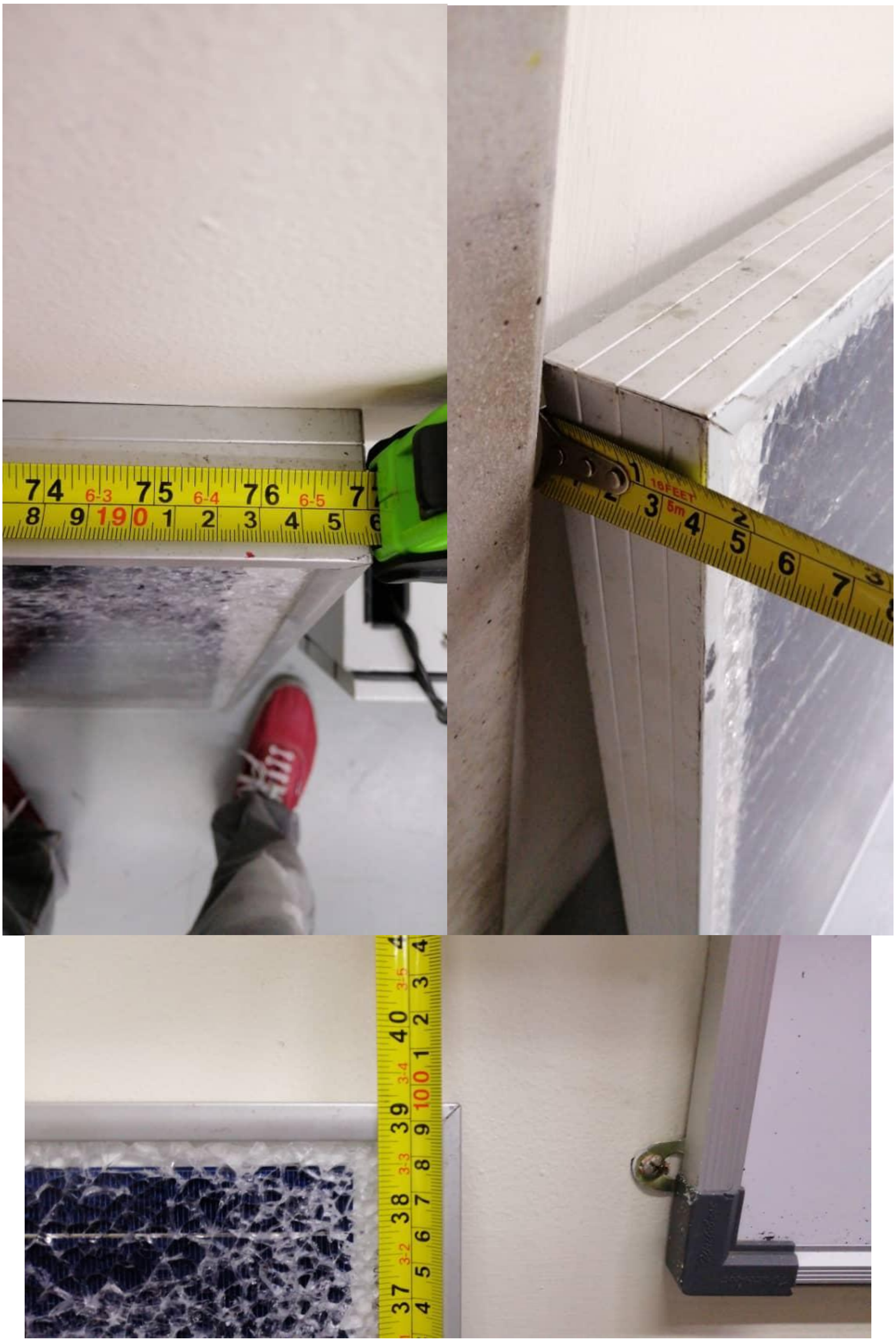


Figure 42: Measurements from left to right and below; length, thickness, height

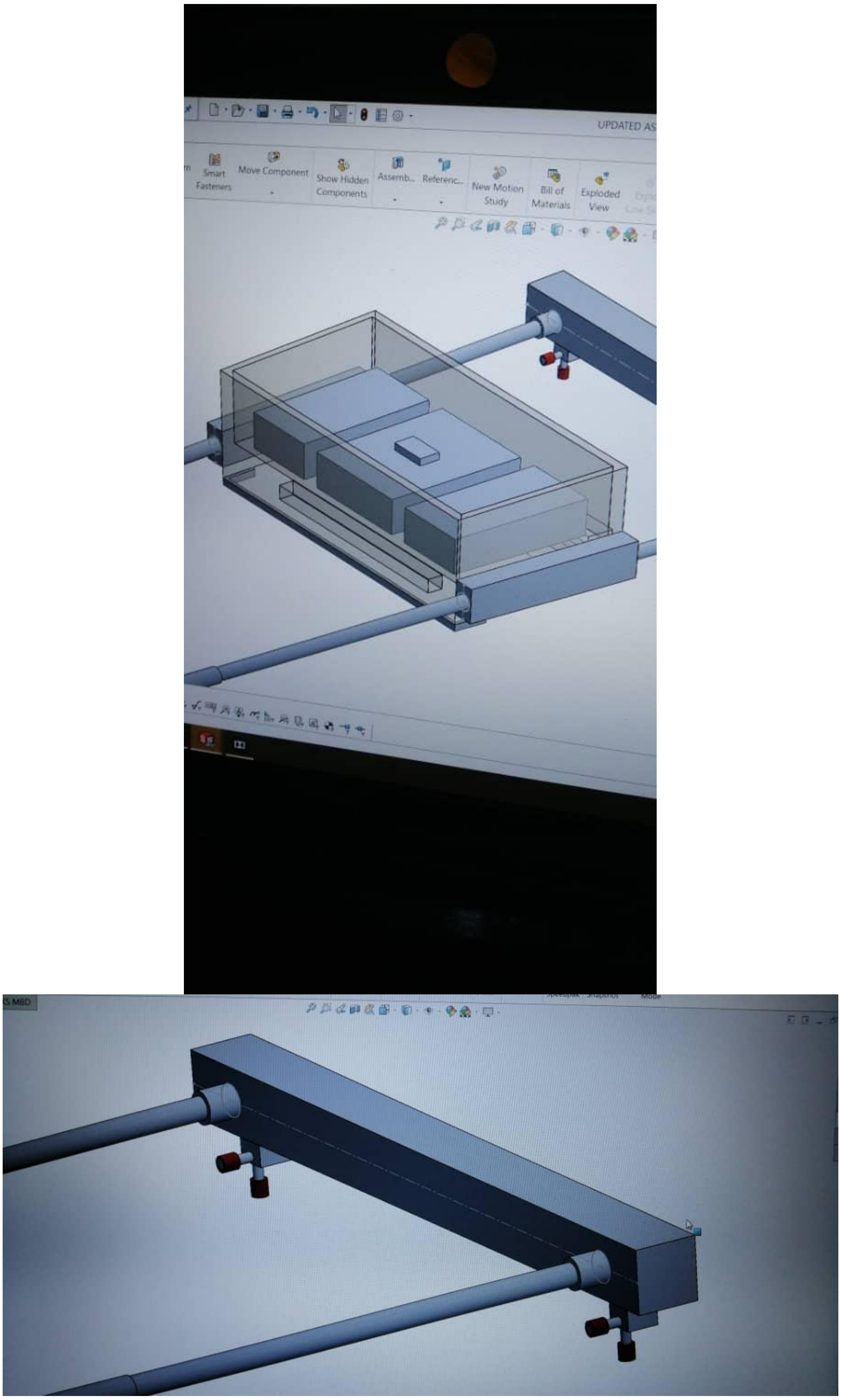


Figure 43: Updated design after considering Mr Rajini's suggestions

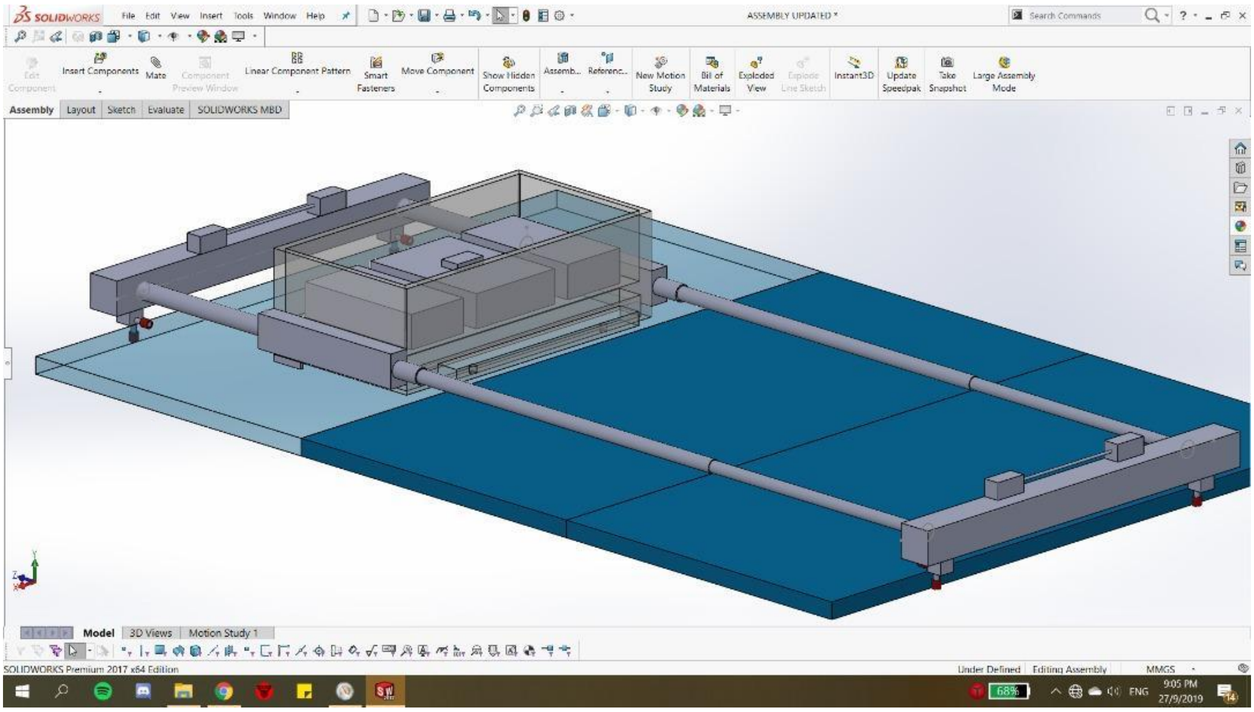


Figure 44: Updated design after considering Mr Rajini's suggestions

Upon receiving the fabricated frame, it was reassembled in the lab and tested the movement on the solar panel. Due to some miscommunication and time constraint, the use of several hollow rods to create a seamless extendable feature was left out. Only one rod was utilised, hence the extendable feature was still possible with the exception that the ends of the rods on each side could not be shortened. A wooden platform was constructed to be secured to the frame of the robot. Before securing it to the frame, it was sandpapered and spray painted for aesthetic purposes. Also, four wheel bearings were fixed to each bottom corner of the wooden platform to assist with the motion of the frame.

Figure 45: Testing the movement of the frame on solar panel

Figure 46: Constructing and securing wooden platform on robot frame

Figure 47: Sanding and spray painting the wooden platform

Figure 48: Securing wheel bearings underneath the wooden platform

A Perspex home was built for the main control unit system and it was attached right next to the vacuum cleaner on the wooden platform. With the Perspex home, this could separate the main control unit system from the water sprinkler or any dirt/dust from reaching it. Also, a Perspex stand was constructed for the Arduino Mega and breadboard so it can be easily reached when working on the troubleshooting of electronic system.

Figure 49: Constructing Perspex home for the control unit system

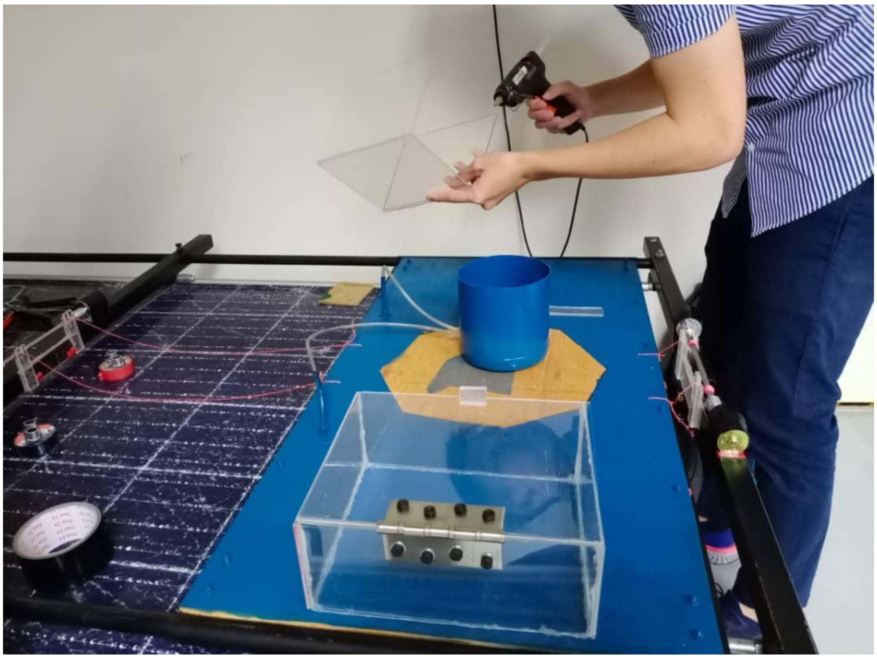


Figure 50: Constructing Perspex home for the control unit system

In order to connect the cable from the motor shaft to the frame, two holes were milled at both ends of the motor shaft. The size of the holes was milled based on the diameter of the cable. After measuring the distance of the frame from the motor shaft, the length of the cable was cut accordingly and tied through the holes of the motor shaft. However, there was a change of plan where the nylon cable was used to replace the metal cable because the metal cable was too rigid and cannot bend around the motor shaft. Testing on the motion of the frame was performed and it was found that the cable will snap when moving the weight with 1 strand. Therefore, the team had decided to combine 3 strands of the nylon cable by braiding them together to strengthen it. The nylon cable was wrapped with tape to increase the diameter of it after the team faced the issue where the cable tangled when the motors are rotating.

Figure 51: Drilling into shaft using milling machine

Figure 52: Metal cable (left) and Nylon cable (right)

Figure 53: Braiding string to avoid tangling (left) and tying to platform and shaft (right)

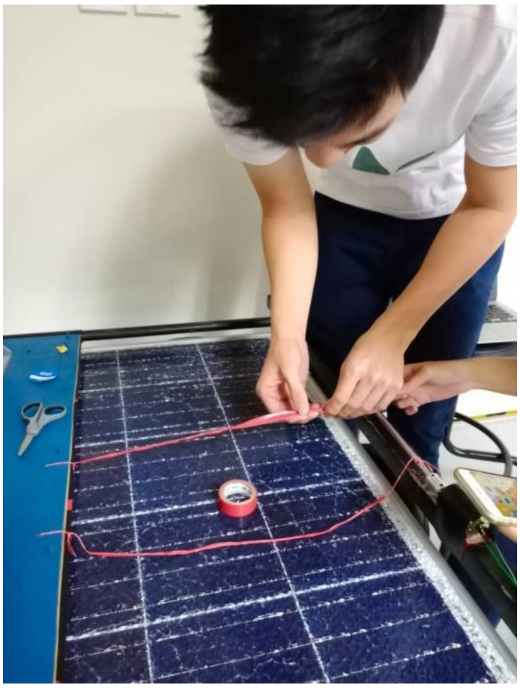


Figure 54: Wrapping the cable

Due to the pressure difference, there was an issue faced where the water can't flow towards the water sprinkler. This happened because the level of the water tank was the same as the rubber tubing which was connected to the water sprinkler. Hence, an elevated platform was constructed using perspex to increase the height of the water tank. This solved the issue of water flowing into the water sprinklers. On the other hand, the water tank can also be placed under the elevated platform when it was not used.

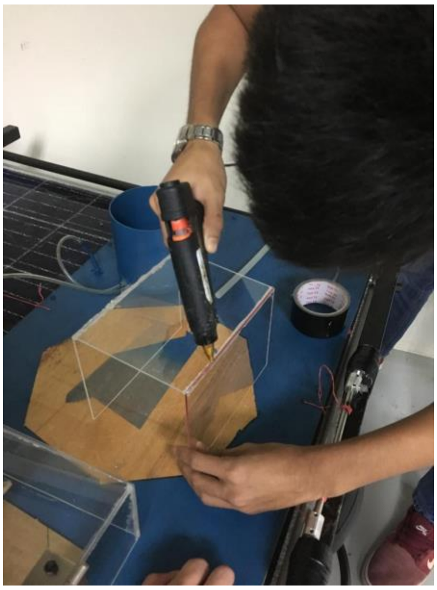


Figure 55: Constructing elevated platform for water tank

5.2.2 Cleaning system

Basic testing of the vacuum cleaner was performed on the solar panel provided and measurements of the vacuum cleaner was taken down. The team proceeded to modify the vacuum cleaner to make it more compact and also to reduce the weight of the whole cleaning system. The modification of the vacuum cleaner started off by constructing a new vacuum cover and cutting off the vacuum container. The vacuum cover was constructed by bending the perspex into a circular shape and was spray painted whereas the top of the cover was remained transparent. Holes were also drilled onto the top to ensure easy access to the wiring and power button. After all the modifications were made, it showed a significant reduction in height and weight of the vacuum cleaner.

Figure 56: The team measuring and testing the vacuum cleaner

Figure 57: Modifications made on the vacuum cleaner

Apart from that, two holes were drilled into the platform to fit the water sprinklers. Extra tubes were used to connect the water sprinklers to water tank since the existing sprinkler tubes were not long enough. The wipers were also secured at the top corners underneath the platform.

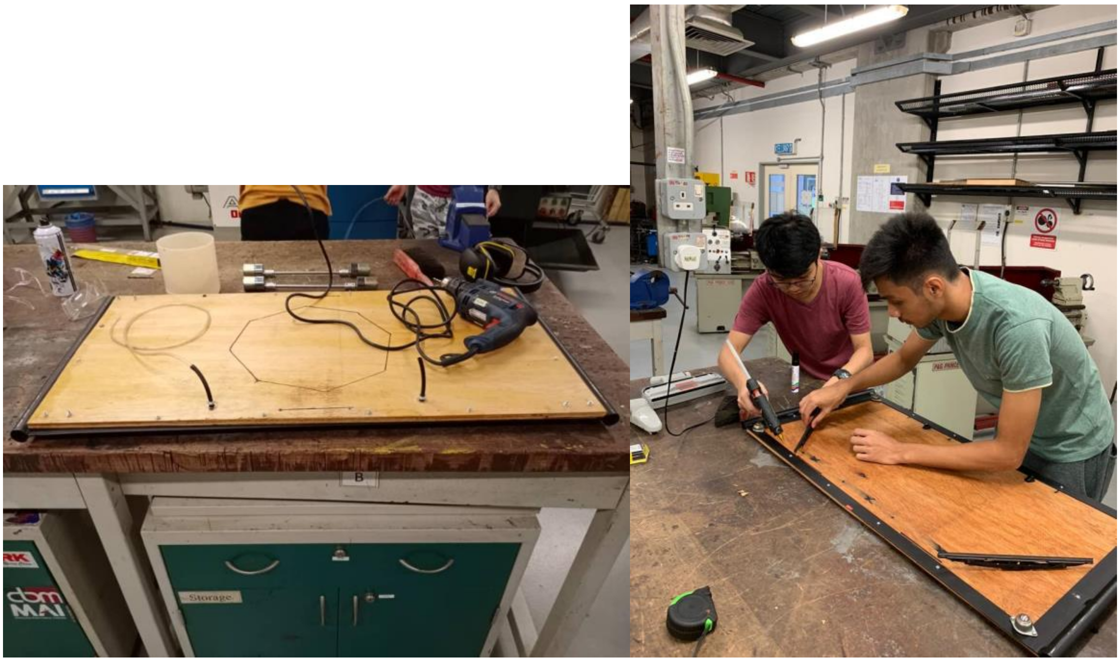


Figure 58: Attaching sprinklers and wipers to the bottom of the platform

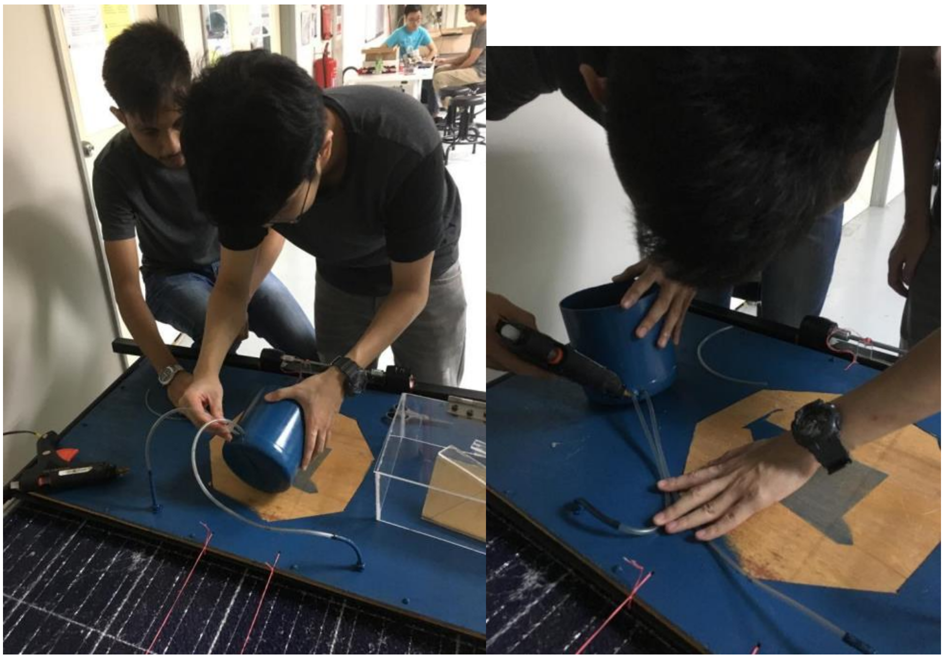


Figure 59: Connecting water tank to sprinklers

After completing the modifications and securing all the accessories (water sprinkler and wipers), the base of the vacuum cleaner was secured onto the platform by drilling through it. Then, the team proceeded to secure the vacuum tubes and head by using plastic cable ties and brackets that were already drilled into the platform. Testing of the suction was done again to ensure that there was no any air leakage after all sorts of modifications were done on the vacuum cleaner.

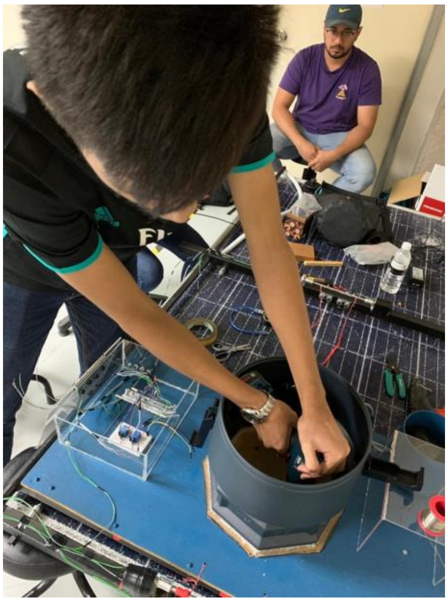


Figure 60: Securing vacuum onto the platform

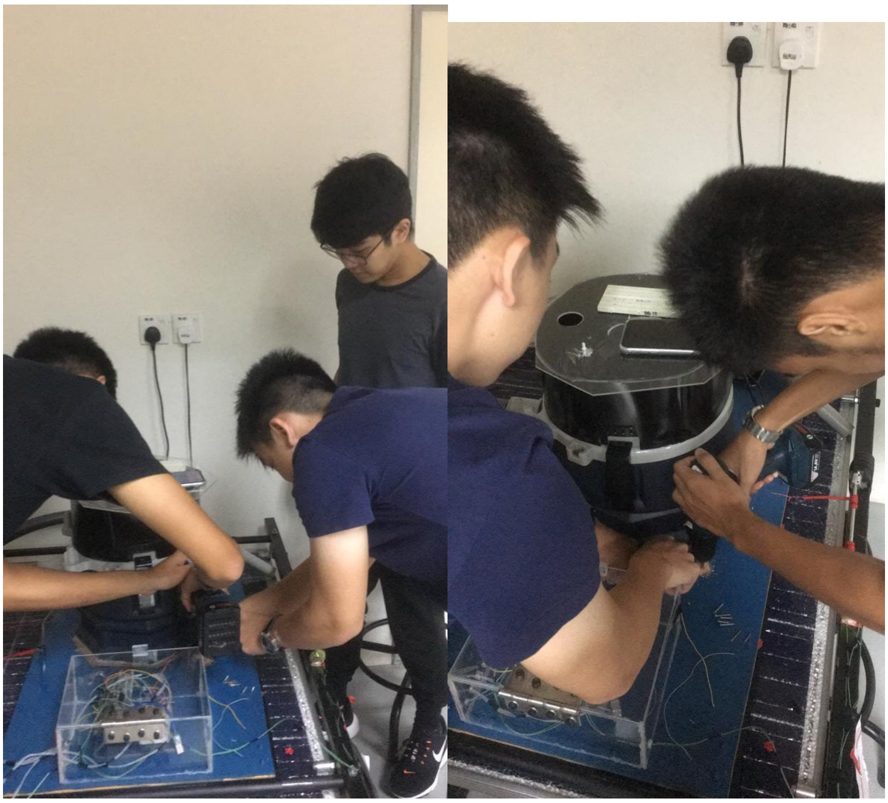


Figure 61: Securing vacuum tubes

5.2.3 Programming

Upon obtaining all the electronic components, a basic testing on the Arduino Mega was conducted by uploading a Blink code to it followed by simple instructions (text display, motor and LED control) via the Arduino software. When it proved to be successful, the Bluetooth module was then configured and tested. Despite many attempts, the Bluetooth module could not carry out any instructions. Hence, the Bluetooth control feature was put on hold.

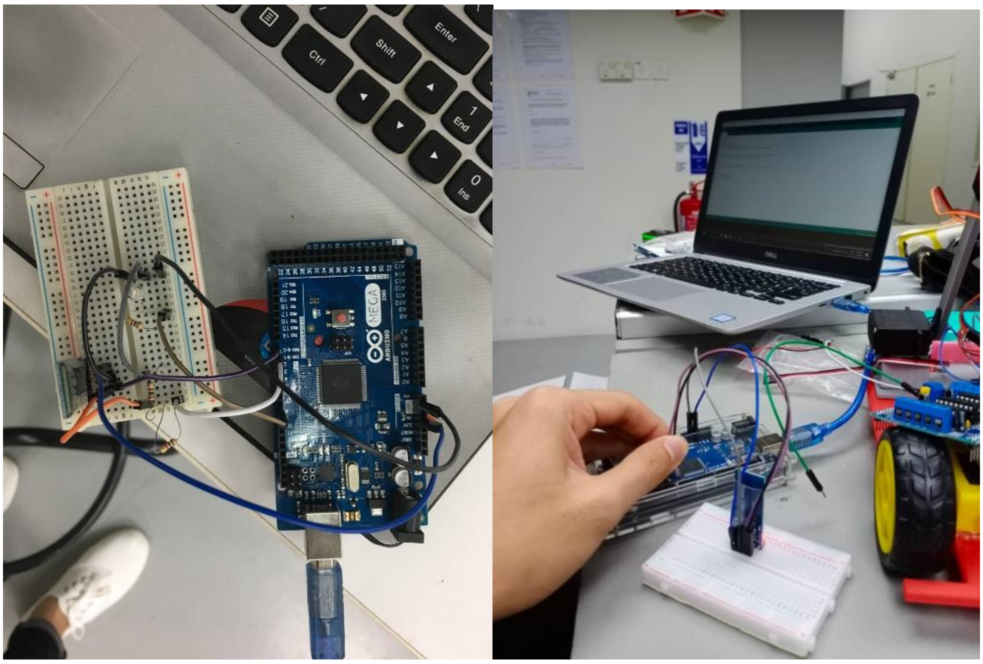


Figure 62: Testing the Arduino Mega (left) and Bluetooth module (right)

To produce an autonomous robot motion, an ultrasonic sensor was programmed to detect, calculate and display the distance between the robot from the winch at all times. With a motor shield, the motors were programmed to move according to the distance values. To be specific, the platform would start to move away from the ultrasonic sensor when the two are in very close proximity and vice versa. Moreover, each pair of motors (on either ends of the frame) were connected in such a way that they would rotate in opposite directions to create a more effective pulling / releasing effect for the cables. For dust monitoring, the optical dust sensor were configured and tested similarly to the ultrasonic sensor. Once proved successful, it was integrated with the other functions in the master code.

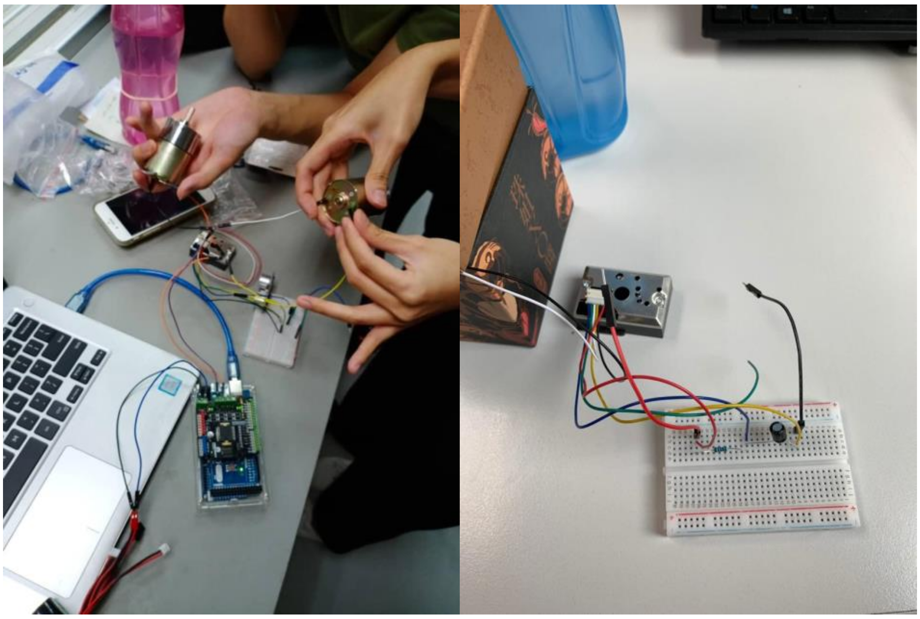


Figure 63: Testing the dust sensor (left) and ultrasonic sensors with motors (right)

During the testing of the motors after full assembly, none of the motors could rotate and at most only vibrated. Even with separate power sources for the Arduino and motor shield respectively, there were no improvements After further attempts, the cause of the issue was concluded to be the motor shield consuming a significant amount of power from the liPo battery and in turn limiting the power supplied to the motors to overcome their initial resistance. Upon consultation and research, the team replaced the motor shield with two relays to control the motors. Since the relays required little power, the Arduino could be powered by a power bank while the liPo battery could power the motors and pull the weight of the fully assembled robot.

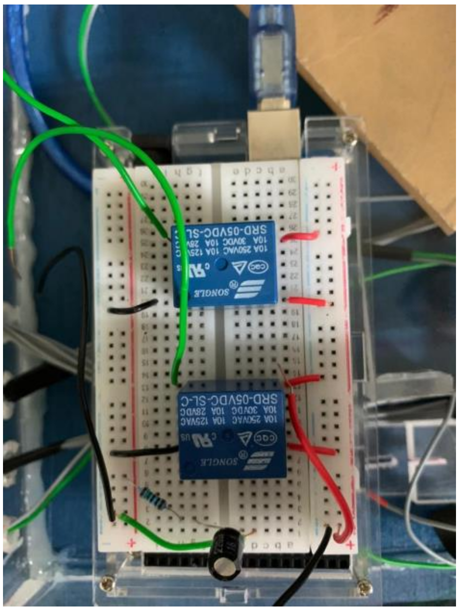


Figure 64: Using relay to control motors

All electronic components were integrated and connected to the main control unit housed in a perspex box. The wires were standardised, colour coded and taped together and to the sides of the frame to avoid tangling or disconnection.

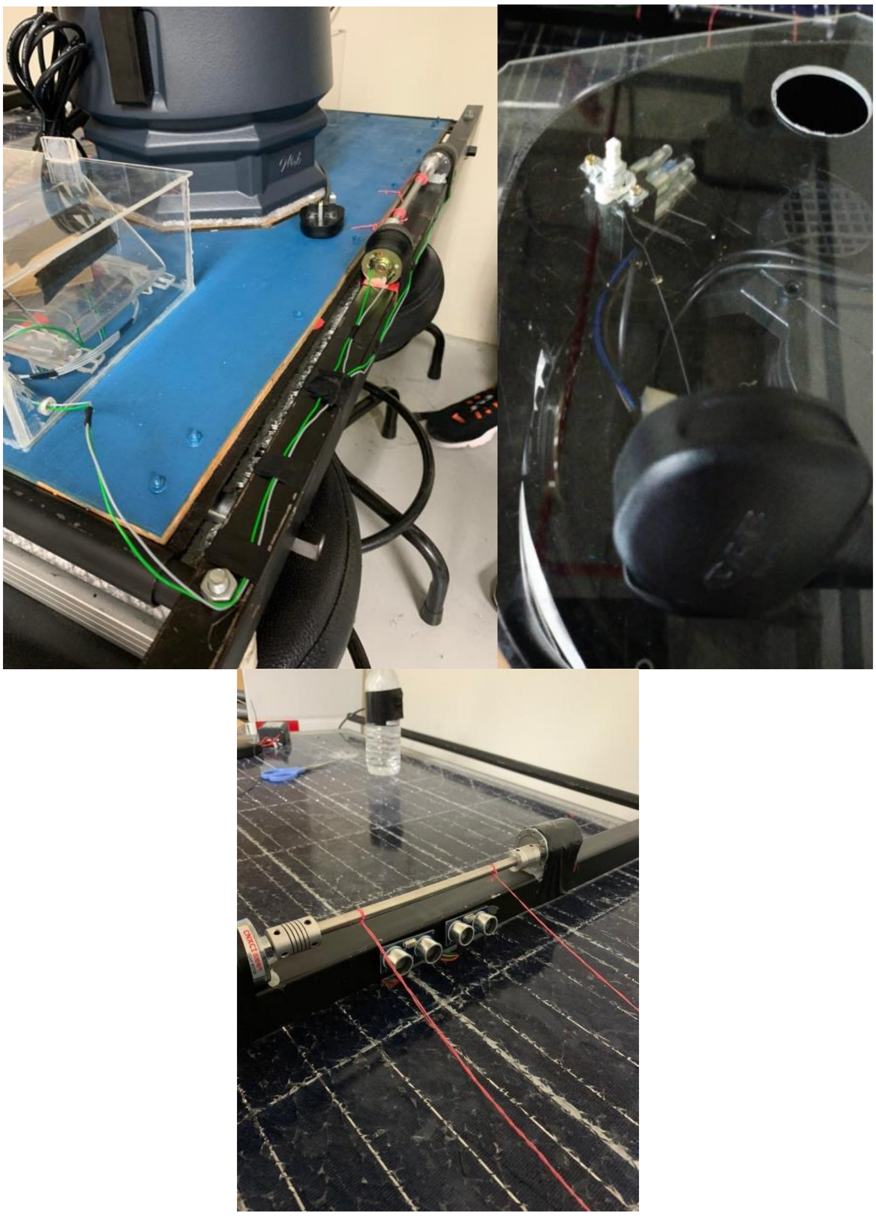


Figure 65: Improved/neater wiring

5.3 Testing

After full assembly and touch up, the team continuously tested the robot and made adjustments to the master code to increase the accuracy of the robot motion. Once the vertical motion was consistent, the team conducted test runs with the vacuum cleaner turned on and the robot in motion concurrently. This was also tested with contaminants such as dust and small bits of leaves on the solar panel. The vacuum cleaner could clearly suck up all the contaminants arranged both horizontally and vertically. Hence, the robot was deemed complete.

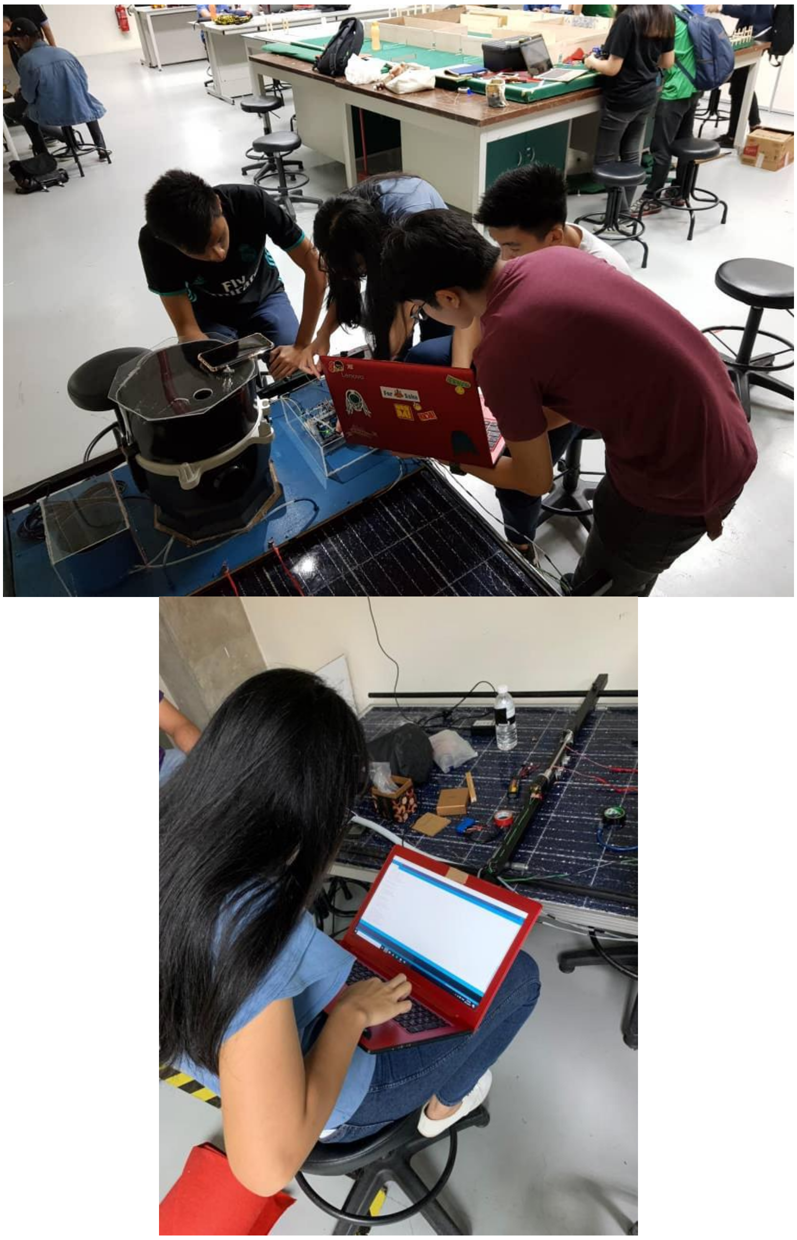


Figure 66: Testing and troubleshooting

6.0 OPERATE

An instructional technical operations & maintenance manual was created by the group to help the user on how to use the product with ease as well as guidelines on how to properly use and maintain the product after usage.

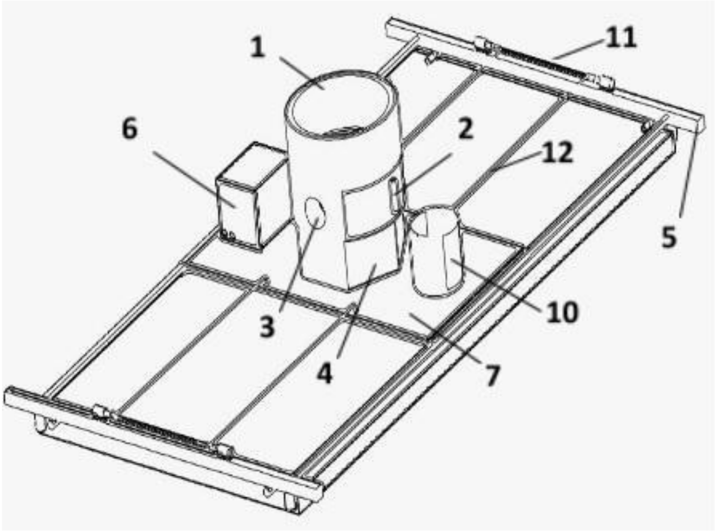
AUTONOMOUS SOLAR PANEL CLEANING ROBOT

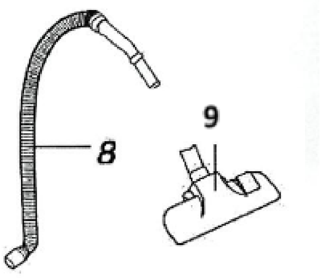
TECHNICAL OPERATIONS & MAINTENANCE MANUAL

BY TEAM SOLAR FAM

Table of Content

Parts Introduction





Legend:

1. Vacuum Motor
2. Securing Clamp
3. Suction Inlet
4. Vacuum Tank
5. Frame
6. Home Central Unit
7. Platform
8. Hose
9. Nozzle
10. Water Tank
11. Winch
12. Cable

Technical Specifications

Vacuum

Voltage	220-240V @ 50Hz
Wattage	1200
Max Vacuity Degree	17.5kPa
Max Wind Quantity	$29dm^3/S$
Weight	6.0kg

Home Central Unit

Arduino Mega	7-12V @ 16MHz
Solderless Mini Breadboard	1 IC/Circuit Areas, 630 tie-points 2 Distribution strips, 200 tie-points Size: 6.5 x 2.2 x 0.3in
2 x 5-pin 5V Relay	Max Load current: 10A @ 30V
Power Bank	10400mAh 5V @ 2.1A
LiPo Battery	2200mAh 11.1V Continuous Discharge: 66A

Winch

4 x Gear Motor	12V 500rpm

Before Using

- Please read these instructions carefully before use and keep them for future reference.
- Check your local main voltage whether it is the same as stated on the rating label.
- Before using, ensure that the connections are secure.
- Confirm that the switches are all turned off.
- Place the frame securely onto the solar panel.
- Fill water tank to an appropriate level.

How to Operate

- Must insert the filter bag in the vacuum tank.
- Assemble the vacuum motor cover with the vacuum motor and lock it manually with the securing clamps.
- Connect the hose to the suction inlet.
- Connect the nozzle to the other side of the hose.
- Connect the plug to a power outlet.
- Connect the LiPo battery to the Arduino Mega.
- Finally, switch on both the vacuum motor and the home central unit.
- After use, must wash and clean the filter bag, water tank and the vacuum tank. The filter bag and vacuum tank must dry then can it be fit back with the vacuum motor head and cover.

Cleaning & Maintenance

- Always unplug the product and the LiPo battery and let it cool down completely prior to cleaning. Do not leave the vacuum cleaner unattended when plugged in.
- Do not use an abrasive sponge, scouring pads or stiff brush to clean the appliance.
- Please be cautious when cleaning the product near to the motor housing area and the home central unit.
- Use only a damp cloth to wipe the exterior surfaces of the unit. Do not immerse the main body in water.
- For proper storage, always place the product in a low humidity environment.

Important Guidelines

- The current voltage which indicates on the plate must correspond to your local voltage.
- The product should only be operated only on condition that the type of power supply corresponds to the marking label. Otherwise, it will not work or even be damaged. Never operate the product unless it is fully assembled.
- Do not overload outlets or extension cords. This can result in fire or electric shock.
- Do not operate the appliance if the power supply cord or plug has been damaged.
- Do not immerse the cord, plug or appliance in water or other types of liquid and do not pour water onto it to avoid fire, electrical shock or personal injury.
- After use, always clean the filter bag, vacuum tank and water tank.

- Never suck up any inflammable or corrosive liquids such as petrol or other volatile substances and any carbon ash.
- To protect against risk of electric shock, do not force any foreign objects such as pins and wires into any openings.
- Do not pull the cord to remove the plug or the LiPo battery, pull on the pug instead.
- Do not attempt to insert, handle or remove the plug or LiPo battery with wet hands.
- Do not place the product on or near hot gas/electric burner, or a heated oven.
- Do not let the cord hang over the edge of a table or counter or touch any hot surfaces.
- In the event of not using the product for a long period of time, please remove the plug from the power outlet and the LiPo battery as well.
- Do not allow the vacuum motor or other electrical components to be exposed to water.
- Do not use the product to suck up any inflammable substances and also avoid sucking up any sharp objects that could obstruct the hose.
- Always ensure the product is secured onto the solar panel.
- Do not operate the product with a faulty or damaged plug, or after the appliance malfunctions or has been damaged in any manner.

This marking indicates that this product should not be disposed with other household wastes throughout the nation. To prevent possible harm to the environment or human health from uncontrolled waste disposal, recycle it responsibly to promote the sustainable reuse of material resources. To return your used device, please use the return and collection systems or contact the retailer where the product was purchased. They can take this product for environmental safe recycling.

7.0 PROJECT MANAGEMENT

In order for the team to build the prototype within the time limit (14 weeks) and budget (RM2000) given, project management skills had to be applied in order to ensure that the prototype was not only successfully built within the limits stated but also able to fully function properly. The project management skills used are as follows.

7.1 Organization Chart

The team first made an organization chart to establish each member's roles. This was based off last semester's chart. However, the team included more defined roles as this was the final group project (MEGP 2). Thus, the team added a sense of professionalism into making this semester's organization chart. The chart is as shown below.

Figure 67: Team Solar Fam's Updated Organization Chart

7.2 Gantt Chart

Next, the team made a Gantt Chart for this semester in order to have a better in depth view of all the tasks that were involved in the project in order for the prototype to be completely built. This chart acted as a guideline for the team to estimate and decide how long each task will take to complete and when will the final prototype be made. The Gantt Chart also helped the team divide work among members based on every one's respective skill set. This in turn cut the amount of time needed to complete each task.

Task Code/ Tasks	AUGUST	SEPTEMBER					OCTOBER				NOVEMBER			
	26/8/2019	2/9/2019	9/9/2019	16/9/2019	23/9/2019	30/9/2019	7/10/2019	14/10/2019	21/10/2019	28/10/2019	4/11/2019	11/11/2019	18/11/2019	25/11/2019
	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8	Week9	Week10	Week11	Week12	Week13	Week14
A. IMPLEMENT														
A1 Design Finalization														
A1.1 Decision on Type Final Prototype to be Built														
A1.2 Final Alterations and Modifications to Design														
A2 Materials and Supplies														
A2.1 Final Decision on Materials to be used for Prototype														
A2.2 Survey on Prices of Materials														
A2.3 Purchasing/ Ordering of Materials														
A3 Building Process Frame of Robot														
A3.1 Measuring Size of Parts														
A3.2 Cutting of Measured Parts														
A3.3 Welding/ Joining of Frame Parts														
A3.4 Assembly of Frame														
A3.5 Assembly of Caster Wheels to Frame (Movement System)			ML											
A4 Building Process Solar Panel Clearing Robot														
A4.1 Measuring & Cutting Parts for Body of Robot														

Figure 68: Team Solar Fam's Gantt Chart

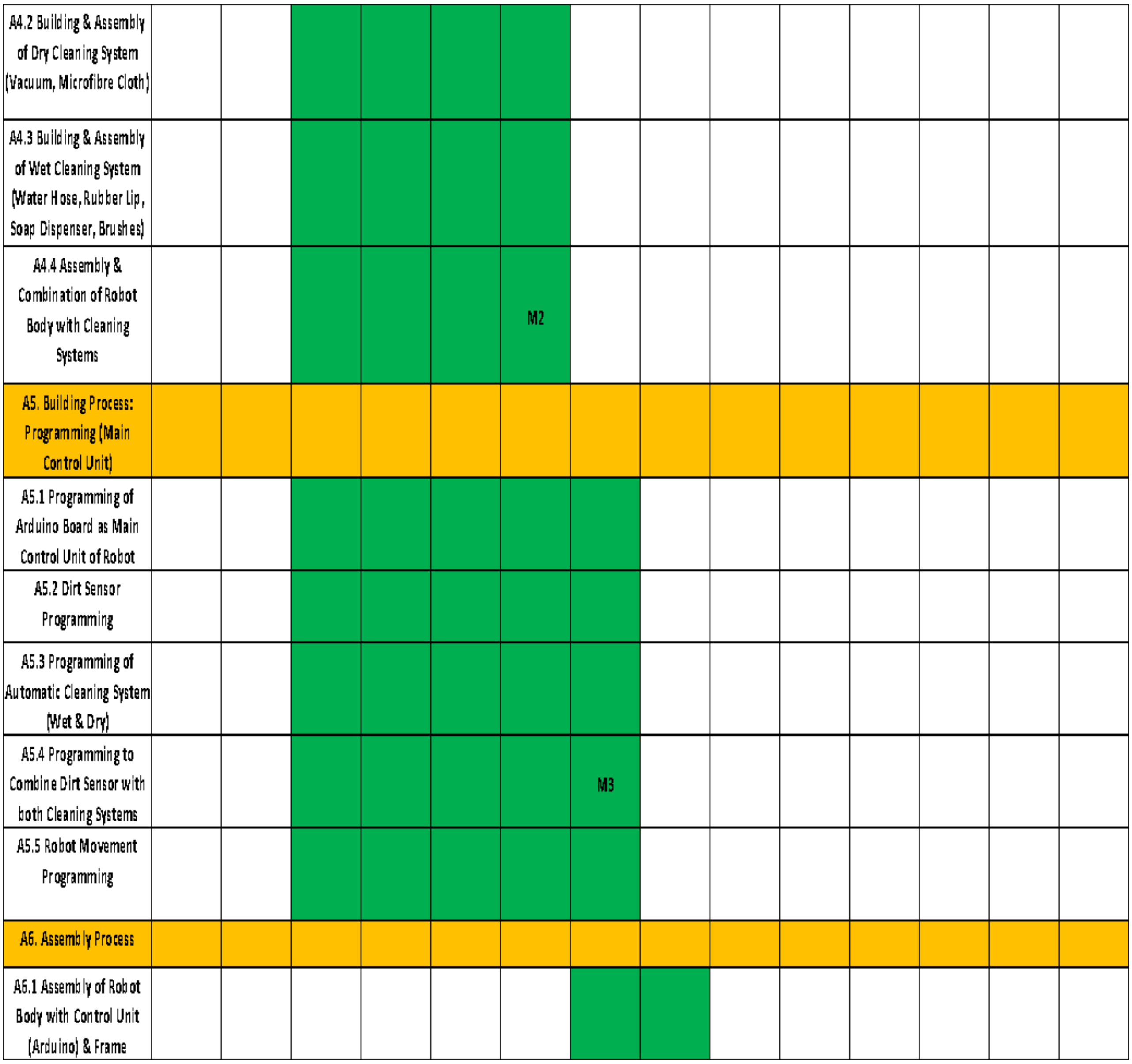


Figure 69: Team Solar Fam's Gantt Chart

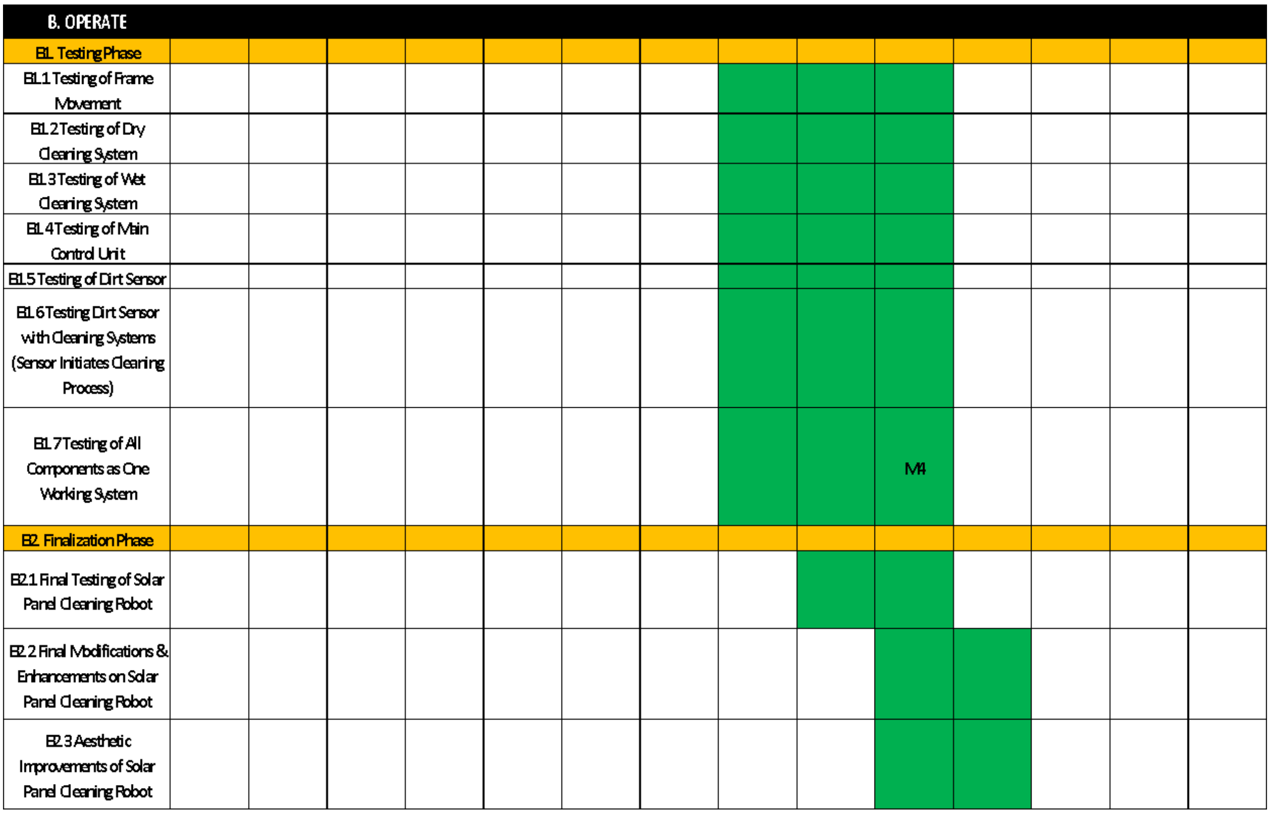


Figure 70: Team Solar Fam's Gantt Chart

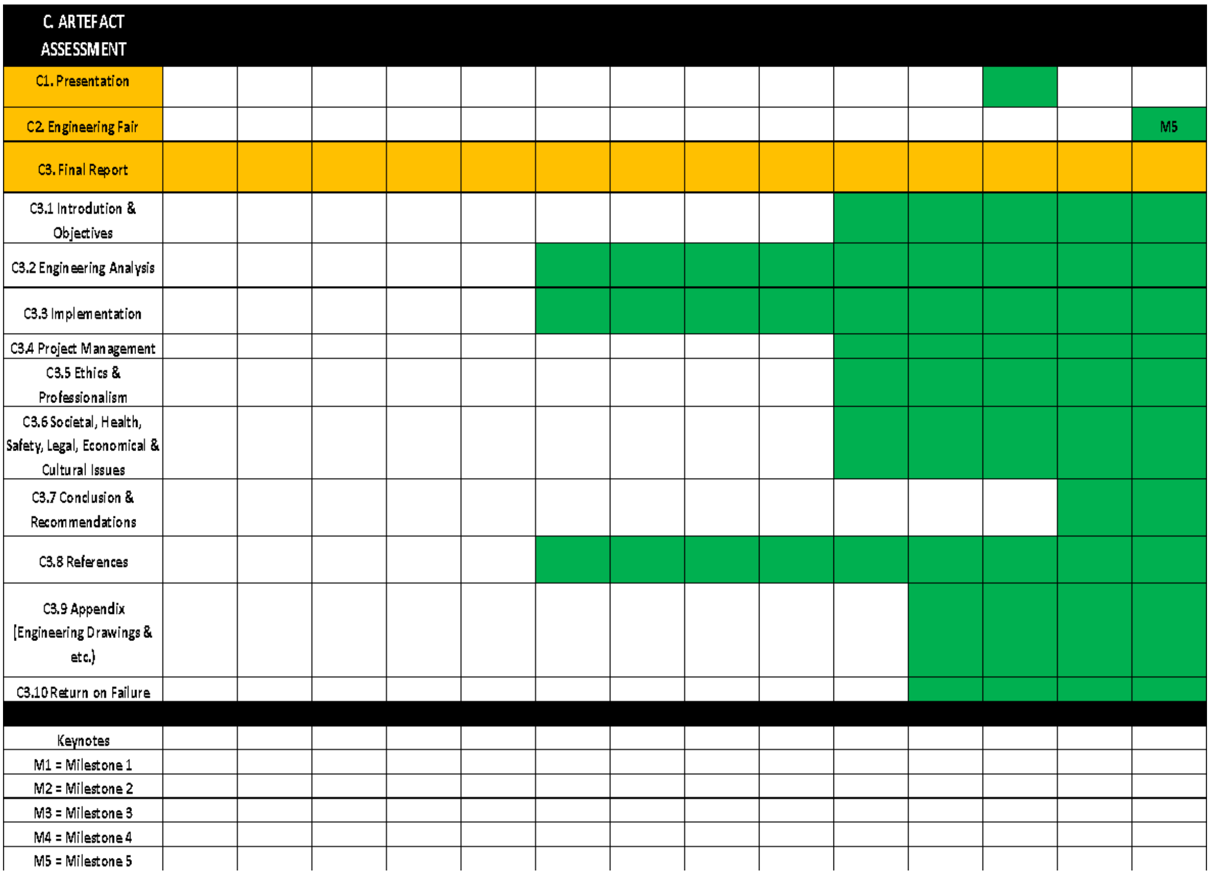


Figure 71: Team Solar Fam's Gantt Chart

7.3 Linear Responsibility Chart

In addition to these charts, a linear responsibility chart was also made to determine which member led a certain task and the amount of members that were needed to assist on each task. This chart gave a clearer distribution of task among members based on the Gantt Chart.

Table 12: Team Solar Fam's Linear Responsibility Chart

	Person in Charge/ Level of Assistance				
Task Code/ Task	**Arielle**	**Zharif**	**Samuel**	**Eugene**	**Hafis**
A. IMPLEMENT					
A1. Design Finalization					
A1.1 Decision on Type Final Prototype to be Built	5	5	5	5	5
A1.2 Final Alterations and Modifications to Design	5	5	5	5	5
A2. Materials and Supplies					
A2.1 Final Decision on Materials to be used for Prototype	2	2	5	2	5
A2.2 Survey on Prices of Materials	2	2	5	5	2
A2.3 Purchasing/ Ordering of Materials	5	5	5	5	5
A3. Building Process: Frame of Robot					
A3.1 Measuring Size of Parts	3	2	5	4	4
A3.2 Cutting of Measured Parts	3	2	4	5	4
A3.3 Welding/ Joining of Frame Parts	4	4	4	4	5
A3.4 Assembly of Frame	3	2	3	5	5
A3.5 Assembly of Caster Wheels to Frame (Movement System)	3	2	4	3	5
A4. Building Process: Solar Panel Cleaning Robot					
A4.1 Measuring & Cutting Parts for Body of Robot	4	2	3	5	3
A4.2 Building & Assembly of Dry Cleaning System (Vacuum, Microfibre Cloth)	3	2	5	3	4
A4.3 Building & Assembly of Wet Cleaning System (Water Hose, Rubber Lip, Soap Dispenser, Brushes)	3	2	4	3	5
A4.4 Assembly & Combination of Robot Body with Cleaning Systems	4	3	5	4	5
A5. Building Process: Programming (Main Control Unit)					
A5.1 Programming of Arduino Board as Main Control Unit of Robot	5	2	2	2	4
A5.2 Dirt Sensor Programming	5	2	2	2	4
A5.3 Programming of Automatic Cleaning System (Wet & Dry)	5	2	2	2	4
A5.4 Programming to Combine Dirt Sensor with both Cleaning Systems	5	2	2	2	4
A5.5 Robot Movement Programming	5	2	2	2	4

A6. Assembly Process					
A6.1 Assembly of Robot Body with Control Unit (Arduino) & Frame	5	3	4	4	5
B. OPERATE					
B1. Testing Phase					
B1.1 Testing of Frame Movement	4	3	5	4	5
B1.2 Testing of Dry Cleaning System	5	3	4	5	4
B1.3 Testing of Wet Cleaning System	4	3	5	4	5
B1.4 Testing of Main Control Unit	5	3	4	5	4
B1.5 Testing of Dirt Sensor	4	3	5	4	5
B1.6 Testing Dirt Sensor with Cleaning Systems (Sensor Initiates Cleaning Process)	5	3	4	5	4
B1.7 Testing of All Components as One Working System	5	3	4	5	4
B2. Finalization Phase					
B2.1 Final Testing of Solar Panel Cleaning Robot	5	5	5	5	5
B2.2 Final Modifications & Enhancements on Solar Panel Cleaning Robot	5	5	5	5	5
B2.3 Aesthetic Improvements of Solar Panel Cleaning Robot	5	5	5	5	5
C. ARTEFACT ASSESSMENT					
C1. Presentation	5	5	5	5	5
C2. Engineering Fair	5	5	5	5	5
C3. Final Report					
C3.1 Introduction & Objectives	2	2	2	2	5
C3.2 Engineering Analysis	2	2	5	2	2
C3.3 Implementation	5	2	2	5	2
C3.4 Project Management	2	2	2	2	5
C3.5 Ethics & Professionalism	2	5	2	2	2
C3.6 Societal, Health, Safety, Legal, Economical & Cultural Issues	5	5	5	5	5
C3.7 Conclusion & Recommendations	2	2	2	2	5
C3.8 References	2	2	2	2	5
Keynotes **Person in charge (5)** **Level of Assistance (4-1)**					

7.4 Budget Plan

A bill of materials was made by the team to list down all the materials to be bought that were required to complete the prototype. This was also to ensure that the team did not exceed the budget of RM 2000 given. Based on the bill of materials made from last semester, the estimated costing of the whole project was RM 1182.24 which was within the budget given. This bill of materials is as shown below.

Table 13: Team Solar Fam's Estimated Bill of Materials

Bill of Materials						
No.	**Material**	**Description**	**Vendor**	**Unit Price (RM)**	**Quantity**	**Total (RM)**
1	Aluminium Frame (8m total)	0.13 m x 0.13m x 0.3 m RM 10 per 0.3m = RM 270	Lelong	RM 10/0.3m	8m	RM 270
2	Stainless steel body	0.5 m x 0.3m x 0.0005 m = RM 136.55 x 2 = RM 273.10 Or Scrap metal = FOC	Online Sho[	RM 26.20/rod	2m	RM 52.40
3	Electrical Cable (5m)	Old project / scrap = FOC	Shopee	RM 2 per 15 cm x 10 pc	40	RM 8.00
4	12V DC motor (x2)	Old project = FOC Pudu shop = RM 23	Shopee	RM 23/pc	2	RM 46.00
5	Roller Brush	RM 3.34 per pc	Alibaba	RM 3.34	1	RM 3.34
6	Vacuum	Wet/ Dry Vacuum	Karcher	RM 600	1	RM 600.00

7	Sprinkler system (x2)	Low Pressure	Lelong	RM 15	2	RM 30.00
8	Castor wheel (x2)	4.6 cm diameter RM 16 per 4pc = RM 8	Lelong	RM 4 per pc	2	RM 8.00
9	Rubber Lip	Multi-Purpose Rubber Lip for Variety of Dirt	Karcher	RM 20	2	RM 40.00
10	Arduino	Motherboard	Cytron	RM 96	1	RM 96.00
11	Battery	12V Lipo	Cytron	RM 12.50	1	RM 12.50
12	Lock	Lock Plate Set	Lelong	RM 4	4	RM 16.00
Grand Total (RM)						**RM 1182.24**

A new bill of material was then made by the team for this semester. This latest and updated budget plan contained all the materials bought by the team that were needed to build the prototype. As shown in the table below, the actual total cost of the prototype was RM 1557.50. This was about RM 400 more than the estimated budget plan from last semester. However, the reasoning behind the increase in budget was due to factors such as minor electrical components that were needed to solve power issues, aesthetic products such as paint and shellac to further enhance the look of the prototype and also other components for design changes such as the use of a winch mechanism instead of a simple gear motor system. Even though the actual cost was higher than the estimated cost, the amount was still not an issue as it did not exceed the budget given of RM 2000.

Table 14: Team Solar Fam's Actual Bill of Materials

No.	Material	Description	Vendor	Unit Price (RM)	Quantity	Total (RM)
1	Wiper Washer	Water Sprinkler	Meter Trading	28	1	28
2	Carboy Wiper 12"	Rubber Lip	Meter Trading	13	1	13
3	Mega Ch340G	Arduino Mega	QQ Trading	60	1	60
4	Optical Dust Sensor	Dust Sensor	QQ Trading	50	1	50
5	Arduino Motor Shield	Motor Shield	QQ Trading	15	1	15
6	Bluetooth Module HC-05	Bluetooth Module	QQ Trading	25	1	25
7	Jumper M-F 12cm	10 pc Jumper M-F 12cm	QQ Trading	1.8	1	1.8
8	Jumper M-M 12cm	10 pc Jumper M-M 12cm	QQ Trading	1.8	1	1.8
9	Jumper M-F 20cm	10 pc Jumper M-F 20cm	QQ Trading	2	1	2

10	Jumper M-M 20cm	10 pc Jumper M-M 20cm	QQ Trading	2	1	2
11	Lipo Battery	Lipo 11.1V 8C 2200 MAh	QQ Trading	62	1	62
12	Metal Shaft	Metal Shaft (8mm x 400mm)	QQ Trading	14	2	28
13	Disc Screw Coupling	Shaft Connector (6mm for 8mm Shaft)	QQ Trading	10	4	40
14	DC Gear motor	Gear Motor (12V 500RPM 37mm)	QQ Trading	43	4	172
15	Ultrasonic sensor HC SR04	Ultrasonic sensor HC SR04 DC 5V	QQ Trading	6	2	12
16	Breadboard 400	400 pin Breadboard 8.3*5.5cm	QQ Trading	6	1	6
17	Pensonic Vacuum	WetDry Vacuum 1200W	HLK Chain Store	226	1	226
18	Shellac	Shellac	Dian Be Hardware	8.9	1	8.9
19	Metal wire	Wire Rope (4 m)	Dian Be Hardware	4	1	4
20	Metal frame	Robot metal frame	Rajini metal works	800	1	800
Grand Total				**RM 1557.5**		

With the use of these project management skills, the team was able to successfully build the prototype within budget and made it fully functional in time for the presentation at the annual Taylor’s Innofest.

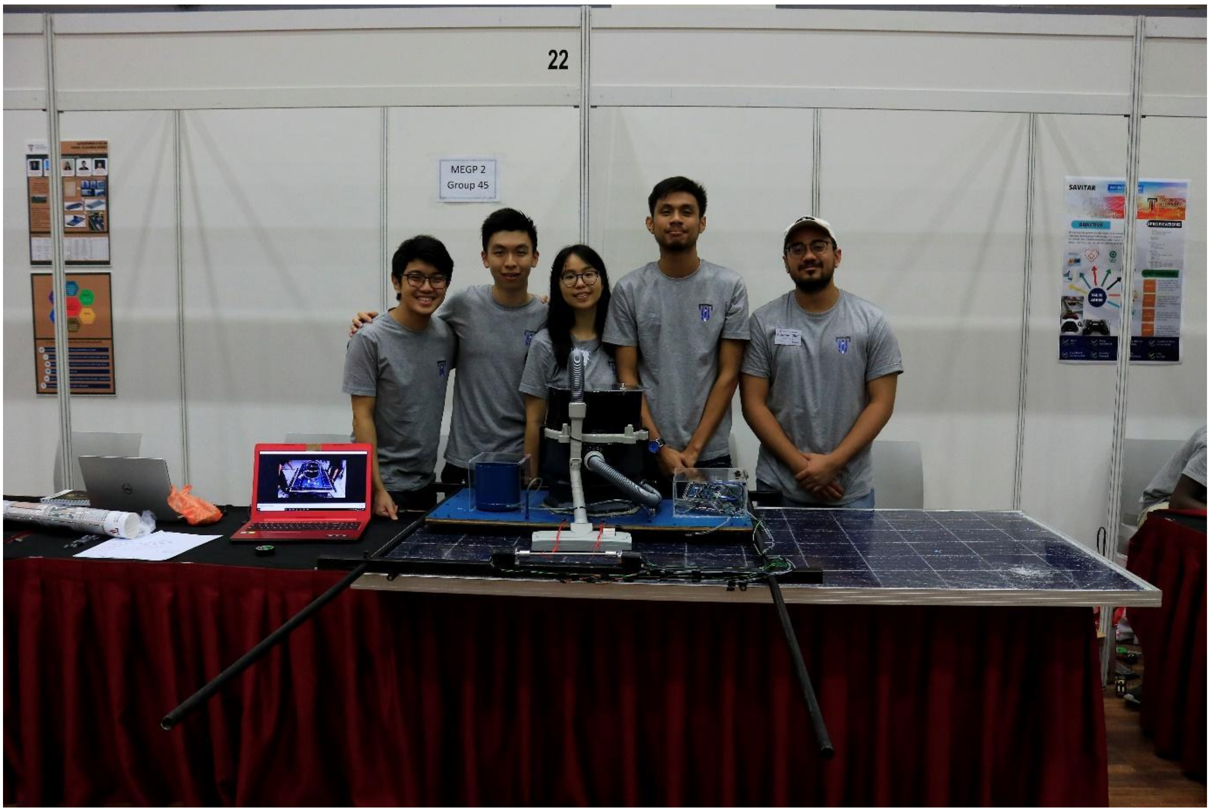


Figure 72: Team Solar Fam with the Autonomous Solar Panel Cleaning Robot Prototype at Taylor’s Innofest

8.0 ETHICS & PROFESSIONALISM

As a team, we followed the standards and code of ethics set by the National Society of Professional Engineers. **[21]** The code of ethics are as follows:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honourably, responsibly, ethically, and lawfully so as to enhance the honour, reputation, and usefulness of the profession.

To start, we ensured that the wiring of the project is waterproof to eradicate the risk of being shocked which in turns follows the first code of ethics, "Hold paramount the safety, health and welfare of the public". Throughout the time the team took to build the project, we tried to follow the last code of ethics as best as we can to enhance our productivity.

Next, we delegated tasks amongst each and every one of us to combat with the time limitation of building this product which in turn follows the second code of ethics, "Perform services only in areas of their competence". When it comes to avoiding deceptive acts, the complexity of our product correlates to the level of our skill, qualification and knowledge. In addition, we consulted with our lecturers for the placement of our parts/sensors.

Furthermore, to working with TNB we ensured them with in-depth, relative and up to date data when it came to our project and how it can affect the community and society. This follows the fourth code of ethics, "Act for each employer or client as faithful agents or trustees". When following the third code of ethics, all of the data that was obtained by the team are gained from either physical or digital form from trusted resources.

9.0 SOCIETAL, HEALTH, SAFETY, LEGAL, ECONOMICAL & CULTURAL ISSUES (IMPACT OF PROJECT)

9.1 Society

The generation today is surrounded by technology which consumes a lot of electricity such as hand phones, smartwatches, televisions and many more. Of the many ways how electricity is generated, burning fuel and natural gas eats up the Earth's natural resources, or in other words, is a form of non-renewable energy. It is no surprise how easily society today takes electricity for granted and neglect the fact that our natural resources are being used up daily at an astonishing rate. In tackling this challenge given by TNB Malaysia, the team indirectly promotes the importance of renewable energy to youth. With this project, the team hopes that this will encourage the future generation to support the usage of solar energy.

9.2 Health

As designers of the prototype for this project, the health and welfare of workers who will be using the prototype in real life applications was made a priority. The team made sure that the prototype would yield little to no harm at all to the user. This was important as the team did not want anybody using the prototype to hurt or injured. There were a few design criteria that were taken into consideration to ensure the well-being of workers. For example, the modified vacuum was firmly attached to the platform on the frame. This was to ensure that the vacuum does not fall off the platform and onto any workers when being used on solar panels that are inclined at certain angles. Besides that, the rubbish container was secured well with the suction part of the vacuum to make sure that any dust, contaminants or dirt collected from the solar panels does not escape containment. This securement was crucial in the team's design considerations as some workers/ users may be allergic to dust, dirt and certain types of contaminants in the air. Therefore, the team had to think thoroughly about all design aspects in order to maintain the health and well-being of workers/ users.

9.3 Safety

The safety of the cleaning robot was one of the project impact whereby it has to be user friendly and do not harm the users as well. Previously, the team had encountered short circuit and electrocution during the testing process. In order to solve this issue, the team had sealed all the connections with insulated wires. The team also built a home for the control unit system so it will not be exposed to the outer environment where there will be direct sunlight and rainwaters. Besides that, the inconsistent motion of the frame with a possibility of falling off from the solar panel was also another risk the team had faced. Thus, the team had incorporate caster wheel bearings and rollers at both horizontal and vertical sides of the robot frame.

9.4 Legal

In terms of the legal impact of our project, it does not break any international, local or environmental laws. It follows the standards set by the Malaysian government. Speaking of environmental laws, we are using a LiPo battery which does not consume as much energy or create any pollution when compared to resources such as petrol or natural gases. In addition, a LiPo battery is also recyclable and reusable. Part 4 Section 22 (1) of Malaysian Act 127 Environmental Quality Act 1974 which states that no person shall, unless licensed, emit or discharge any hazardous substances, pollutants or wastes into the atmosphere in contravention of the acceptable conditions specified in Section 21 which our product does not break. **[22]**

9.5 Economy

In the economy aspect, the proposed solution will positively impact the overall cost for TNB in the long run taking into consideration the calculated / estimation of labour costs for using the previous manual cleaning method which was covered in the background of Fortune 11 Solar Farm section. On top of this, the design allows the use of sustainable materials in construction/ manufacturing. Hence, this project may encourage TNB or any other parties' interest in producing these types of robots commercially and outsourcing this to local companies which will ultimately benefit the nation's economy.

As mentioned in the introduction section, the efficiency of solar panels in generating electricity improves when the solar panels are clean and free from contaminants. Thus, the use of solar panel cleaning robots may potentially lead to higher production rates of electricity which will bring TNB and Malaysia to greater heights in terms of creating sustainability. This aligns with the notion that renewable energy is the future.

9.6 Culture

In terms of the cultural aspect, the team has also ensured that the team did not violate or offend any culture, religion or race while doing this project. Besides that, with the rise in technology which is heading towards using electricity instead of fuel or natural resource, the current generation is slowly turning and focusing on generating renewable sources of electricity such as wind, water and solar energy. While doing this project, the team hoped to cultivate a greener future for the generations to come and that they will also do the same.

10.0 CONCLUSIONS & RECOMMENDATIONS

In conclusion, this report acts as a closure for all the hard work and effort put in to complete the final group project (MEGP 2). Continuing from the previous semester (MEGP 1), the team moved on to the Implement (I) and Operate (O) stage of CDIO to actually build, test and make a fully functional autonomous solar panel cleaning robot based on the requirements set. The criterion were:

- Effective and efficient
- Lightweight and easy-to-use
- Low cost and maintenance
- Adaptable to shifting arrangements of solar panels
- Flexibility in cleaning various types of contaminants
- Has its own dirt tracking system

With that in mind, the team built the prototype from scratch after attaining all the materials and components required. This was the Implement (I) stage of the project (as seen in **5.0 Implementation**). Moving on, the team then proceeded to test the prototype and make adjustments/ modifications in order to ensure that it was fully functional. This was the Operate (O) stage of the project (as seen in **5.0 Implementation** & **6.0 Operate**). An operations manual for the prototype was also made by the team to help end users on how to use the final prototype made.

Figure 73: Team Solar Fam's Autonomous Solar Panel Cleaning Robot

Not only the project was considered a success, but it also managed to teach each member of the team various lessons in terms of the project itself and personal values. As this was the final group project, it was considered a major achievement to be able to not only completely build the prototype but also make it a fully functional one. The project tested the team mentally, physically and emotionally as a lot of unexpected issues arise that had to be solved quickly in order for project completion. The team had to work long hours to prevent failure from becoming a reality. However, the team stood strong and worked together to overcome the challenges faced. Every member had to put in extra effort and initiative in order for the prototype to be a successful one. It can also be said that this project brought out a sense of unity among the team as each member had the common goal of finishing the prototype. The project also brought out the best in each team member. Current skillsets were enhanced and new skillsets were learned. This gave an advantage for each member for upcoming projects in the future. As the icing on top of the cake, the team also managed to come in 1st place for the annual Taylor's Innofest. This further justifies all the effort and sacrifices the team had to make in order to complete this project. In the end, this project was a journey full of ups and downs. Nonetheless, it was a memorable one.

Figure 74: Team Solar Fam Accepting 1st Prize in Taylor's Innofest

As the saying goes, not all solutions are perfect and have their own respective flaws. The same can be said about the team's autonomous solar panel cleaning robot. The team realized that there was room for improvement to further enhance the quality of the prototype made. Therefore, the team came up with a list of recommendations for improvement in future prototypes that are similar to this one.

The first recommendation is to have automated movement of robot frame/ platform in both the horizontal and vertical direction (x and y axis). This is because the current prototype was only programmed to move in the vertical axis which is in the up and down direction. Therefore, the team feels that with a greater budget and longer time limit, the team will be able to do further research and come up with a prototype that has movement capabilities in both the x and y axis in the future.

Besides that, another future recommendation will be to have a renewable energy powered vacuum and recyclable water source for the whole system. In the current robot, the vacuum system is powered by electricity which is a non-renewable energy source. Hence, the team wishes to gather more information in future through research to try and design a self-made vacuum powered by a renewable energy source such as a rechargeable battery, solar or even wind energy. As for the water source, the prototype's sprinkler system uses clean water from the container built. However, clean water needs to be filled in once the water level is low. Thus, the team intends to develop a filtering system in the vacuum that is able to separate clean water from soap and dirt once they are sucked into the vacuum. This will in turn eliminate the need to add in water into the container as water used can be recycled. Hence, reducing and preventing water wastage.

Furthermore, the team intends to have a wireless control of components and dust monitoring feature. In the current prototype, the vacuum cleaner, sprinkler system, motors for winch mechanism and control unit (Arduino Mega) are all activated by hand. Therefore, a future solution for this is that all these components are able to be turned on wirelessly via Bluetooth or Wi-Fi by using a Bluetooth or Wi-Fi module in the system. Thus, the system can be turned on either by the use of a smartphone or computer from further distances.

The team also intends to connect all these components together with each other without the use of wires. Hence, eliminating wiring issues faced. Moving on, the team also wants to improve on the current dust monitoring system whereby the cleanliness of solar panels can be monitored via a smartphone or computer at any place and at any time. Currently, the cleanliness of panels can only be checked by connecting the sensor to a computer which is less convenient to the user.

Moreover, another recommendation would be to use weather resistant materials. As of now, the current prototype is exposed to environmental changes such as rain. The main control unit (Arduino Mega), vacuum motor, electrical components and winch mechanism all have the potential to get short-circuited by rain water. Therefore, the team intends to overcome this issue by using waterproof materials such as plastic or rubber. Another way is to place all these components in a 3-D printed container which is waterproof. Wires can also be enclosed in rubber tubing to prevent water from getting to them. Waterproof coating can also be used to make the system more water resistant.

Next, the team wants to improve the current prototype by using lighter/ compact design and materials which are not only minimalistic but also fully functional. As seen in the current prototype, the vacuum and frame of the whole system is not only large but also heavy and may not be aesthetically pleasing to the public eye. Therefore, the team intends to solve this issue by using lighter materials such as carbon fibre or aluminium instead of steel. In addition, the team wants to decrease the size of vacuum and frame to make it more compact and minimalistic. Hence, increasing overall aesthetic value of the prototype.

Lastly, another recommendation would be to have automated moving sensors. The main reason behind this is to improve efficiency. The current prototype only has one dust sensor to detect the cleanliness of solar panels. However, it is stationary and can only detect the cleanliness of a certain area on the panel. Therefore, the team wants to overcome this by making the sensor movable all throughout the solar panel by installing multiple dust sensors. Alternatively, motors could be attached to the sensors to allow them to move around the panel and check on the cleanliness. Thus, increasing efficiency of reading.

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