SCHOOL OF ENGINEERING

BACHELOR OF ENGINEERING (HONOURS) MECHANICAL ENGINEERING

ASSIGNMENT PROJECT REPORT MARKING RUBRIC

Electronics and Microprocessor ENG4213

Title of Project Sheet	**AUTONOMOUS SOLAR PANEL CLEANING ROBOT**
Lecturer:	**MR. TAGHI HAJIBEIGY**
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Area	**Actual Mark**
Format (5)	
Abstract and Introduction (5)	
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General Results and Discussions (25)	
Conclusion and References / Appendix (5)	
Total (50)	

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1.0 ABSTRACT

The proposed project is linked to the team's MEGP 2 module, regarding the solar panel cleaning robot in collaboration with TNB. The objective of this project is to build an autonomous cleaning robot consisting of few subsystems which are the motion and dust monitoring system. The materials used were the ultrasonic sensors, dust sensors, relay system, Arduino Mega and motors. The dust sensor was used to detect the dust density of a specific region. The relay system acts as a switch to trigger the motion of motors based on the detected distance obtained from the ultrasonic sensors that was programmed through the Arduino Mega. When the detected distance is above 15 cm, the motion of the platform will move downwards while for the distance which is below or equal to 15 cm, it is vice versa. The motion of the platform as well as the amount of dust density will be displayed on the serial monitor for the user's reference. A few recommendations were considered to enhance the quality of the future prototype. This includes by having an automated moving dust sensor in order to improve the dust detecting efficiency and to have a wireless control of components and dust monitoring feature. Lastly would be by incorporating an automated movement of robot frame for both vertical and horizontal axis so that the whole cleaning system will be fully automated.

2.0 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 practice 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 in Malaysia with a single-axis system. **[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 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 while also being a cost efficient system. The project given to our team is divided into 2 parts. The first part will be focused on planning and designing the system while the second part will be focused on 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. Based on the CDIO method, this is called the Conceive (C), Design (D), Implement (I) and Operate (O) stage of the project. [**4**] Therefore, our team will be using the appropriate and necessary methods in the stages of CDIO to try and come up with a solution for the issue at hand.

3.0 OBJECTIVES

The objective of this project are as listed below:

1. To detect and display the distance of an obstacle away from the ultrasonic sensor on the serial monitor.
2. To change the direction of motor shaft rotation either clockwise or anticlockwise based on the distance of an obstacle from the ultrasonic sensor.
3. To detect and display the dust level values at a specific region on the serial monitor.
4. To complete this project by Week 13 (19th November 2019).

4.0 FIGURES & DIAGRAMS

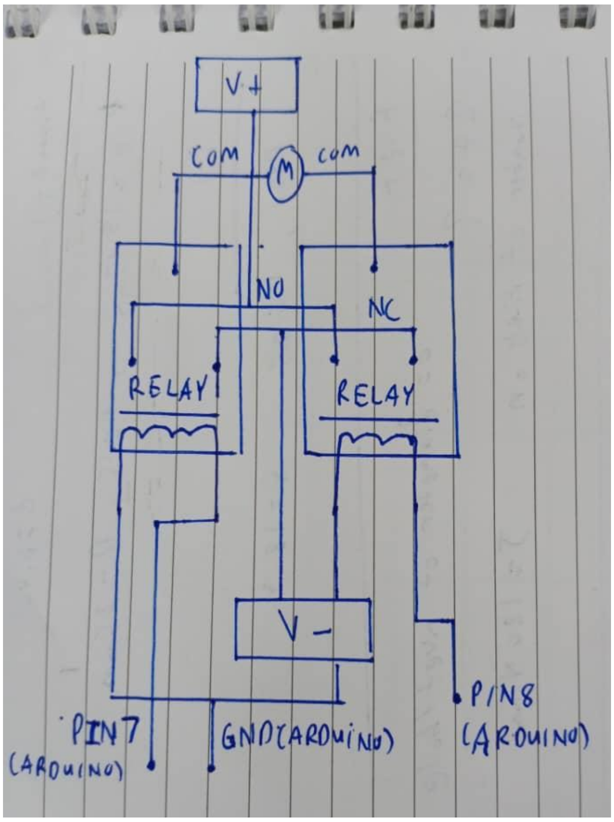


Figure 1: Schematic diagram of the relay connection

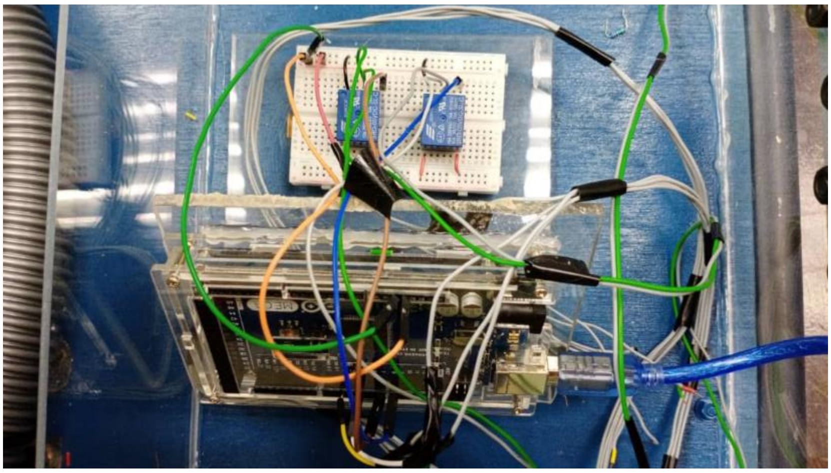


Figure 2: Connection in the HCU

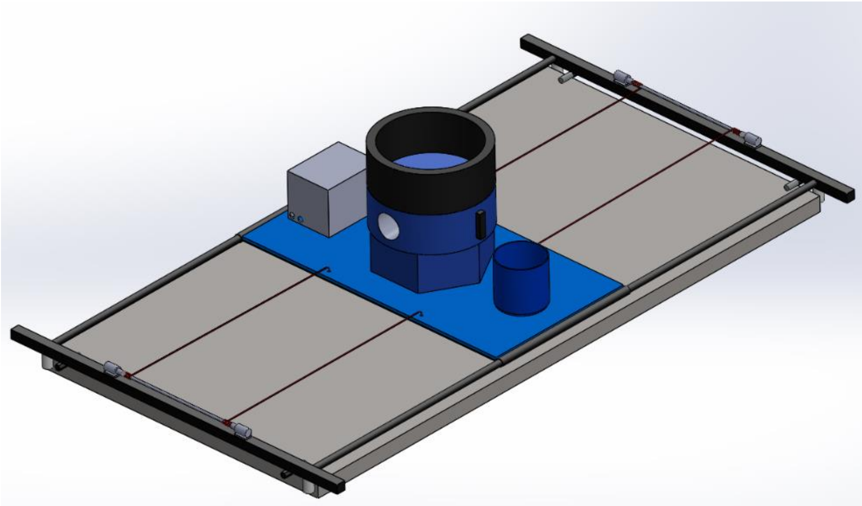


Figure 3: Solidworks of the actual prototype

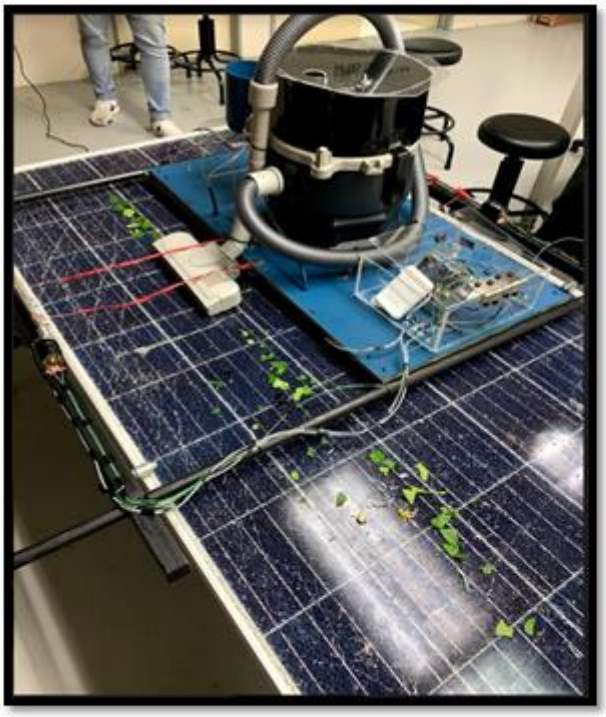
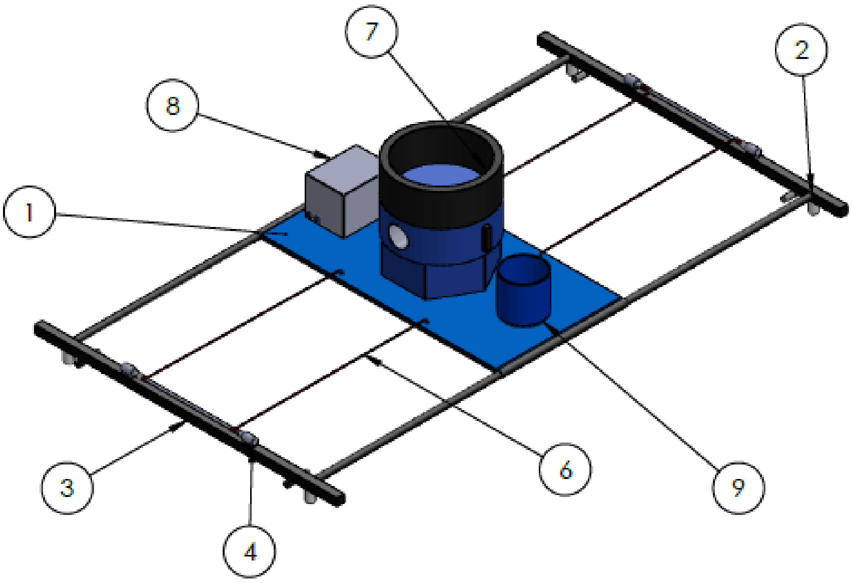


Figure 4: Complete prototype ready for presentation



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 5: Bill of material

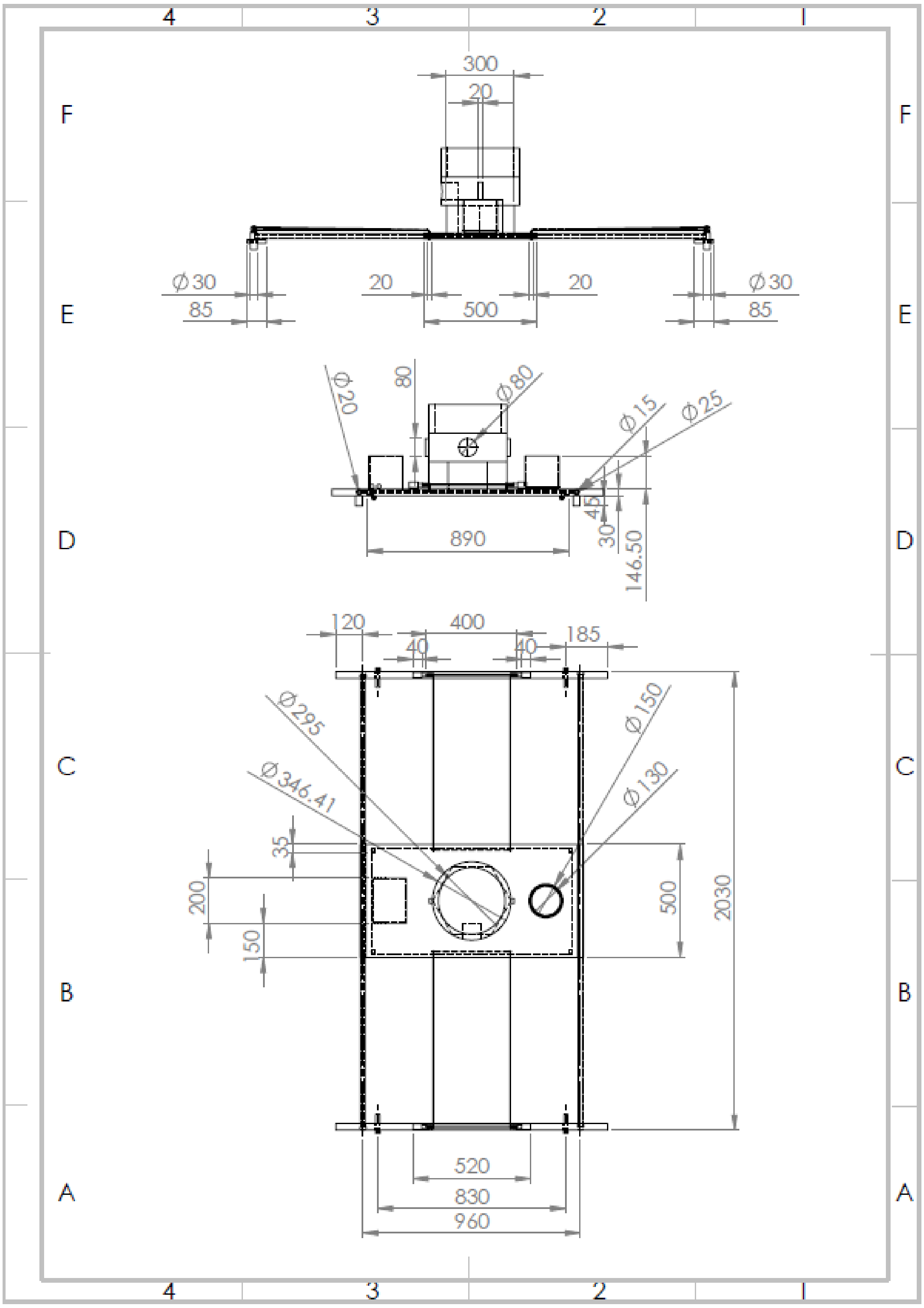


Figure 6: Prototype specifications

5.0 MATERIALS & METHOD

5.1 Materials

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 cost of the whole project was RM 1182.24 which was within the budget given. This bill of materials is as shown below.

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**

Figure 7: Proposed Bill of material and the respective prices

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.

Bill of Material							
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	Carboy 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**

Figure 8: Actual Bill of material and the respective prices

5.2 Technical Specifications

Figure 9: Modified Pensonic 211 wet dry

a) Vacuum

Table 1: Vacuum specifications

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

The Vacuum that we used is the Pensonic Vacuum Cleaner 211 (Wet & Dry). It uses 1200W and 220-240V at 50Hz. Its storage space is 32L but after modification, it can store up to about 12L. The vacuum weight was reduced from 6kg to 4.5kg after modifying the bottom and the cover of the vacuum. Inside the vacuum, it has a washable filter and also has a blowing feature on the top. It is able to suck up dry dirt and wastewater with ease.

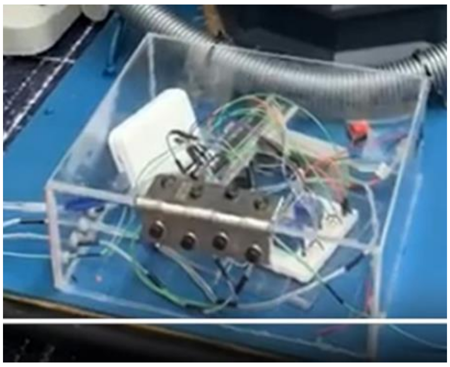


Figure 10: HCU consist of Arduino, breadboard, relay, power bank and LiPo Battery

b) Home Central Unit (HCU)

Table 2: HCU specifications

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 Block	Max Load current: 10A @ 30V
Power Bank	10400mAh 5V @ 2.1A
LiPo Battery	2200mAh 11.1V Continuous Discharge: 66A

The home central unit (HCU) is made from Perspex and consists of a few things including microcomputer (Arduino Mega), Solderless mini breadboard, 5 pin 5V relay, a powerbank and a LiPo Battery. The Arduino Mega is the microcomputer that is accessible by a cable and functions to read inputs and write outputs. Example of the Arduino functions are reading a sensor, activating a motor, turning on an LED and many more. The solderless breadboard we used is for quick connections for testing without soldering. Coupled with the electronic jumper cables, connectivity between the other micro components become seamless and less time consuming.

The relay we used is the 5V Relay block which helps us to switch the polarity of motors to facilitate the clockwise and anti-clockwise movement to pull or release the cables.

The power bank is connected to power up the Arduino microcomputer. By separating the current and voltage from the motor connection, the prototype is able to run longer since the Arduino is not taking power from the LiPo battery. The power bank only needs to be recharged after 30 full runs.

The LiPo battery with the rating of 11.1V and has a capacity of 2200mAh is used to power up all 4 gear motors which act as winches for both sides. The LiPo needs to be recharged for about 2 hours after 10 full runs.

Figure 11: 2 Gear Motors making up one side of the winch mechanism

c) Winch

Table 3: Motor specifications

4 x Gear Motor	12V 500rpm

The gear motors we used is the 12V 500rpm (XC37GB30) where we placed 2 on each side of the prototype. On one side, the motors are placed facing each other. On one end of the prototype, 2 motors will pull the cables which are attached to a shaft interconnecting the 2 gear motors while the other 2 motors on the other end will release the cable. The cable coiled around the shaft needs to be taut to ensure smooth movement.

The polarity connection on one end of the motor will follow according to the poles and the other motor needs to be connected with opposite polarity to cause both motors on one end to move in the same direction. The R stands for red which is the positive pole of the motor and the other pole is negative. If the positive wire is connected to R (positive) and the negative wire is connected to the other pole, then the motor will turn clockwise (CW). If the wires are connected to the opposite poles, the motor will turn counter-clockwise (CCW). For one side to turn the same direction, one motor needs the wires to connect to the correct poles and for the other side to connect to the opposite poles. This will result the platform movement to move in one direction. With the help of the relays, the polarities of the motors will be switched, and the platform will move back in the opposite direction. This can be further illustrated in the picture below.

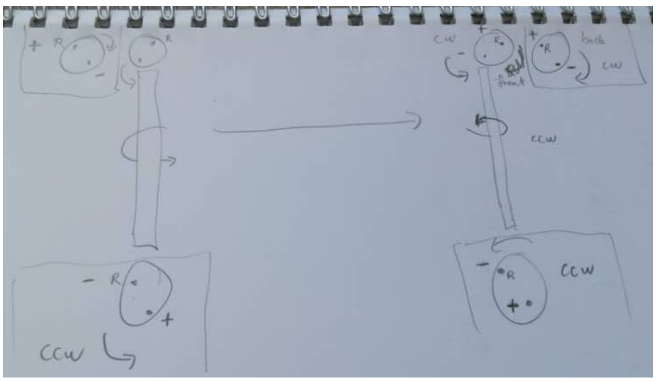


Figure 12: Illustration of the winch mechanism movement of the motors

Figure 13: Ultrasonic sensor on the frame

d) Ultrasonic Sensor (HC-SR04)

Table 4: Ultrasonic specifications

Power Supply	5V DC
Dimension	45mm x 20mm x 15mm
Ranging Distance	2cm – 400 cm
Trigger Input Pulse width	10uS
Effectual Angle	<15°
Working Current	15mA

The ultrasonic sensor detects the distance of the closest object in front of it ranging from 2 cm - 400 cm. It works by sending out a burst of ultrasound and listening for the echo when it bounces off of an object. The module sends a short pulse through pin ‘Trig’ to trigger the detection, then listens for a pulse on the pin ‘Echo’. The duration of this second pulse equals to the time taken by the ultrasound to travel to the object and back to the sensor. Using the speed of sound, this time can be converted to distance.

Using ultrasonic sensors, we can detect the position and the movement of the platform along the frame. When the platform moves closer to the frame, the ultrasonic sensor will send data to the Arduino to process the data and command the motors to move in the other direction.

e) Optical Dust Sensor

Figure 14: Optical dust sensor

The Dust sensor located beneath the wooden platform facing the solar panel helps us monitor dust levels on the solar panel and submits the data to the Arduino. Below shows how the dust sensor works.

Light from the light emitting diode is spotted with a lens and a slit as shown in Chart A. For the photodiode, a lens and a slit is positioned in front of it to cut disturbance light and to detect light reflection (when detecting dust) efficiently. The area where the 2 optical axes cross is the detection area of the device.

Chart B shows how the device works with the absence of dust. The device identifies voltage output even when there is no dust detection. The output voltage in no-dust condition is specified as Voc because light emitted from the LED reflects at the device's case and part of it reaches the detector.

Chart C shows how the device works with the presence of dust. The photodiode detects light reflected from the dust. Current in proportion to the amount of the detected light comes out from the detector and the device identifies analog voltage output after the amplifier circuit amplifies the current from the detector.

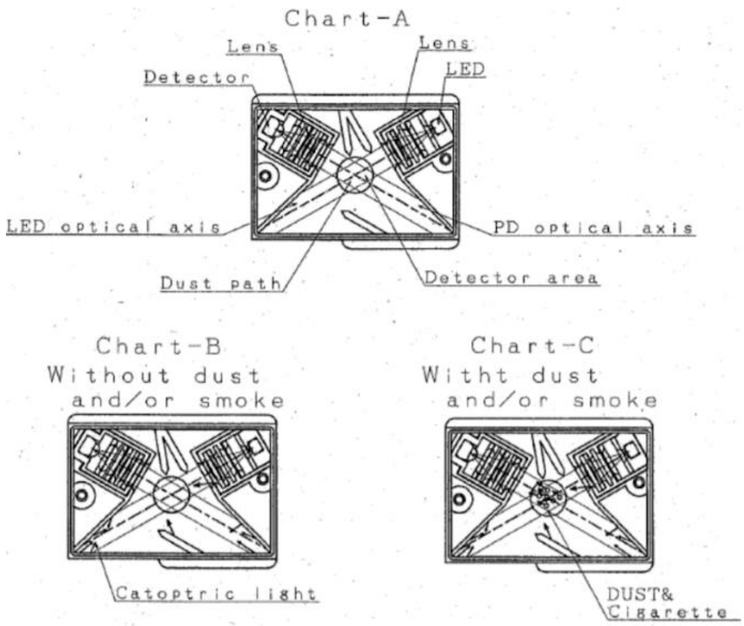


Figure 15: Chart A, Chart B and Chart C

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.

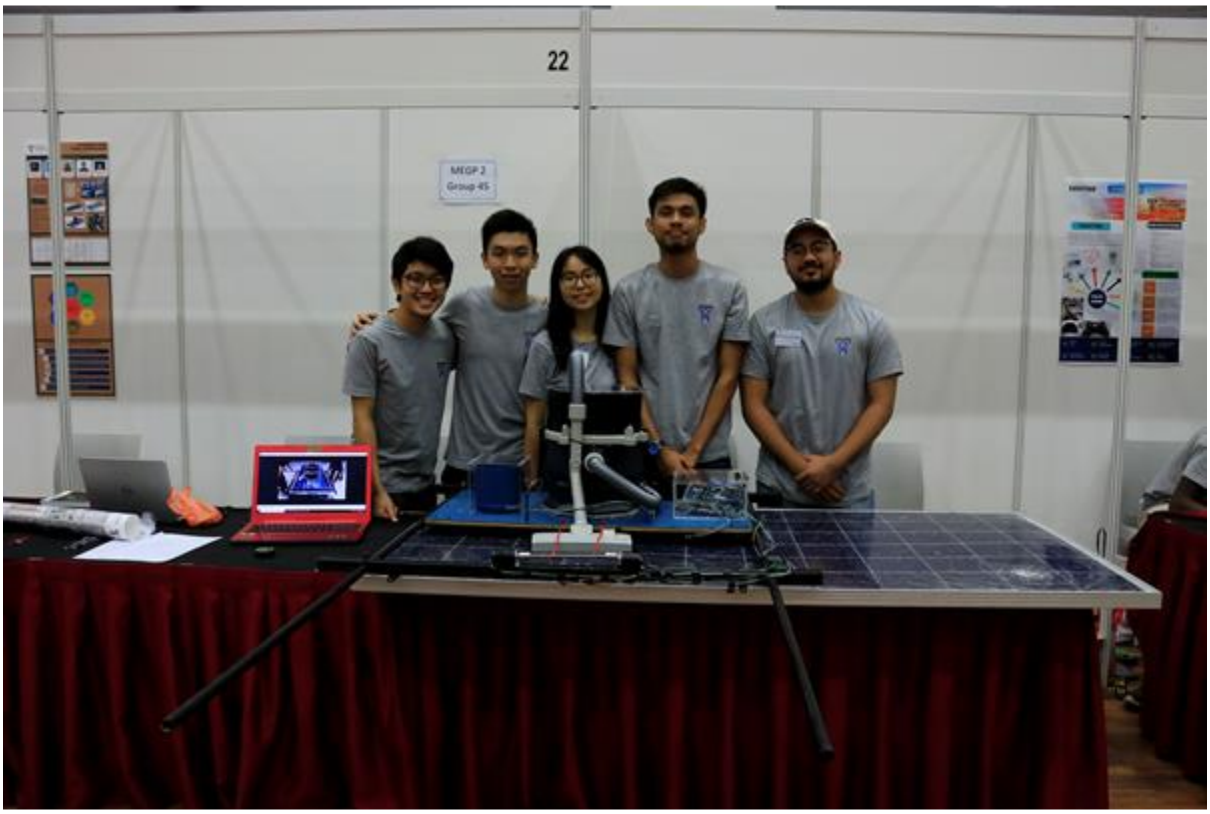


Figure 16: Team Solar Fam with the Autonomous Solar Panel Cleaning Robot Prototype at Taylor's Innofest

5.3 Methods

Below shows the step by step to operate the prototype.

Figure 17: How to mount the prototype on the panel

1. Mount the whole prototype on the solar panel frame. Ensure that the wheels are resting on the edges of the solar panel and Lock the adjustable bar according to the size of the solar panel.
2. Check if the cables are taut and reel the cables manually if it is slacking.
3. Connect a power bank to the blue cable in the home unit to power up the microcomputer (Arduino).
4. Make sure that the water container is filled with water or soapy water depending on the cleaning method.
5. Connect and turn on the vacuum plug to a socket as well as push start the toggle switch.
6. Turn on the main switch in the HCU to power up the motors which will move the platform vertically.
7. Move the prototype horizontally after one oscillation of vertical movement.
8. Once cleaning is one, turn off the main switch in the HCU and push off the toggle switch of the vacuum and turn off the AC plug for the vacuum.

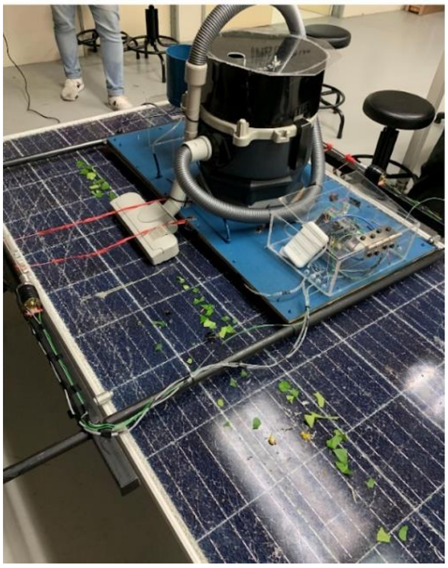


Figure 18: Before cleaning

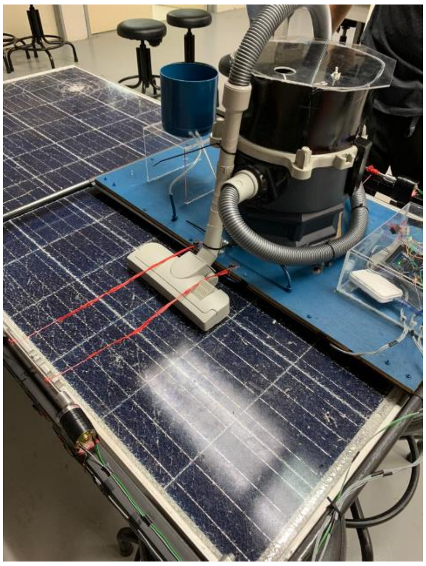


Figure 19: After cleaning

Figure 20: Before cleaning

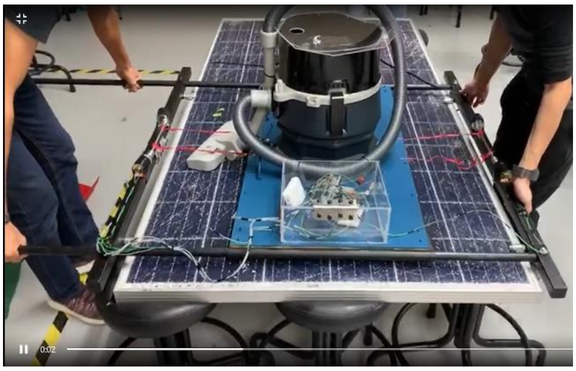


Figure 21: After cleaning

As seen in the figures above, the prototype is able to move on the solar panel to clean the dust, leaves and other dirt particles on the panel.

6.0 RESULTS & DISCUSSION

6.1 Motion System (Ultrasonic sensor, relays, motors)

Results

Table 5: Distance reading with corresponding relay state

Actual distance without sensor (cm)	Calculated distance with sensor (cm)	Relay State	
		Relay 1	Relay 2
10	10	HIGH	LOW
20	20	LOW	HIGH
30	30	LOW	HIGH
40	40	LOW	HIGH

Table 6: Motor reaction based on relay state

Relay State		Direction of Rotation		Platform Motion
Relay 1	Relay 2	Motors A & C	Motors B & D	
HIGH	LOW	Anticlockwise	Clockwise	Upwards
LOW	HIGH	Clockwise	Anticlockwise	Downwards
LOW	HIGH	Clockwise	Anticlockwise	Downwards
LOW	HIGH	Clockwise	Anticlockwise	Downwards

Discussion

```
//Relay
int in1 = 7;
int in2 = 8;

//Ultrasonic
const int trigPin1 = 4;
const int echoPin1 = 2;
long duration1;
int distance1;
int value = 0;

//Dust Sensor
int measurePin = A5;
int ledPower = 12;
unsigned int samplingTime = 280;
unsigned int deltaTime = 40;
unsigned int sleepTime = 9680;
float voMeasured = 0;
float calcVoltage = 0;
float dustDensity = 0;

void setup()
{
  Serial.begin(115200);

//Relay
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);

//Ultrasonic//
  pinMode(trigPin1, OUTPUT);
  pinMode(echoPin1, INPUT);

//Dust Sensor//
```

```
void setup()
{
  Serial.begin(115200);

//Relay
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);

//Ultrasonic//
  pinMode(trigPin1, OUTPUT);
  pinMode(echoPin1, INPUT);

//Dust Sensor//
  pinMode(ledPower,OUTPUT);
}

//MAIN//
void loop()
{
      //Ultrasonic 1//
      digitalWrite(trigPin1, LOW);
      delayMicroseconds(2);
      digitalWrite(trigPin1, HIGH);
      delayMicroseconds(10);
      digitalWrite(trigPin1, LOW);
      duration1 = pulseIn(echoPin1, HIGH);
      distance1 = duration1*0.034/2;

      Serial.print("Distance 1: ");
      Serial.println(distance1);

      //BOTH CLOSE TO WINCH//
      if (distance1 <= 15)
```

```
    //BOTH CLOSE TO WINCH//
    if (distance1 <= 15)
    {
      digitalWrite(in1, HIGH);
      digitalWrite(in2, LOW);
      Serial.println("MOVE UP/RIGHT");
      delay(5000);
     }

    //BOTH FAR FROM WINCH//
    if (distance1 > 15)
    {
      digitalWrite(in1, LOW);
      digitalWrite(in2, HIGH);
      Serial.println("MOVE DOWN/LEFT");
      delay(5000);
    }

    //Dust Sensor//
    digitalWrite(ledPower,LOW);
    delayMicroseconds(samplingTime);
    voMeasured = analogRead(measurePin);
    delayMicroseconds(deltaTime);
    digitalWrite(ledPower,HIGH);
    delayMicroseconds(sleepTime);
    calcVoltage = voMeasured*(5.0/1024);
    dustDensity = 0.17*calcVoltage-0.1;
    if ( dustDensity < 0)
    {
      dustDensity = 0.00;
    }
    Serial.println("Dust Density:");
    Serial.println(dustDensity);
}
```

Figure 22: Full code

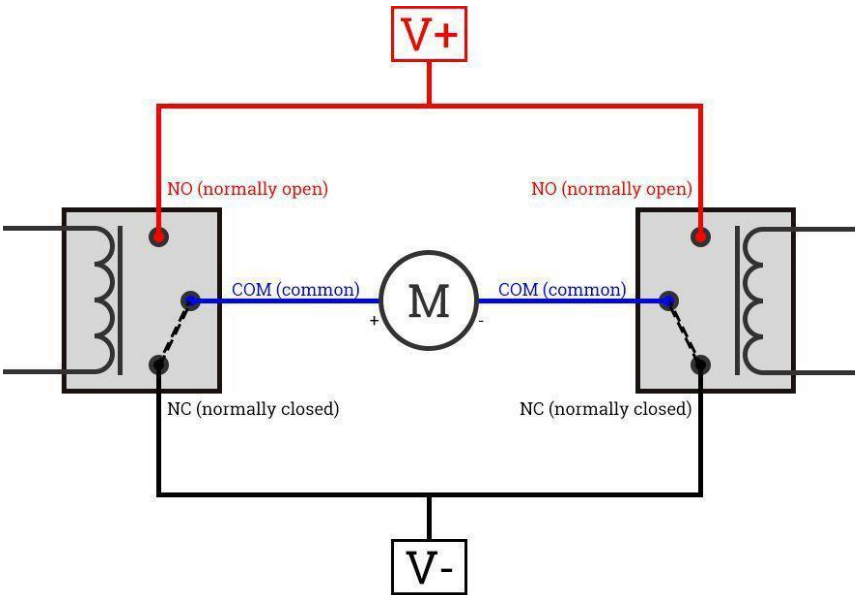


Figure 23: Relay configuration

Referring to the Table 5 above, the actual distance was measured from the platform of the frame to the next obstacle using a measuring tape. The calculated distance was detected from the same position using the ultrasonic sensors. Both of the measured distance was the same and this proved that the ultrasonic sensors were able to detect the distance accurately. The reaction of the motor was programmed based on the distance using the Arduino Mega and relay system. The default setting of the 2 relays will be Normally Closed (NC) and in LOW state as shown in Figure 23. When it is in HIGH state, the relay will be Normally Opened (NO). From Table 5, when the distance between the platform and the ultrasonic sensor is more than 15 cm, Relay 1 is programmed to be LOW state while Relay 2 will be in HIGH state. For distance below or equal to 15 cm, it is vice versa. As for the motion of the cleaning robot system, when the ultrasonic sensor detects the obstacle (frame platform) at a distance of more than 15 cm, the motion of the platform will move downwards. On the other hand, when the ultrasonic sensors detect the distance of less than or equal to 15 cm, the motion of the platform will change its direction and move upwards. Using the 'if' statement below, all the four motors will act accordingly to its corresponding direction based on the arrangement as shown in Table 6. This is also done by pairing 2 motors (A & B / C & D) together and connecting them to 1 relay. However, each motor in the pair is connected in the opposite polarity to its partner but in same polarity as one of the motors in the other pair (A opposite polarity to B but same polarity as C).

```
//PLATFORM CLOSE TO ULTRA SENSOR//
   if (distance1 <= 15)
   {
    digitalWrite(in1, HIGH);
    digitalWrite(in2, LOW);
    Serial.println("MOVE UPWARDS");
    delay(5000);
    }
```

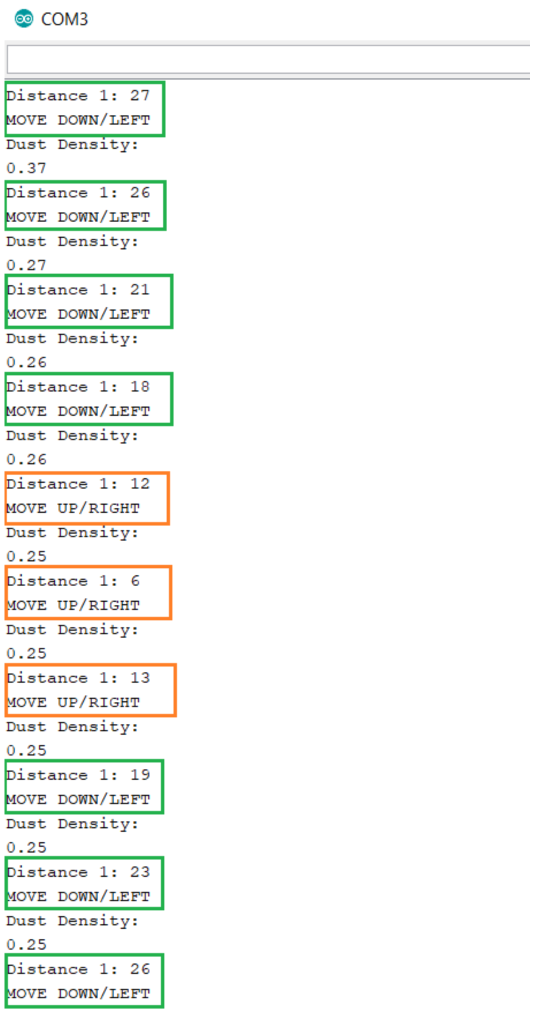


Figure 24: Sample of distance values displayed on the serial monitor

6.2 Dust Monitoring System

Results

Table 7: Dust sensor readings

Condition / Dust Density (mg/m3)
0
> 0 but < 1
> 1

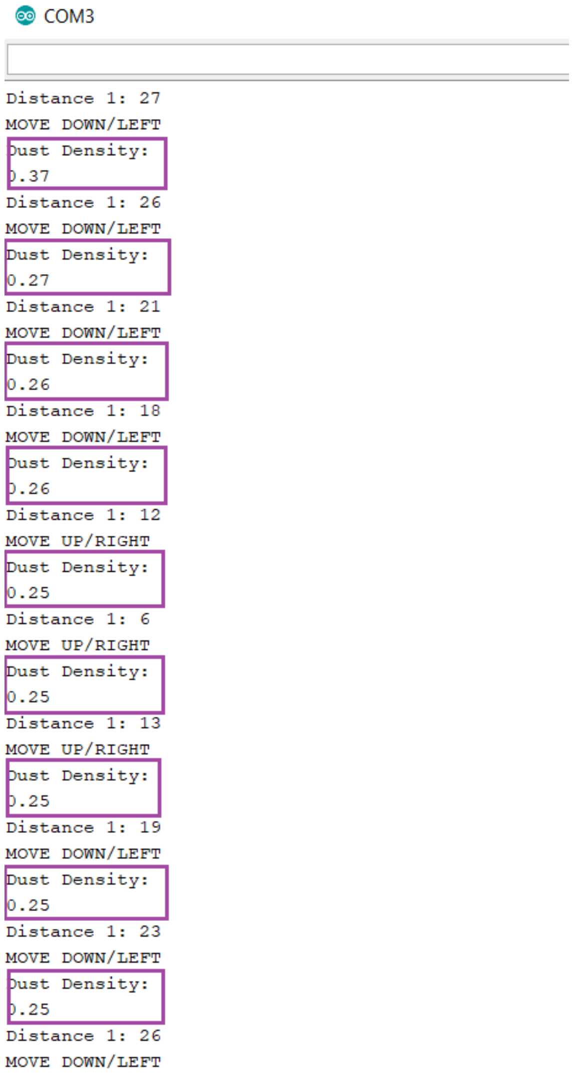


Figure 25: Dust density values displayed on the serial monitor

Discussion

Following the working mechanism of the dust sensor as covered in the Materials and Method section, the dust sensor detects the dust level on the solar panel at all times when the Arduino is powered up. Through the formula below, the dust density is calculated in mg/m3and displayed in the Serial Monitor.

calcVoltage = voMeasured*(5.0/1024);

dustDensity = 0.17*calcVoltage-0.1;

Currently, the dust level can be tracked by referring to the Serial Monitor for monitoring purposes, but ideally the dust sensor would also be used to signal the cleaning process to begin automatically when its value is equal to or more than 1. This can be done using the 'if' statement, similar to the motion system.

7.0 CONCLUSION & RECOMMENDATION

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 was:

- 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.

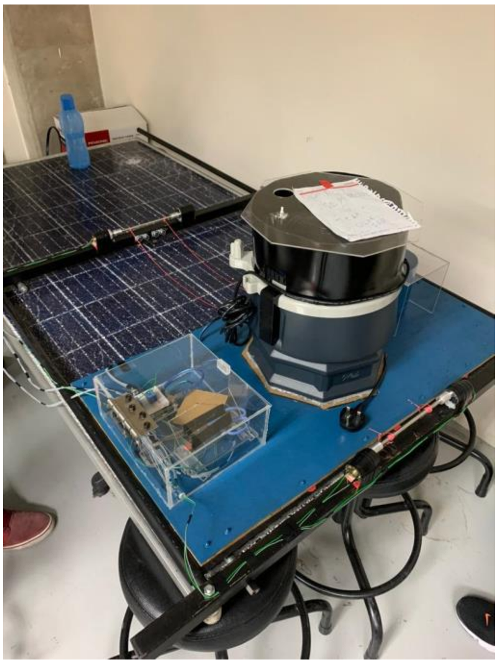


Figure 26: Team Solar Fam's Autonomous Solar Panel Cleaning Robot

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 1^{st} 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 27: Team Solar Fam Accepting 1^{st} 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 fiber 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.

8.0 REFERENCES

[1] IR. Abdul Aziz, "Solar Panel Maintenance & Cleaning Issue", Mukim Tanjung 12, Sepang, 2019.

[2] "Best Way to Clean Solar Panels - Energy Informative", *Energy Informative*, 2019. [Online]. Available: https://energyinformative.org/solar-panel-cleaning/. [Accessed: 11- Apr- 2019].

[3] "Solar Panel Cleaning Systems", *energy*, 2019. [Online]. Available: http://energy.asu.edu.jo/index.php/r-d/solar-panel-cleaning-system. [Accessed: 11- Apr- 2019].

[4] "Worldwide CDIO Initiative", *Cdio.org*, 2019. [Online]. Available: http://www.cdio.org/. [Accessed: 11- Apr- 2019].

Appendix (Programming code)

```
//Relay
int in1 = 7;
int in2 = 8;

//Ultrasonic
const int trigPin1 = 4;
const int echoPin1 = 2;
long duration1;
int distance1;
int value = 0;

//Dust Sensor
int measurePin = A5;
int ledPower = 12;
unsigned int samplingTime = 280;
unsigned int deltaTime = 40;
unsigned int sleepTime = 9680;
float voMeasured = 0;
float calcVoltage = 0;
float dustDensity = 0;

void setup()
{
  Serial.begin(115200);

//Relay
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);

//Ultrasonic//
  pinMode(trigPin1, OUTPUT);
  pinMode(echoPin1, INPUT);

//Dust Sensor//
```

```
  pinMode(ledPower,OUTPUT);
}

//MAIN//
void loop()
{
     //Ultrasonic 1//
     digitalWrite(trigPin1, LOW);
     delayMicroseconds(2);
     digitalWrite(trigPin1, HIGH);
     delayMicroseconds(10);
     digitalWrite(trigPin1, LOW);
     duration1 = pulseIn(echoPin1, HIGH);
     distance1 = duration1*0.034/2;

     Serial.print("Distance 1: ");
     Serial.println(distance1);

     //BOTH CLOSE TO WINCH//
     if (distance1 <= 15)
     {
       digitalWrite(in1, HIGH);
       digitalWrite(in2, LOW);
       Serial.println("MOVE UP/RIGHT");
       delay(5000);
      }

     //BOTH FAR FROM WINCH//
     if (distance1 > 15)
     {
       digitalWrite(in1, LOW);
       digitalWrite(in2, HIGH);
       Serial.println("MOVE DOWN/LEFT");
       delay(5000);
     }

     //Dust Sensor//
     digitalWrite(ledPower,LOW);
     delayMicroseconds(samplingTime);
     voMeasured = analogRead(measurePin);
     delayMicroseconds(deltaTime);
     digitalWrite(ledPower,HIGH);
     delayMicroseconds(sleepTime);
     calcVoltage = voMeasured*(5.0/1024);
     dustDensity = 0.17*calcVoltage-0.1;
     if (dustDensity < 0)
     {
       dustDensity = 0.00;
     }
     Serial.println("Dust Density:");
     Serial.println(dustDensity);
  }
```

MARKS BREAKDOWN

Area	Actual Marks	Scoring Band	Criteria
Format		3-5	The report has all the sections presented in a neat and tidy manner.
		0-2	Inadequate sections presented in a messy manner.
Abstract and Introduction		3-5	Abstract provides a concise summary of the entire report and presents upfront the major conclusion derived from the experimental/simulation investigations. Introduction shows clear objective of the experiment and provide with all the necessary background, the scientific theory behind the experiment/simulations and basic background needed to understand the experiments/simulations.
		0-2	Abstract not providing a concise summary of the entire report. Introduction states no background, scientific theory and basic background of the experiments.
Figures, and Diagrams		3-5	Clear and completely labeled figures/diagrams of the experiment/simulation setup.
		0-2	Figures/Diagrams and labeling of the experiment/simulation layout setup are not correct and/or unclear.
Materials and Method		3-5	Detailing of materials for experimental/simulation setup and clear explanation of the procedure needed to calibrate /set the measurements are clearly described.
		0-2	List of materials for experimental set up and procedure are not clearly described. Materials and method are copy and paste from laboratory manual.
General Results, Conclusion and Discussions		21-25	All the parts of the project works according to the project agreement and complete data collection and presentation using tables/figures/ graphs with appropriate labels. Discussion of the results with prudent judgment. Have comparison of the measured results with theoretical values and citation from the peer-reviewed references.
		11-20	Some of the parts of the project works according to the project agreement and discussion shows little understanding of what the experiment/simulation is all about.
		0-10	Only few parts of the project works according to the project agreement and only restatement of the results without commenting on the expected key points. Incorrect judgment/ arguments were used.
English and References/ Appendix		3-5	State whether the aim of the experiment has been achieved or not, summarised the key features of the methods used, and summarised the most important results. Complete references to any book, articles and websites indicating in-text citations report with correct referencing format are in place.
		0-2	No sensible conclusion. Incomplete references and were presented in wrong format. No evidence, attachments, appendices are attached. Online referencing was used.
Sum			
Total mark deducted		0-1	For each day delay the total Mark will be reduced 10%. One day late the total mark X 0.9, two days late total mark X 0.8 …etc
Actual Mark			

____

Signature of Lecturer

Date: ____________