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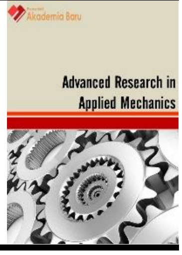

Development of Solar Tracking Robot for Improving Solar Photovoltaic (PV) Module Efficiency

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ABSTRACT

Solar energy is considered as the cleanest and most abundant renewable energy source available planet-wide. Solar energy is produced by the sun's light that can be harnessed and converted directly into electrical energy using solar photovoltaic (PV) module. The solar energy that is harnessed is used for generating electricity, and heating water for domestic, or industrial use. However, conventional solar panels are usually installed in a fixed position where the solar panel does not change orientation towards the sun as it constantly changes position varying with time. As a result, these solar panels are unable to acquire maximum exposure of solar radiation which results in low energy conversion efficiency. Therefore, the aim of this project is to develop a four wheeled base automated solar tracking robot that is capable of tracking light source. The efficiency of solar photovoltaic (PV) module was increased since the robot automatically tracks the movement of the sun for maximum amount of solar radiation. The main components of the robot were consisted of microcontroller, light sensors, servo motors and DC motors. The robot was programmed to detect light source by calculating the average resistance value between four light dependent resistors (LDR) and servo motors to rotate panel either vertically or horizontally. When there is shading on the solar PV module, DC motors was rotated to move the robot to search for new light source. The robot was tested based on its ability to detect light effectively and accurately. The robot was able to track light accurately with accuracy of 93.33%. The performance of solar tracking robot was also analysed by comparing the output power between solar tracking robot and fixed panel. It is found that the solar tracking robot was able to provide a 10.47% increase in solar energy conversion efficiency compared to fixed panel.

Keywords:
Renewable Energy, Solar Tracking, Solar Photovoltaic (PV) Module

1. Introduction

With the increase of population and technologic development, human used a lot of energy as a planet. In Malaysia, most of our electricity are generated primarily from limited resources such as burning oil and coal. However, these resources have a huge negative impact to our environment and will eventually deplete one day. Therefore, there is an urgent need for the development of renewable energy and solar energy is the most essential and prerequisite resource of sustainable energy[1].

Solar energy from the Sun is considered as the cleanest and most abundant renewable energy source available planet-wide[2]. A photovoltaic (PV) module, or solar panel, is an electronic device that convert sunlight directly into electrical energy [3].Harnessing solar energy through photovoltaic

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(PV) panels, is considered one of the most promising markets in the field of renewable energy[4]. It is essential that this energy is harvested efficiently and in the most cost-effective way to get the most out of the free solar energy.

2. Analytical Review

2.1 Performance of Photovoltaic (PV) Module

The performance of a photovoltaic module is measured in term of its efficiency of converting solar energy into electrical energy. The efficiency is most commonly used parameter to compare the performance of one solar cell to another[5]. A typical cell operates under the conversion efficiency of around 10%~20%[6]. It is essential that this energy is harvested in the most cost-effective way because not all of the sunlight that reaches the PV module is converted into electrical energy. In other words, only part of the solar radiation is absorbed by solar modules and the remainders are reflected. Thus, maximizing solar module efficiency becomes imperative. In order to improve this conversion efficiency, it is important to keep in mind the several factors, such as temperature, irradiance, partial shading and cleanliness that play a crucial role in limiting the performance of the photovoltaic module[7][8][9].

2.2 Tilt Angle of Photovoltaic (PV) Module

The orientation of and the tilt of a solar panel strongly affect the amount of the collected yield [10]. Figure 1 illustrates the effect of different tilt angles of PV panels on solar radiation yield. From the figure, the orientation that yields the most solar radiation during sunlight hours is when absorbing surface of the solar panel is perpendicular to incoming sunrays. Therefore, solar panel must be orientated towards the equator and slanted at an angle equals to the local latitude so as to collect the maximum solar energy available in a specific region[11]. The angle, βis then calculated according to equation (1) and (2) as shown

Altitude angle of Sun, $\alpha = 90° - \text{Latitude of location}$ (1)

Tilt angle of PV module, $\beta = 180° - (90° + \alpha)$ (2)

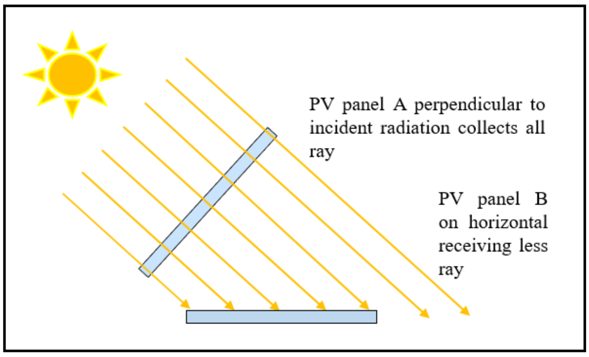


Fig. 1. Effect of different tilt angles of PV panels

While most conventional solar panels may be static mounted with a reasonable titled angle based on installation site latitude, they are still somewhat inefficient. This is because the position of the sun is constantly changing throughout the day. As the Earth orbits around the sun, the angle of the sunrays against the solar panel shifts towards and away from optimal angle. Therefore, to fix this, a solar tracking system is the most appropriate way to increase efficiency of solar panel [12][13][14]. A solar tracker is used to maximize solar energy absorption by adjusting the solar panel automatically to be perpendicular to the sun's radiation [15].

Solar trackers can be divided into two main types that depend on their movement degree of freedom[16]. These two main types are the single-axis tracker and dual-axis tracker[17]. A single-axis solar tracker has only one degree of freedom which tracks the sun's daily motion from east to west at a constant tilt angle. But, the sun, however, does not only change its location throughout the day from east to west; in fact, it also changes position seasonally throughout the year[1].

Thus, in this project, an automated dual-axis solar tracker robot was designed to improve the conversion efficiency of the photovoltaic (PV) module. The dual-axis solar tracker has two degree of freedom and is able to track the sun from sunset to sunrise and can also compensate for seasonal changes of the sun's direction. Dual-axis tracking system would result in greater irradiance than a single-axis tracking system, due to its ability to minimize losses since the panels are always perpendicular to the sun's beam[18].

3. Methodology
3.1 Project Design

In this project, the robot will be divided into 2 parts which are the tracker with solar panel and the base of the robot. The tracking part of the robot will be controlled by four light dependent resistors (LDRs) acting as input signals, two servo motors to rotate the panel vertically and horizontally, while the base of the robot will be controlled by four DC motors to rotate the wheels. Figure 2 shows the block diagram for solar tracking robot.

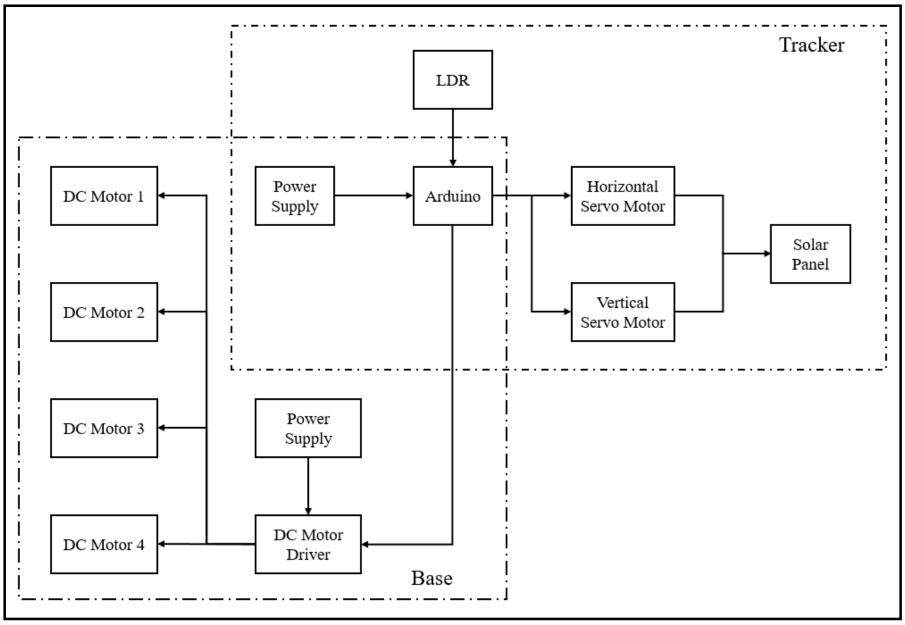


Fig. 2. Block diagram for solar tracking robot

A light dependent resistor (LDR) also known as photo resistor, is a light controlled variable resistor. The resistance of the LDR is inversely proportional to light intensity falling on it [19]. Thus, the analog values of each light dependent resistor are read by Arduino and the average differences between the resistors are calculated to determine the exact position of light. This will then trigger the servo to match with the position of sun in dual-axis direction. When there is shading onto the panel, the DC motors will rotate and move the robot to search for new light source.

Figure 3 shows the illustration of solar sensing device using SolidWork. The four light dependent resistors should be divided into 4 segments with "walls" in between them. The partition is very important in finding the brightest light source because it creates shadow on the light dependent resistors when the solar panel is not perpendicular to the light source. When either one of the light dependent resistors falls in shadow, the average difference between their resistance will triggers the servo motor to move until the panel is perpendicular to the sun's ray.

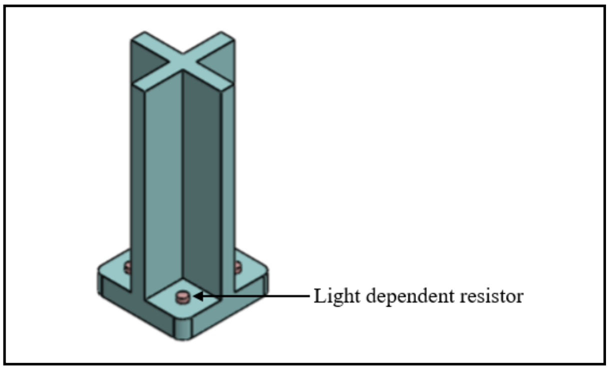


Fig. 3. Solar sensing's device

Figure 4 shows the circuit design for solar tracker robot. Each light dependent resistor is connected to a voltage divider because voltage is very easy for Arduino to read, while resistance is not. Therefore, voltage divider is needed so that the changes in resistance of a light dependent resistor are converted to changes in voltage. As a side note, the resistors also act as a safety measurement to prevent short-circuits if the other component's resistance drops too low.

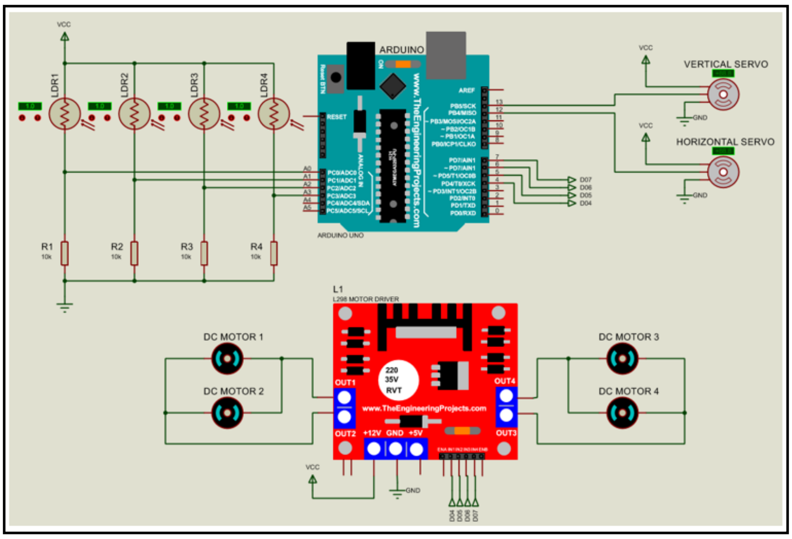


Fig. 4. The circuit design of Solar tracker robot

Figure 5 and Figure 6 show the solar sensing device and the wiring for solar tracker respectively. The solar sensing device consist of 4 light dependent resistors separated into 4 segments and are then connected in a voltage divider circuit to the Arduino.

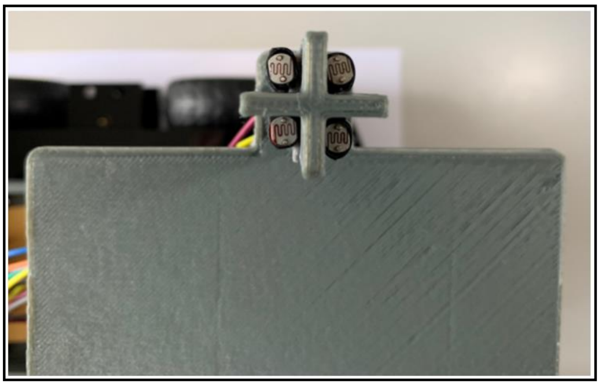


Fig. 5. Solar sensing device

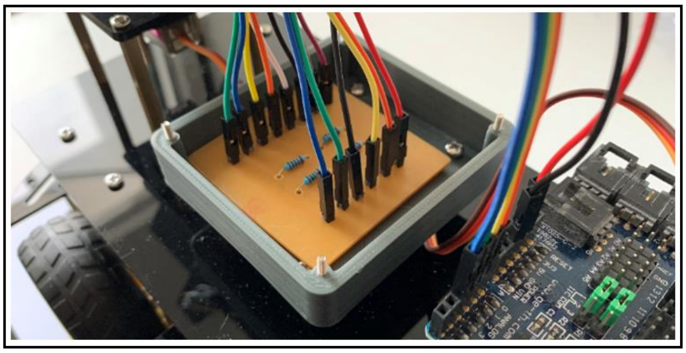
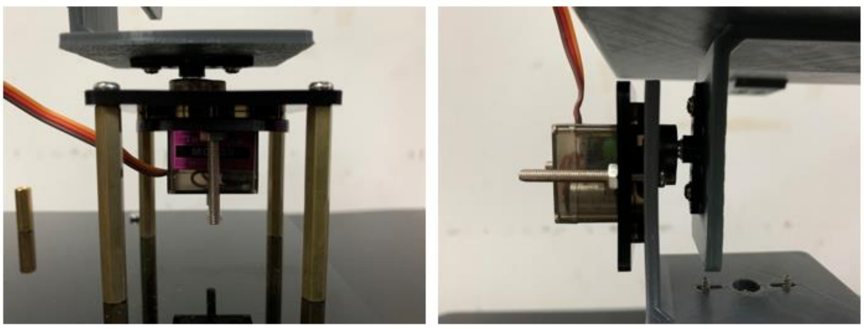


Fig. 6. Wiring for solar tracker

Figure 7 shows the horizontal motor and vertical motor that are used to rotate the panels. The final product after assembly is shown in Figure 8. The product weighs in at around 1.8 kg and is 27cm tall. The products are mainly lightweight materials such as acrylic plates and 3D printed materials. The reason for these two types of materials is that the technology that produces the materials are capable of producing high precision and high quality mockups into actual replicates with little errors.



Horizontal Motor   Vertical Motor

Fig. 7. Horizontal and Vertical Motor

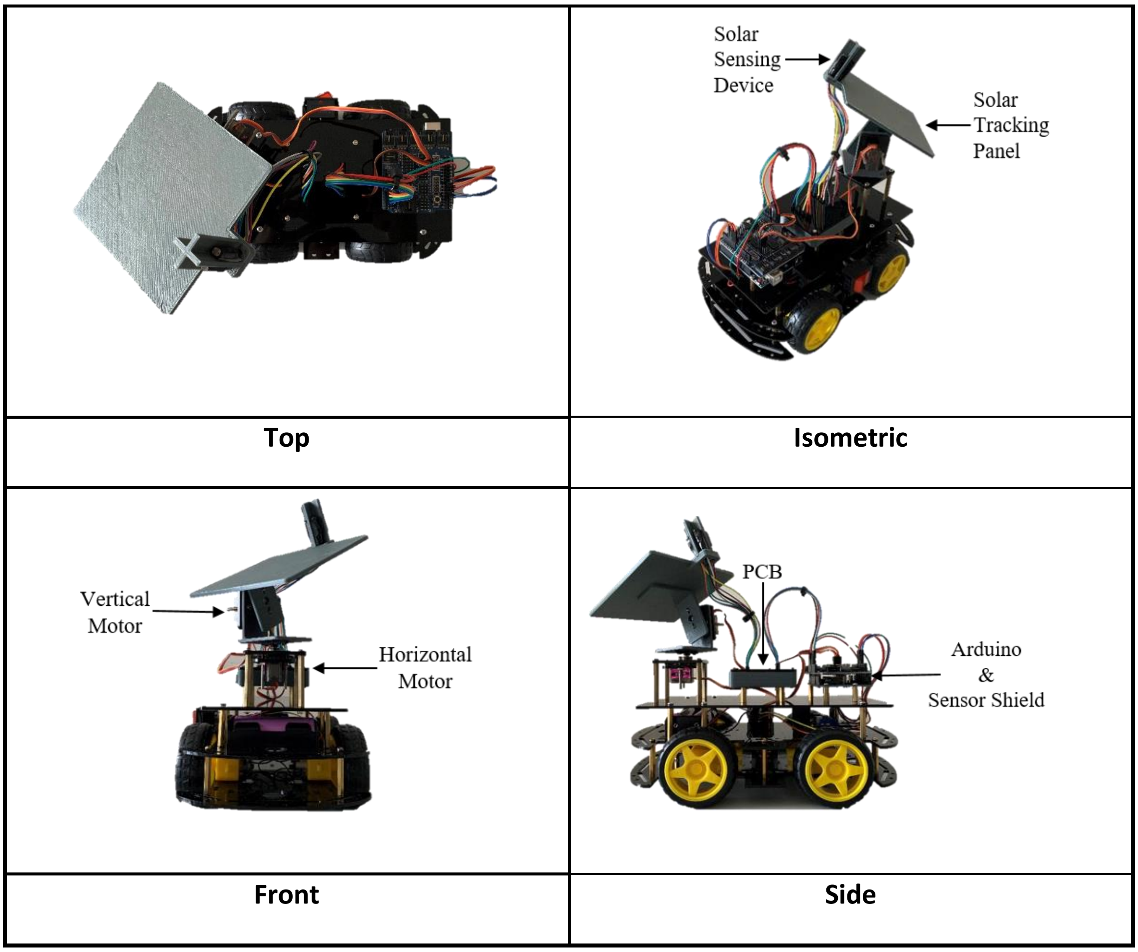


Fig. 8. Final product

3.2 Experimental Set Up

Figure 9 shows the set up to evaluate the performance of the solar tracking robot in comparison to the fixed solar panel. The set up was conducted at Kolej Kediaman UniCITI Alam, Universiti Malaysia Perlis, Malaysia. The South position was declared using pre-installed phone compass app and both panels were placed initially facing the South. The fixed PV panel was stationary at a fixed tilt angle of 7° to receive maximum solar radiation at noon for comparison. This is because facing a panel towards the equator and tilting it up at an angle equal to the local latitudes is a good rule-of-thumb for annual performance[11]. The voltage and current obtained by both panels at every hour was measured using multimeter and readings were recorded in Section 3. Figure 10 shows the fixed panel slanted at an angle.

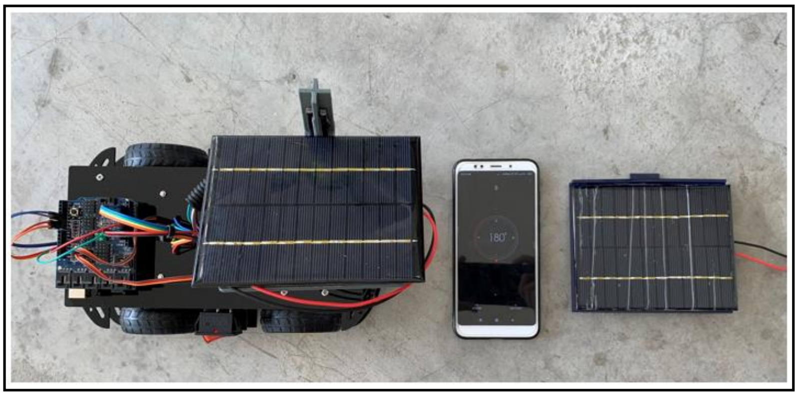


Fig. 9. Both solar panel facing South direction

Fig. 10. Fixed solar panel slanted at 7°

4. Results

4.1 Accuracy Test on Tracking Mechanism of Solar Tracking Robot

A confusion matrix approach was applied to test the tracking ability of the solar tracking robot. The tested was based on 3 different direction of light source and each direction was tested for a total of 10 times. Each '✓' was given each time the robot was able to track light accurately. The results obtained were tabulated in Table 1.

4.2 Real-time Performance Evaluation of PV Module

The performance of PV module of solar tracking robot as compared to the fixed module was evaluated for a total of 4 days which is at 3rd, 5th, 9th and 14th of November 2019 to get more results for comparison.

Table 1
Confusion Matrix of accuracy test

Trials	Direction		
	Front	Top Left	Top Right
1	✓	✓	✓
2	✓	✓	✓
3	✓	✓	✓
4	✓	✓	×
5	✓	✓	✓
6	✓	✓	✓
7	✓	×	✓
8	✓	✓	✓
9	✓	✓	✓
10	✓	✓	✓

4.2.1 Assessment 1: 3rd November 2019 (Sunday)

The hourly voltage and current output were recorded every hour from 10:00 AM to 18:00 PM. The hourly output power generated by both solar panels were calculated and plotted against local time shown in Figure 11. From the results, it can be observed that at 10:00 AM, there is much improvement in power output by the tracking panel compared to the fixed panel. As time passed, the power current of both panels increased gradually and the difference in current between both panels decreases. At 13:00 PM, the maximum power output of the fixed panel and tracking panel was found as 2.583 watt and 2.689 watt respectively. The difference in current between both panels increased again as the sun moves towards west direction. From 16:00 PM to 18:00 PM, the power generated by both panels falls drastically due to low duration of day light. From the figure, it is observed that much more power was able to be generated by the tracking panel in the morning and afternoon because it was able to accurately track the position of sun at these times while the fixed panel cannot.

4.2.2 Assessment 2: 5th November 2019 (Tuesday)

The hourly voltage and current output were recorded every hour from 10:00 AM to 18:00 PM. The hourly output power generated by both solar panels were calculated and plotted against local time shown in Figure 12. From the results, the output power of both solar panels increases gradually with time and reached maximum value at 12:00 PM, and then decreases in the evening. At 12:00 PM, output power by both the fixed panel and solar tracking panel were at their highest, which is 2.167 watt and 2.336 watt respectively. However, from 17:00 PM to 18:00 PM, the output power for both panels dropped drastically and were extremely low due to the rainy weather. Although much more power was able to be generated by the tracking panel throughout the day, however, the efficiency of the solar tracking robot was still limited by weather conditions.

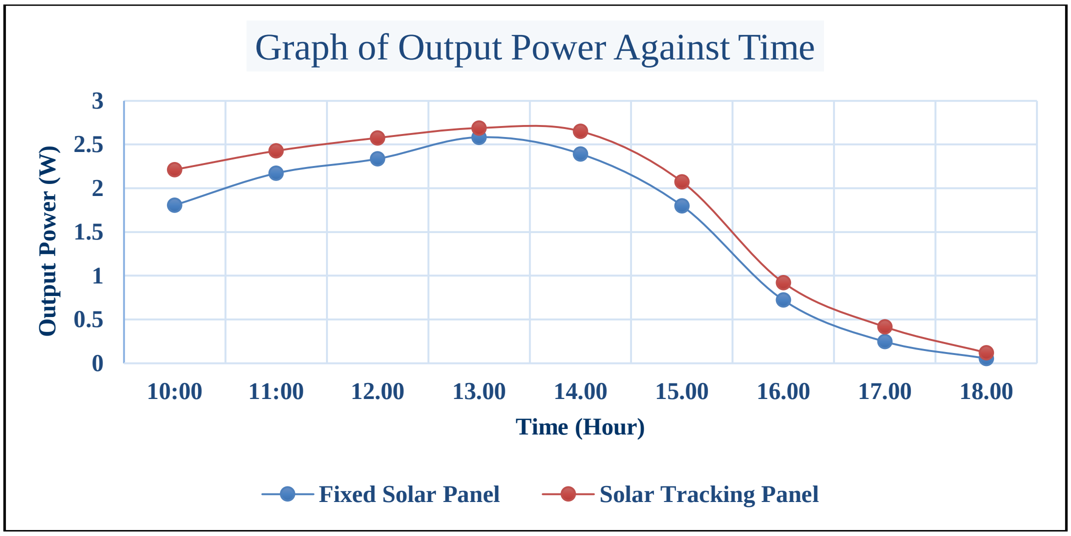


Fig. 11. Hourly output power of both solar panels on 3rd November 2019

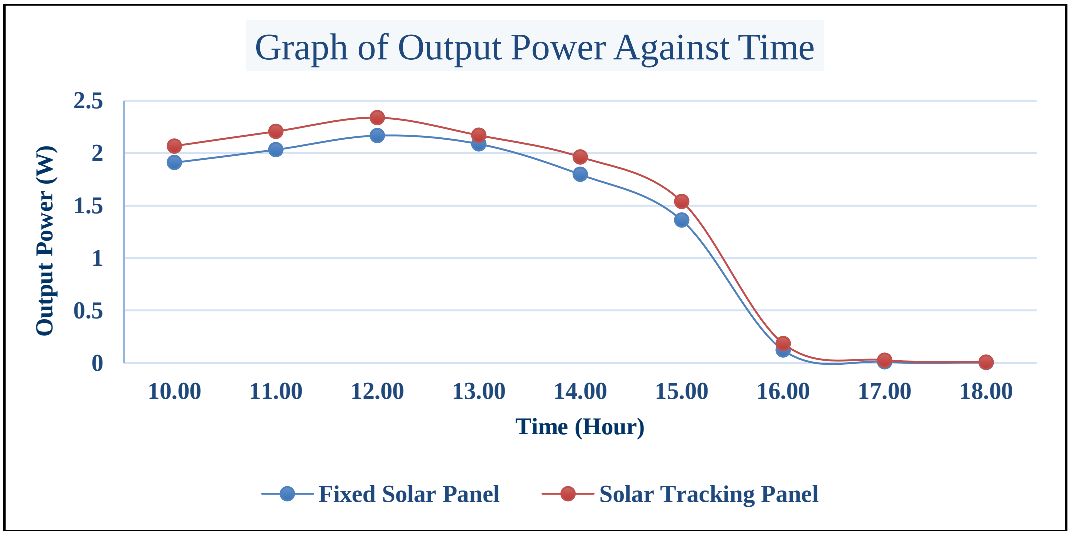


Fig. 12. Hourly output power of both solar panels on 5th November 2019

4.2.3 Assessment 3: 9th November 2019 (Saturday)

The hourly voltage and current output were recorded every hour from 10:00 AM to 18:00 PM. The hourly output power generated by both solar panels were calculated and plotted against local time shown in Figure 13. At 13:00 PM, output power by both the fixed panel and solar tracking panel were at their highest while also having least difference in value, which is 2.374 watt and 2.396 watt respectively. As time passed, the output power of both panels increased gradually and the difference in current between both panels decreases. The difference in power between both panels increased again as the sun moves towards west direction. From 16:00 PM to 18:00 PM, the power generated by both panels falls drastically due to rainy weather.

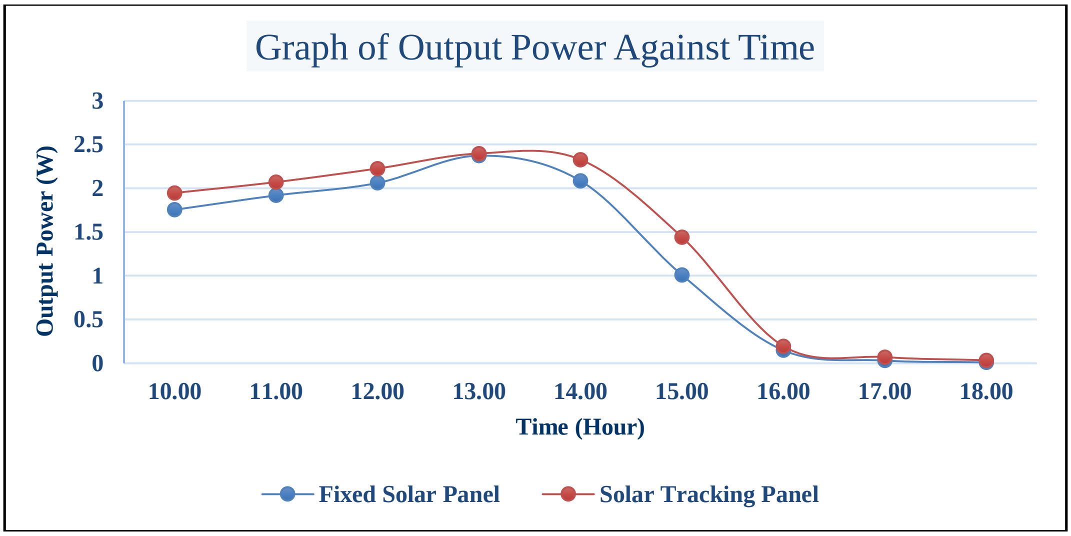


Fig. 13. Hourly output power of both solar panels on 9th November 2019

4.2.4 Assessment 4: 14th November 2019 (Thursday)

The hourly voltage and current output were recorded every hour from 10:00 AM to 18:00 PM. The hourly output power generated by both solar panels were calculated and plotted against local time shown in Figure 14. From the results, output power by both the fixed panel and solar tracking panel were at their highest, which is 2.381 watt and 2.435 watt respectively at 12:00 PM. From this, it can be observed that both panels are perpendicular to the sun light and are generating approximately the same amount of power. The difference in power between both panels increased again as the sun moves towards west direction. From 16:00 PM to 18:00 PM, the current generated by both panel falls drastically was due unpredicted climate changes.

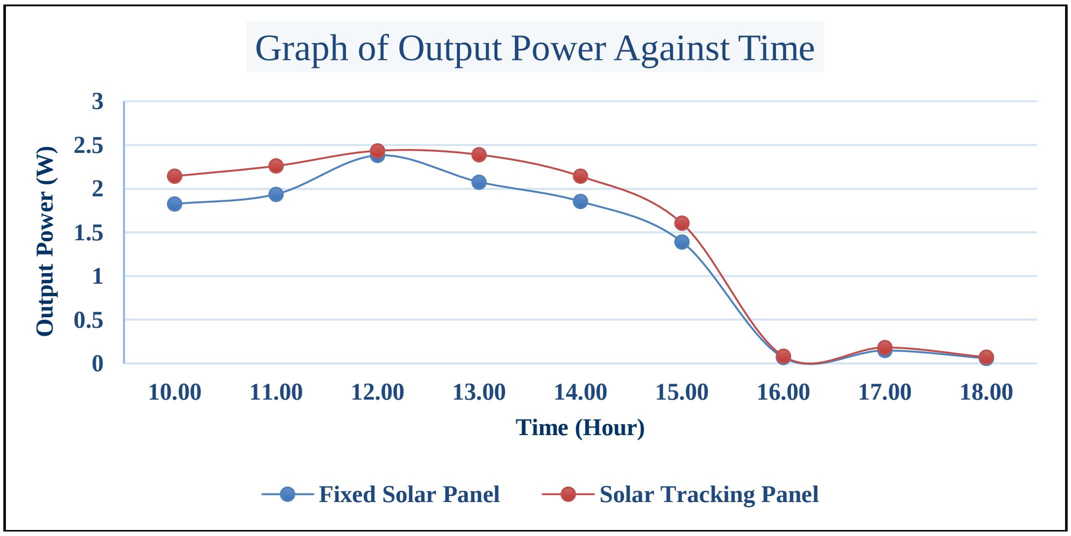


Fig. 14. Hourly output power of both solar panels on 14th November 2019

4.2.5 Summary

Several assessments were carried out on different days to analyse the real-time performance of the solar tracking robot compared to fixed solar panel. From the results, all of these assessment shows similar trend, which is starting from 10:00 AM, the output current of the solar tracking robot was comparatively greater than the output current of fixed panel. As time passed, the difference in current output between both panels was not that great until later in the evening.

Table 2 shows the percentage summary of the output power. The efficiency of solar tracking robot as compared to the fixed panel was calculated. As shown in the table, the output power of solar panel with tracking efficient up to 11.63%, 8.13%, 10.26% and 11.84% for Assessment 1, Assessment 2, Assessment 3 and Assessment 4 respectively. Overall, the solar tracking robot was able to provide a 10.47% increase in solar energy conversion efficiency in comparison to fixed solar panel.

From the results, it is clear that the dual-axis solar tracking robot was able to receive more sunlight and consequently generated more power overtime compared to fixed panel due to its ability to maintain the solar panel at the direction perpendicular to sunlight throughout the day. However, the efficiency of the dual-axis solar tracking robot was still limited by weather conditions as the overall output from the solar tracking robot was not as great as expected during bad weather conditions.

Table 2
Percentage summary of the output power

Assessment	**Average Hourly Power Output (W)**		**Efficiency (%)**
	With Tracking	**Without Tracking**	
1	15.972	14.115	11.63
2	12.495	11.479	8.13
3	12.694	11.391	10.26
4	13.321	11.744	11.84
		Average	10.47

5. Conclusions

Based on the objectives of this project, a dual-axis solar tracking system was developed and was able to track light source accurately which allow the solar panel to always be positioned perpendicular to the sunlight. In addition to that, an automated dual-axis solar tracking robot was developed and was able to relocate itself to other location with greater presence of light when shading occurs. Lastly, the performance of the dual-axis solar tracking robot was evaluated and was proven to have a greater solar energy conversion efficiency of 10.47% in comparison to the fixed solar panel. In conclusion, all the objectives of this project were achieved.

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