Article

Design and Programming of a Micro-controller-Based Solar Tracking System

Saman Jaafar [1],[†],[‡] 🆔 **and Farhad Mahmood** [2],*

[1]   Physics department, College of science, University of Halabja ; saman.jaafar@uoh.edu.iq
[2]   Physics department, College of science, University of Halabja; farhad.mahmood@uoh.edu.iq
*   Correspondence: saman.jaafar@uoh.edu.iq

Abstract: This paper is regarding design and program an Micro-controller Arduino Uno board by using Arduino software to work as a photo-sensor(Active) single axial solar tracker system(SASTS). A solar panel, two photo-resistors (LDR) in two sides (north/south) of the photo-voltaic(PV) and a servo motor are connected to the Uno board, which is running a code that prepared by Arduino software IDE in advanced then it works as a tracking system. Here, the LDRs send the signal of presence or absence of the light to the board and based on that sent signal the Uno reflects a new signal to the servo motor to rotate and finds the light source. Lastly, the photo-sensor single axis tracker is made while Continuously, the system tries to face the panel to the sun and whilst changing the irradiance intensity it starts searching to find the angle of highest irradiance. Based on results that are extracted from the data, the tracker system significantly boosts the output efficiency of the solar panel. By using the Micro-controller Uno board, LDRs, servo motor and special designed mechanical base, the tracking system is constructed, based on acquired data the influence of the STS on the increasing the solar panel efficiency is more obvious. Significantly, the tracker system rises the efficiency of the PV .

Keywords: Solar cell energy; Single Axial Solar Tracking System; Solar cell efficiency; Arduino Uno Board

1. Introduction

The high consumption of energy and the industrial revolution lead to some concerns about the environment and energy sources. Particularly, raising the temperature of the earth and limitation with the fossil sources. As a result, the researchers so far tried to highly utilize renewable energies to minimize those issues. The solar cell energy is one of the renewable energy that highly recommended as a green energy source for that situation. As Edmond Becquerel discovered the principle of PV system in 1839 , and due to the fact that PV is not introduce any pollution to the environment, therefore it can be called as a renewable energy [7]. Nowadays, the solar panel is mainly used as a major source to produce electrical energy in most of the countries throughout the world, due to the above mentioned facts. Because, it doesn't have a bad impact on the environment such as air pollution (carbon dioxide) and global warming, also, the source of support is the sun while it is an infinite source of energy [1,2]. While the produced energy is directly change with the intensity of the radiation. The intensity of the sun radiation changes due to deflection angle of irradiance. Thus,The output efficiency of the PV depends on the irradiance angle and irradiance intensity. The best and most effective angle is a normal angle, that means the sun light are normally radiate on the PV. Due to continuously change of the position of sun, the radiation energy will not be high during the day time. Since, the Solar Tracker System (STS) is needed to solve that problem[1]. The STS is expensive because it requires a mechanical base and installation. also, it requires electrical energy to work. Mainly, STS has some types:[1]:

- Tracking based on optical sensors and microprocessor (Active)
- Tracking based on date and time (Active)
- Fixed or manually change tracker

Mainly, the Active STS can be divided into Single axial and dual axial tracker. When the single axial STS only tracks solar in azimuth path but can't track solar in altitude path[3]. Strongly, the cost of the tracker's structure (Mechanical base, installation) depends on the amount and type of material that want to be used. Also, the geometry of the structure is important in order to be expensive [4]. Here, the paper seeks to investigate the effect of the STS on the output efficiency of the solar panel.Based on the measured data the efficiency has raised by 20%.

2. Methodology

2.1. Solar Radiation

Solar radiation is the main key to achieve output efficiency from the PV. The irradiance has two-part, the first is the direct beam, that reached to the PV surface and the second is reflected irradiance which is reflected from the PV surface, in addition to that; it does not provide energy to PV in order to produce electricity[5]. The direct irradiance received on the PV surface is given by the equation

$$I_D = I_{DN} \cos \theta \tag{1}$$

where I_D is direct irradiance, θ is irradiance angle, and I_{DN} is normal direct irradiance.
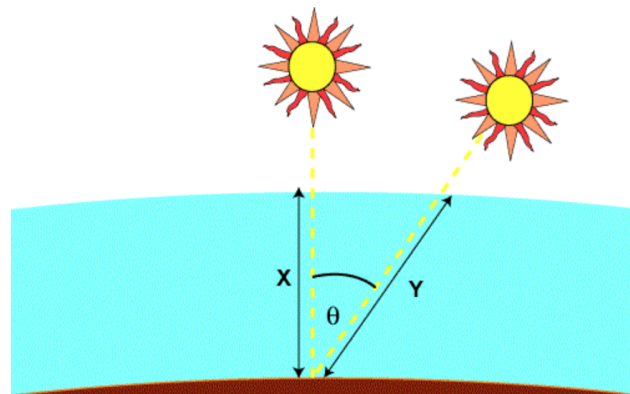

Figure 1. Sun Radiation Angle

Sun position can be determined by two angles: Altitude angle and Azimuth angle. this angle is given by

$$\alpha = \sin^{-1}\left(\cos\phi \times \cos\delta \times \cos\omega + \sin\phi \times \sin\delta\right) \tag{2}$$

While the second angle is given by

$$\cos\gamma = \frac{\sin\alpha \times \sin\phi - \sin\delta}{\cos\alpha \times \sin\phi} \tag{3}$$

Both angles of altitude and azimuth can be calculated by using the information on local attitude,(ϕ) Solar declination angle,(δ) and hour angle,(ω) [6].

2.2. Design and Equipment

The mechanical structure of the tracker system is made of Aluminum and it has lightweight with servo motor together about 200g. the overall volume which may be taken by the structure is about $30cmx25cmx25cm$. it consists of A structure holder, gear shaft, panel holder and servo motor holder.

53 It could be move in altitude path (West to East) and easily can work as a Single Axial Solar Tracking
54 System(SASTS). the motion of the gear shaft is controlled by the servo motor and it rotates with low
55 torque which can be handle by the servo motor (MG-996R). the main point is that the Uno board
56 can supply the servo motor for rotation with specifying speed and angle. The rigidness and low air
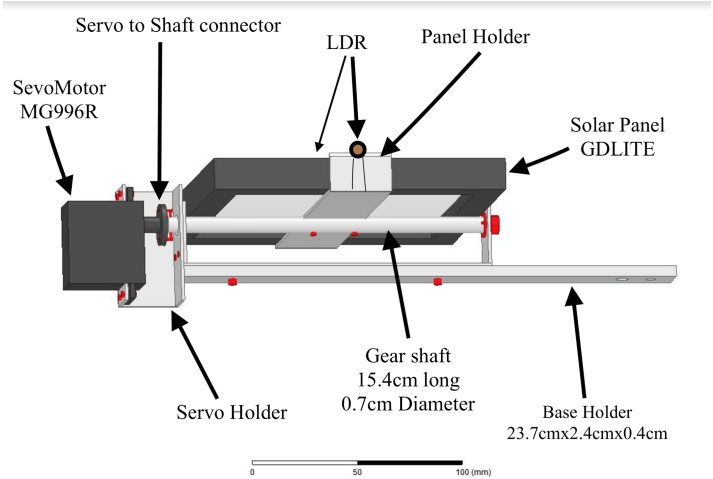57 resistance are the good points of the mechanical structure of the SASTS.

Figure 2. Mechanical Structure of SASTS

58 *2.3. Uno Board*

59 The Arduino Uno board is an open-source micro-controller[12]. It has sets of digital and analog
60 Input/Output(I/O) pins, here,as shown in the Figure 3, the digital pins of 2,3,4,5 which working as
61 output pins are sending the signals to switching on/off the MOSFETs one by one and in pair and
62 triple and all together. also, the analog pins such as A0,A1 get the signal from the LDR's and A3, A4,
63 A5, and A6 get the output voltages from the switching circuit and these pins work as input pins. the
64 micro-controller also has USB type B which can connect to the computer and can load with Arduino
65 IDE (Integrated Development Environment). It can be powered by a voltage between 9-20V and all
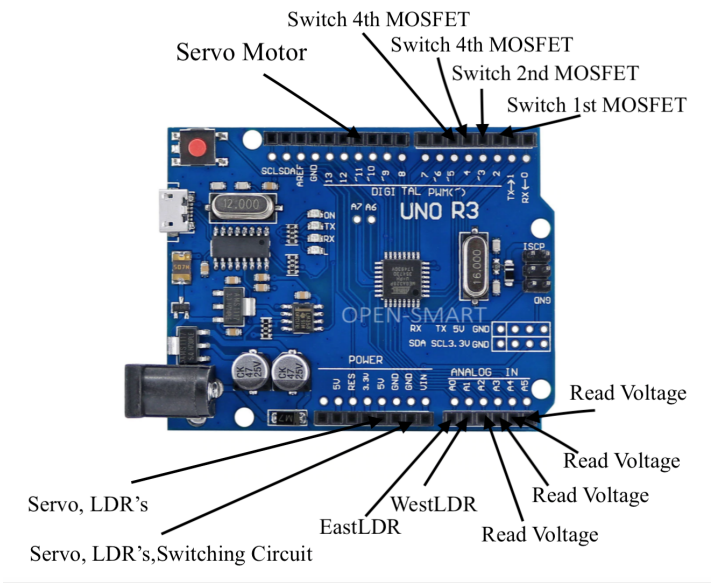66 digital and analog pins support 5V voltage [13].

Figure 3. Micro-controller Uno Board

67 *2.4. LDR*

LDR is abbreviation from Light Dependent Resistance, it made from semiconductor materials and its resistance depend on the intensity of the light, by increasing the light the resistance will decrease and wise versa[5]. Here, the LDR working as photo-sensor and two LDR's are used and when the light intensity be different on them, their resistances can not be equal, like Figure4 and the circuit would be unbalanced, then, they will send a signal to Uno board and based on the written code in the micro-controller a signal send to the servo motor to rotate until the LDR's circuit to be balanced again[14].

$$R_{LDR1} = \frac{R_1}{\frac{V_s}{V_{LDR1}} - 1} \tag{4}$$

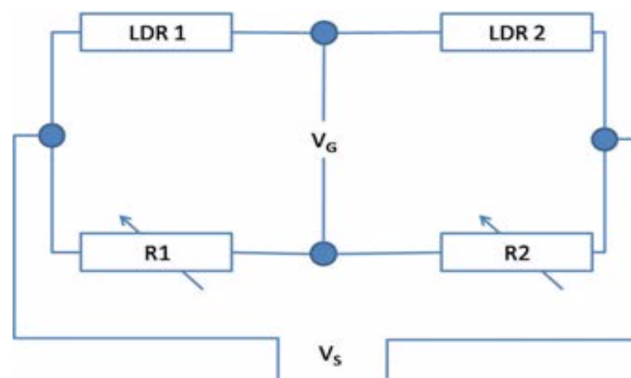$$R_{LDR2} = \frac{R_2}{\frac{V_s}{V_{LDR2}} - 1} \tag{5}$$

Figure 4. Balance Circuit

68   From Equations 4 and 5, if $R_1 = R_2$ and $V_{LDR1} = V_{LDR2} = V_g$ and then $R_{LDR1} = R_{LDR2}$ while
69 balance mode, as mentioned before, the resistance value of each LDR depends on the intensity of
70 the light, therefore, this will produce unbalance system if the intensity of the light change too. This
71 phenomenon helps to make a photo-sensor system that continuously searches for maximum intensity
72 to have a balance between both east-LDR and west-LDR.

73 *2.5. Servo Motor*

74   This High-Torque Metal Gear Servo Motor for Robotics(MG996R) Digital Servo can rotate
75 approximately 120 degrees (60 in each direction) and can support about 10Kg load. Meanwhile,
76 any servo code, hardware, or library to control these servos can be used[15]. A servomotors are rotary
77 or linear actuator those allow for precise control of angular or linear position, velocity and acceleration
78 [8]. Therefor based on the output signal which comes from the Uno board to servo motor and then the
79 motor starts to rotate, bearing in mind the weight of the solar panel is about 200g and simply the servo
80 can withstand that amount of load. The main benefits of the servo motor is to supply voltage which is
81 from 4.8V to 7.2V and this amount can be support by the Uno board.

PWM=Orange (⎍⎍)
Vcc = Red (+)
Ground=Brown (−)

Duty Cycle

4.8 V to 7.2 V
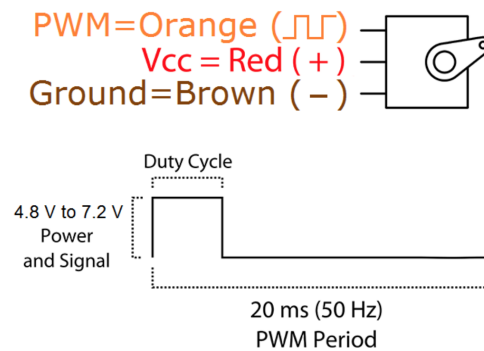Power
and Signal

20 ms (50 Hz)
PWM Period

Figure 5. PWM Period,Duty cycle and Power

2.6. Switching Interface Circuit (Voltage regulator circuit)

The switching interface circuit used for some purposes, the input voltage from the solar panel is around 12V and this amount of voltage is high for microcomputer to read, as it has been mentioned before those pins can support maximum 5V in both digital and analog. Accordingly, the voltage divider board is designed by R_5 to R_{10} and the regulated voltage would be directed toward Uno board through the outgoing signal from the digital pins. The aim of using of R_1, R_2, R_3, R_4 are just for protection of MOSFET's. The MOSFET's work based on the digital pins of the Uno board, while the micro-controller would respond based on the signal from the written code on the board. Additional purpose of designed circuit is to have several different voltages. Each of the MOSFETs can be turned ON by the digital pins of the micro-controller and each time Uno receive one voltage data, once,the first switching mode has been finished then the new as a switching modes will emerge such as double transistors, triple and quadruple based on the aforementioned modes the Uno board can receive about 14 different voltage measurements. Based on Kirchhoff's Voltage Law (KVL), the input voltage (V-pv) and the voltage on R_5 and R_{10} is

$$V_{pv} = V_{R_5} + V_{R_{10}} \tag{6}$$

Both resistors (R_5 and R_{10}) are connected in series, thus, based on Kirchhoff's Current Low (KCL) the amount of current which passes through each resistors are same so, equation 6 can be rearrange as shown in equation 7:

$$V_{pv} = IR_5 + IR_{10} \tag{7}$$

The output voltage which is a part of the total resistance and can be determined as equation 8.

$$V_o = \frac{R_{10}}{R_5 + R_{10}} x V_{pv} \tag{8}$$

The output voltage of solar panel is 11.25V and R_5=147KΩ and R_{10}=100KΩ, while, the output voltage of the Uno board can be determined by substituting the values in to equation 8 as depicted in equation 9.

$$V_o = \frac{100}{100 + 147} x 11 = 4.45V \tag{9}$$

The acquired output voltage (4.45V)is a satisfactory value for the input to the micro-controller. That process of determination of output voltage of switching interface board will be repeated for all other resistors.
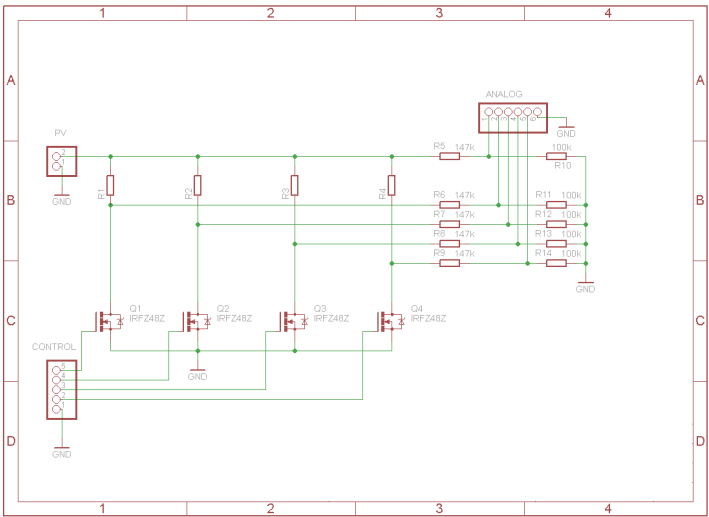
Figure 6. Switching Interface Circuit

2.7. Solar Panel

The mechanical base and servo motor can easily manage the amount of the solar panel's weight due to the specification of the panel since it has light weight and the panel has the following specifications:

Table 1. Specification of GD-020WP Solar Panel

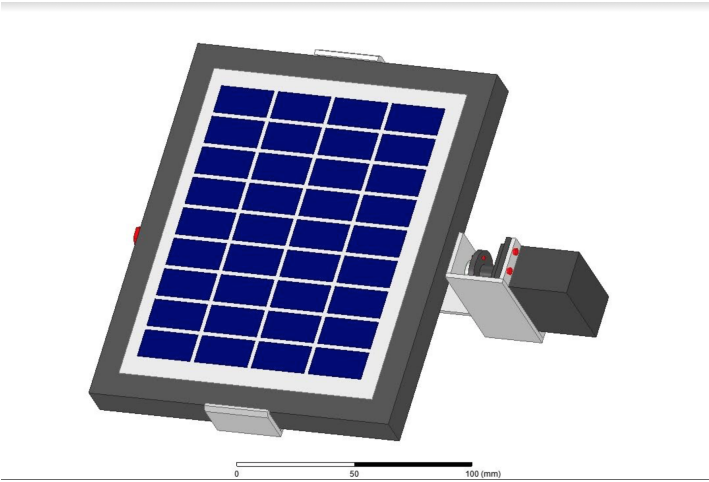| Parameters	Current/A	Volatge/V	Power/W
Peak Power			2
Open Cicuit Voltage	0.267		
Short Circuit Current		11.25	
Maximum Power Voltage		9	
Maximum Power Current	0.23		

Figure 7. Solar Panel GD-020WP

3. Integrated System

The SASTS came from the combination of the micro-controller Uno board, LDR's, servo motor, switching interface circuit, and a solar panel, the system would be weighted around 1Kg, and can be installed on the roof, wall, ground and it could be fastened by two screws. The switching circuit board,

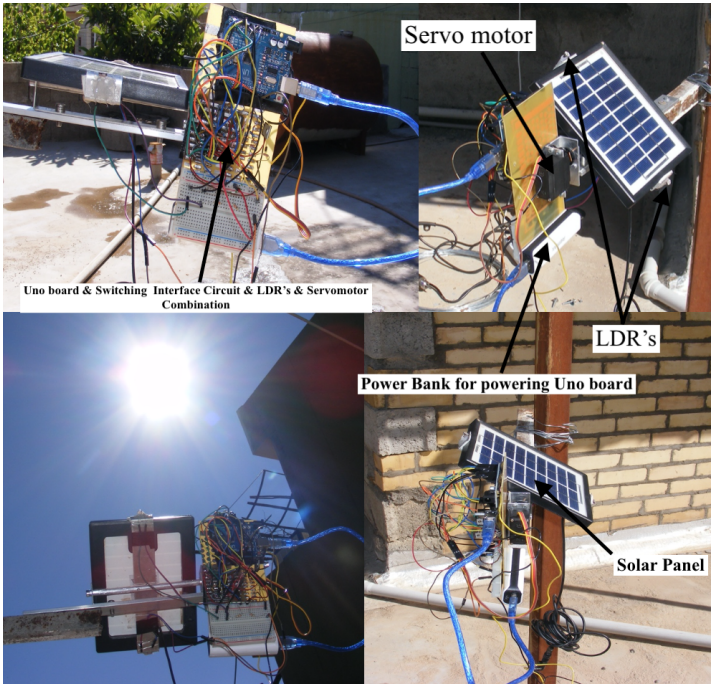94 the Uno board and portable battery are attached to the body of the mechanical base as shown in Figure
95 8.

Figure 8. The Tracker System in Different Angle of View

4. Flow chart

97   The process of the written code in the Arduino Uno board can represented as below flow chart.
98 As it is shown, the tracker system mainly depend on the LDR's signals and the amount of error can be
99 calculated by subtracting the value of westLDR from westLDR. while the intensity of light in one side
100 of solar panel is greater than the other side, then an amount of error will be produced and it would be
101 sensed by Uno board, therefore the Uno board sends a signal to the servo to rotate in the direction of
102 higher intensity LDR and the panel should be adjusted accordingly,then the Uno board recheck the
103 LDR intensities if still the Uno board sensed an amount of the error which is be greater than absolute
104 value of 5 Lux then the panel will rotate accordingly, but, if the error is smaller than absolute value of 5
105 Lux the system would received the voltages data as explained in the section of Switching Interface

Circuit.
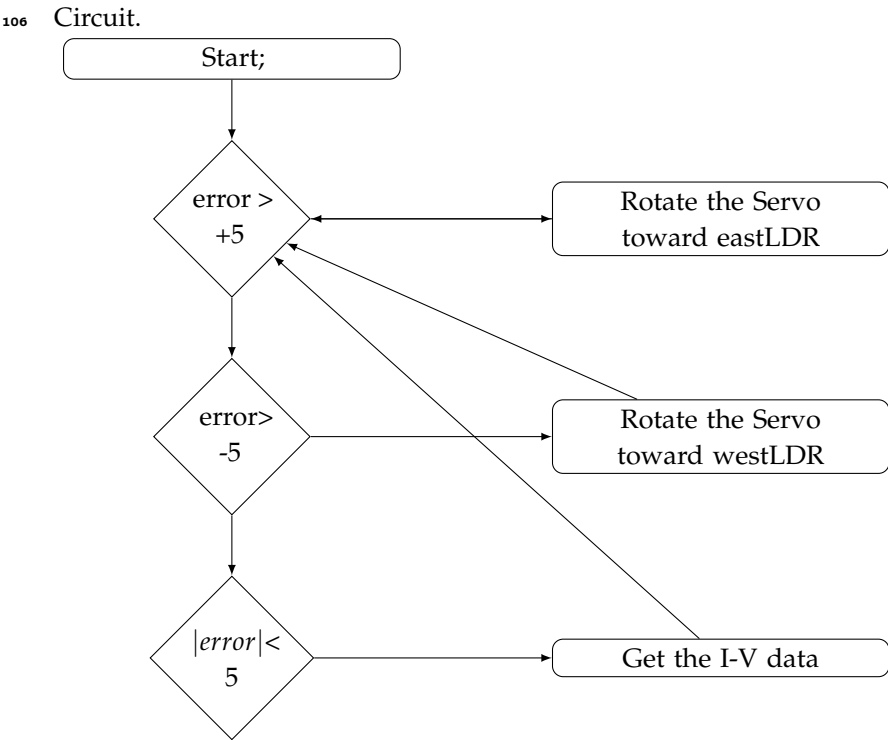
5. Operation of SASTS

LDR's are the eyes of the system. They try to find the sun in the sky and prepare the solar panel to be fixed while incoming normal radiation as proved in equation 4, 5, because the most effective irradiance is that rays which normally incident on the PV based on equation 1. The LDR's lie in both sides of the PV as shown in Figure 2. the incoming a notification or a signal from LDR's to the Uno board makes a change in the decision of the board and it will decide based on the new happened event and send a signal to the servo motor to rotate in the angle toward the highlighted LDR, while doing this process and rotating the servo as a result the new signal will come to the Uno board again from the LDR's and the Uno board specify the value of error, if the error value is smaller than the value which has been assumed, the Uno sends a new signal to the servo motor again and stop the rotation. If the error is larger than the specified value the new signal is going to continue the rotation. The Uno board will get the voltage measures from the switching interface circuit while the error is small. Therefore, only voltage data will be measured, but, based on the code the uploaded to the Uno bard, the current and power for each data will be derived by the known resistors which have been used in the circuit.

6. Experimental detail

After finishing the Single Axial Solar Tracker System (SASTS) it can be used for determine the Maximum Power Point Tracking based on the data measurements. The system is used at the end of April 2020 for two days from 8:00am to 16:00 in Halabja city in Kurdistan region/Iraq. The first day the SASTS is working and the data have been collected while using photo-sensor tracker. The data are taken for each one hour its why there are some samples of the data that the prevalent has taken. In the second day the system used but without tracker system, it is like fixed solar panel. The aim of this two different situation is for proof and determine the influence of the tracker on boosting of the efficiency of the solar panel.

7. Experimental results

As discussed before, the Uno board is the heart of the system. Based on the written code by Arduino IDE it takes responsibility for any coming situation. The data have been achieved from the experiments and shown in both Tables 2, 3 and Figures 9a 9b ,10a 10b. Here, for the case of the fixed solar panel, the data have been collected in the different deflection angles of sun radiation (0 to 90deg) and the average value is chosen (neither the best normal irradiance and nor the worst, 90deg deflection). The Maximum Power Point has been derived from the voltage-Power curve as 10 for both cases of the experiments.

Table 2. I-V-P Data in Fixed Solar Panel

Voltage/V	Current/mA	Power/mW
0	4.1	0
2	4	8
4	3.9	15.6
6	3.8	22.8
8	3.6	28.8
9	3.5	31.5
9.5	3.1	29.45
9.8	2.5	24.5
10	1.8	18
10.1	1	10.1
10.2	0.3	3.03
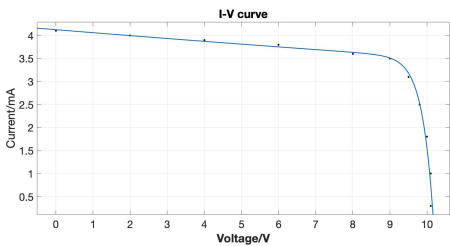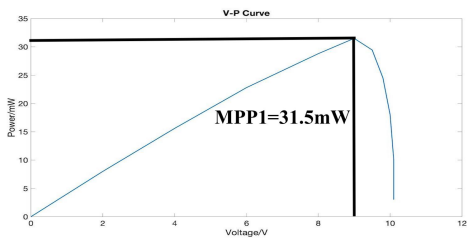
(a) I-V Curve   **(b)** V-P Curve

Figure 9. The Solar Panel Characterization in Fixed Solar Panel

Table 3. I-V-P Data by Using SASTS

Voltage/V	Current/mA	Power/mW
0	90	0
2	87	174
4	85	340
6	80	480
8	78	624
9	75	675
9.5	67	636
9.8	60	588
10	40	400
10.1	30	303
10.2	10	102

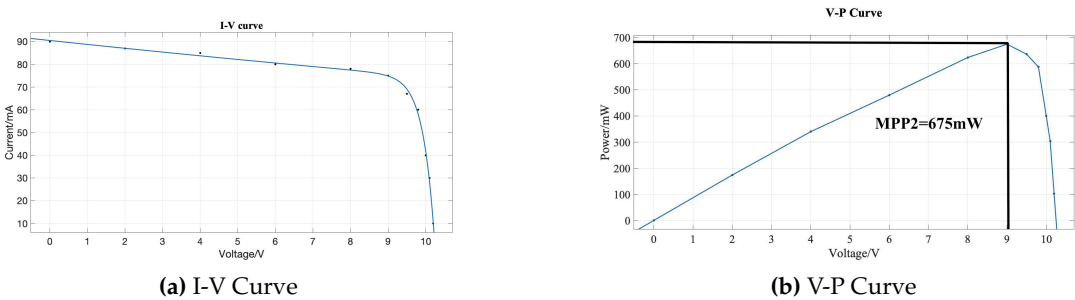**(a)** I-V Curve   **(b)** V-P Curve

Figure 10. The Solar Panel Characterization by Using SASTS

8. Efficiency

In this section the effective of the SASTS can find and understand on the improving the efficiency of the PV. So, the boost of efficiency is determined by the ratio of the achieved MPP point by using SASTS to the MPP point is obtained from a fixed solar panel. The MPP2 is obtained from using STS and MPP1 from the fixed case, the efficiency can be determining as below:

$$\eta = \frac{MPP2}{MPP1} \times 100\% \tag{10}$$

where η is efficiency $MPP2 = 675\ mW$ with STS achieved from the graphs, for a fixed case as shown in the 9b, there are fourteen MPP points but any of them are related to the specific deflection angle. Therefore, the Maximum and the Minimum of the MPP can be focused, that means the biggest and smallest angle of deflection. $MPP1 = 31.5mW$ Now, just we will substitute the values in equation 10.

$$\eta = \frac{MPP2}{MPP1} \times 100\% = \frac{675}{31.5} \times 100\% = 21.42\%$$

9. Comparison

The comparison section will make fine clarification for all the performed tasks. From the plotted data in figure 9b for the fixed case of solar panel, the MPP is low due to a high deflection angle. Based on equation 1 the highest intensity is obtained form the 0 angles of deflection of the sun's rays. Its the main reason for low achieved MPP in that case. Meanwhile, by using SASTS, the plotted data in the Figure 10b were shown that the high amount of the solar radiation has been converted to the electrical energy, because, the MPP point is higher than the previous case. Definitely, it can be said that the main reason for that is the minimization of the deflection angle of radiation by the solar tracker system. The MPP is about 21 times greater than the MPP of the fixed case, thus the solar tracker (photo-sensor tracker) is so effective on boosting the output energy for the PV system.

10. Conclusion

Significantly, using SASTS caused to achieve more power from the solar panel and provide to boost efficiency. It is a good idea to use the tracker for larger projects because based on the determined efficiency due to using the SASTS about 21.4% rising of the efficiency has achieved. The advantages of the solar tracker can be mention as below points.

⋆ The SASTS is a system that needs low energy to work and is supported by the Uno board. But, for two-axial STS would need more electrical energy to handle.

⋆ Here, the system can be handled by the output energy of the solar panel. Therefor, the working of the STS can be done by the self-support of the solar panel

⋆ Advancements in technology and reliability in electronics and mechanics are gradually declining the long-term maintenance concerns about STS [11].

⋆ It is highly recommend for those geographical locations which don't have more time of Sun

168 irradiance or the intensity of the radiation is poor, means the sun radiate by the high deflected angle
169 (usually north part of the earth and far locations from equator line).
170 ⋆ STS caused to speed up the charging of the battery, the battery charging almost depends on the
171 power and efficiency of the PV. So, when the efficiency of the PV increased the charging of the battery
172 will be faster. Thus, the battery will not going to die sooner than its lifetime.
173 There are some drawbacks of the SASTS as discussed below:
174 ⋆ The SASTS may not be able to track all sun motion paths thus, some of the radiation time will be
175 wasted and it will not be used and the output efficiency will be less than the peak value.
176 ⋆ It needs energy to work, for a large project, a large amount of energy needs to handle the process
177 ⋆ For its utilization, the wide and flat ground is needed. That Means, a suitable place is required to put
178 the system on it. Meanwhile, the place must be wide and sufficiently far from the trees and the agent
179 of shadow .
180 ⋆ The construction of the mechanical base of the tracker needs cost, tools, and time. The tracker also
181 needs observation and maintenance.
182

183 **11. Future work**

184   Some points about the future of this project:
185 ⋆ Do the project and the experiments in the northern area of the earth because there the deflection
186 angle of the incident ray is more and the influence of the using solar tracker system can be more
187 understandable.
188 ⋆ Use higher power solar panel since, MPP points are more sensible during finding.
189 ⋆ Do the same procedure with two axial solar tracker system, it maybe the effective of the tracker will
190 be highly observe.
191 ⋆ Using MATLAB Simulink for doing this kind of procedures.
192

193 **Abbreviations**

194 The following abbreviations are used in this manuscript:
195

SASTS	Single Axial Solar Tracker System
MPP	Maximum Power Point
PV	Photo-Voltaic
LDR	Light Depending Resistor
IDE	Integrated Development Environment

196

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