Design and Implementation of Sun Tracking System Using Arduino Board

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Abstract:

Previously, photovoltaic panels were installed at a specific inclination angle so that they were exposed to the greatest possible amount of solar radiation throughout their operation. Scientists have found that the productivity of photovoltaic panels can be increased by making them maintain a maximum vertical angle with the radiation falling on them. This is achieved through solar trackers (solar tracking devices), known as "Solar Tracking Devices or Solar Trackers."

In this paper, the sun's movement table was used to design and implement a sun tracking system in two axes, by operating two servo motors to achieve moving in two-axes at Azimuth and Altitude angles. Arduino board was programmed by listing the Azimuth and Altitude angles of the sun's movement on a specific day of the year, Obtained data and angles was by using the (Astronomical Applications Department) site, and then specifying the location to be measured and determining the day and time range, and the site used in programming is the Institute's website (Higher Institute for Engineering Technologies / Tripoli (32.85642990, 13.26096370)).

Finally, the tracking system was installed, and experiments were conducted to measure the open-circuit voltage (Voc) as well as the short-circuit current (Isc), and compared the results in the case of the fixed position and movement in one axis and in two-axes, where improvement was achieved in the power generated by the panel. Solar power increased by 34.41% by using the dual-axes system with compared to the fixed system, and by 19.03% with compared to the single-axis system (the resulting power in the case of the fixed system was 4.0421 watts, while in the case of movement in one axis the resulting power was 5.48 watts, and it is increased to 6.1669 watts in the case of dual-axes system).

Keywords: Azimuth, Altitude, one axis sun tracker, stepper motor, dual axes tracker

Introduction

We currently live in a world dependent on non-renewable energy sources such as oil and gas, which contribute to air pollution and reduce oxygen levels in the atmosphere, which pose health risks human, it is therefore essential to switch to cleaner and safer energy alternatives. This research will discover a method to harness renewable solar energy and maximize its benefits. Traditionally, photovoltaic panels are installed at a certain angle to capture the maximum amount of solar radiation. However, scientists have discovered that the efficiency of photovoltaic panels can be improved by adjusting their position to maintain an optimal vertical angle to incoming solar radiation. This is possible thanks to solar trackers (solar trackers), called "solar trackers" or "solar trackers". A solar tracking system allows solar panels to follow the path of the sun throughout the day and year, optimizing the angle of solar radiation on the panel surface. [1] This dynamic arrangement can increase the production of electricity from photovoltaic (PV) panels by about 40% compared to fixed installations that maintain a single angle throughout the year. Our goal is to develop a reliable device capable of precisely tracking the sun and adjusting the position of the photovoltaic panel accordingly, improve productivity by moving panels in horizontal and vertical directions instead of keeping them at a static angle. This will be achieved by using tables that show the position of the sun in the sky. [2]

1.1 Solar energy:

Solar energy, or what is called solar radiation, is the energy emitted from the sun's rays mainly in the form of heat and light, and it is the product of nuclear reactions inside the star closest to us, which is the sun. This energy is of great importance to the earth and the living organisms on its surface. The output far exceeds the current energy requirements of the world in general, and if harnessed and exploited appropriately, it may meet all future energy needs. The energy resulting from converting sunlight into electricity is done using PV solar cells, and it is one of the most important and fastest growing renewable energy sources. It promises a promising future in providing energy for various uses.[2],[3] Every location on Earth receives an amount of sunlight throughout the year, but the amount of solar radiation that one spot receives varies from one place to another on the Earth’s surface, and that amount is called solar radiation, which is also known as photoelectric radiation. It is emitted from the sun in the form of light that is captured by solar energy technologies and converted into useful forms of energy.

2.1 Solar tracking systems

Photovoltaic panels are usually installed at a specific inclination angle so that they are exposed to the greatest possible amount of solar radiation throughout their operation. Scientists have found that the productivity of photovoltaic panels can be increased by making them maintain a maximum vertical angle with the radiation falling on them. This is achieved through solar trackers (solar tracking devices), known as “Solar Tracking Devices or Solar Trackers.” A solar tracker provides the ability to make solar panels follow the path of the sun in order to ensure the best incidence angle of solar radiation on the panel surfaces during the day and throughout the year. This process contributes to increasing the electricity production of photovoltaic panels, as the production of mobile photovoltaic panels increases by about 40% compared to if they were fixed at one angle throughout the year. [4]

2.2 Sun tracking systems:

Types of tracking systems can be divided into several sections as: [5]

1. According to the mode of operation, solar trackers can be classified as follows:
- Passive tracking device.
- Active tracking devices.
2. According to the mode of control, they can be classified as follows
- Open Loop Trackers (tuned algorithms or simple timing systems).
- Closed loop tracking systems (following the movement of the sun with the help of feedback sensors).
3. By their method of movement or directional flexibility, solar trackers can be classified to:
- Fixed-axes solar tracking.
- Single-axis solar trackers.
- Dual-axis solar trackers.

2.2.1 Fixed Solar Energy:

Fixed solar is a type of solar energy system that consists of installing solar panels firmly and firmly on supporting structures such as the roof of a building or the ground. This is considered the most common and simple technology in installing solar systems. Solar panels rely on being oriented toward the sun steadily for the longest possible period of time to make the most of solar light. Fixed system is sturdy and stable, and requires less maintenance due to no moving parts. [4]

2.2.2 Single-axis tracker: A single-axis tracker adjusts solar panels by rotating around a single axis, typically oriented in the north-south direction. This mechanism allows the photovoltaic panels to follow the sun's path as it moves from east to west during sunrise and sunset, as illustrated in figure (1).

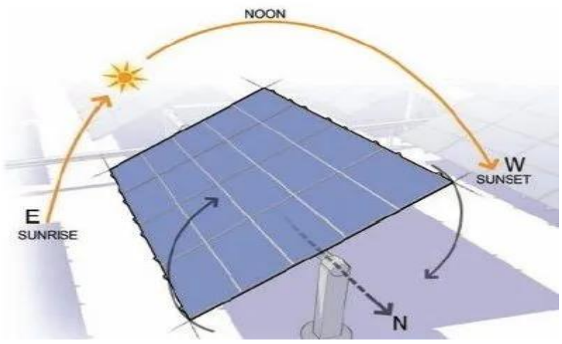


Figure (1) Horizontal single-axis tracking system

It improves the efficiency of solar systems without requiring the installation of additional photovoltaic (PV) modules. It's important to install a single-axis sun tracking system on a flat, sunny, and dry land area. While the initial installation cost of a single-axis sun tracking system is relatively high, it can greatly enhance the productivity of your solar system and can quickly recover the investment. [5]

2.2.3 Dual axes solar tracker:

Dual-axes solar tracker can enhance power output by 30-45% compared to fixed tilt solar systems. While primarily used in residential and small commercial settings, these trackers are beginning to be adopted in larger facilities as well. Each tracker is installed on an elevated platform to accommodate the wider range of angles for the solar panels. A single dual-axis tracker can support up to 20 solar panels. Although the increased height makes the panels less accessible for cleaning, it allows for additional space underneath, which can be utilized for other purposes like agriculture or parking. This technology remains largely untapped in the market, but solutions for rooftop tracking are starting to appear. Surface-mounted trackers operate similarly to dual-axis trackers, rotating along a circular track at their bases, and adjusting the angle of the plate to follow the sun more accurately than single-axis trackers as shown in figure (2). [2], [6]

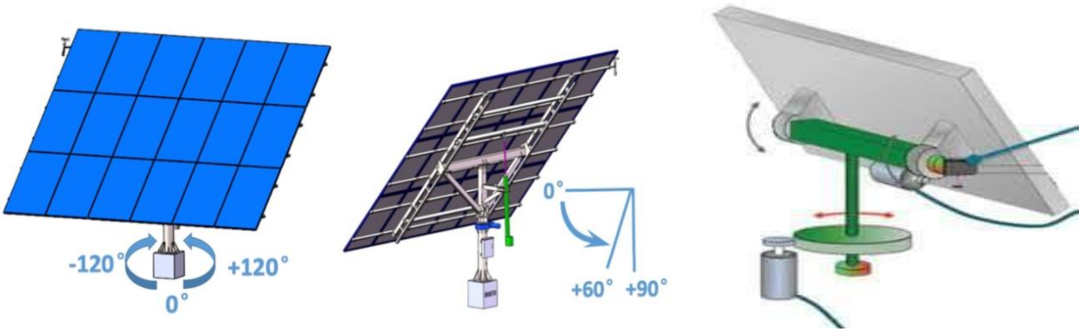


Figure (2) Dual-axis tracking system

1. **Design of dual axes solar tracker:**

A dual-axis sun tracking system consists of several main components that work together to achieve accurate tracking of the sun's motion. The main components of the system are as follows: [6], [7]

• **Tracker Structure:** The support structure forms the foundation of system and serves to support and move other components. It is sturdy and durable to withstand changing weather conditions and ensure system stability.

• **Motors:** Motors move the solar panel modules and adjust their angles following on the sun. The motors are directed by the system's automatic control system.

• **Control System:** The controlling system works to manage the movement of the engines and control the orientation of the system based on the information of the sun angle table. The controlling system uses complex algorithms to control the moving of tracking system and ensure accurate tracking of the moving of the sun.

• **Table of sun angles:** The angle table is the main part that controls the movement of the motors and directs the solar panels in the correct direction based on the angles in it.

• **Solar Panels:** Solar panels mounted are the main source of solar energy generation. They mounted on movable modules and move independently to track the sun and obtain the maximum possible solar radiation.

• **Power Management System:** The power control system controls the distribution of electrical power generated by solar panels to different loads. It is designed to achieve high energy efficiency and achieve the energy balance necessary to operate the system. It should be noted that the exact design and components used in a 2-axis solar tracking system may vary based on manufacturers and specific application requirements. It may also include additional components such as mechanical devices for motion control, indicators, and communications modules for remote control and monitoring of the system. These key components are an essential part of a dual-axis system, working together integrally to achieve accurate and efficient tracking of the sun's movement and increase solar energy yield.[5], [8]

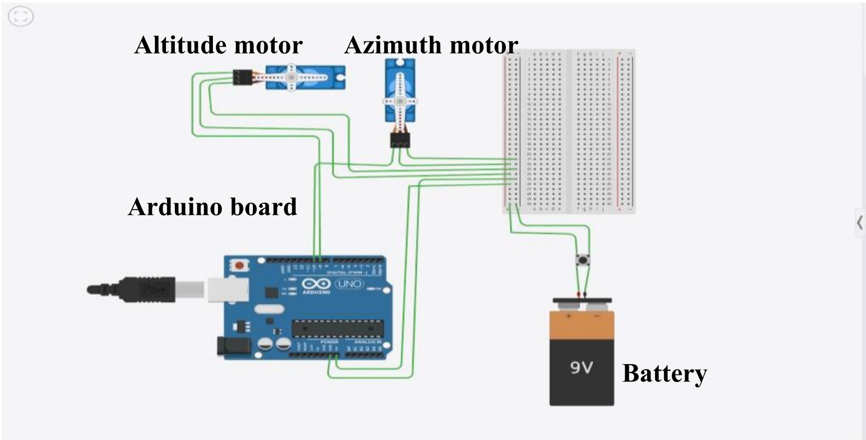


Figure (3) Design of a control circuit for a dual-axis solar tracker

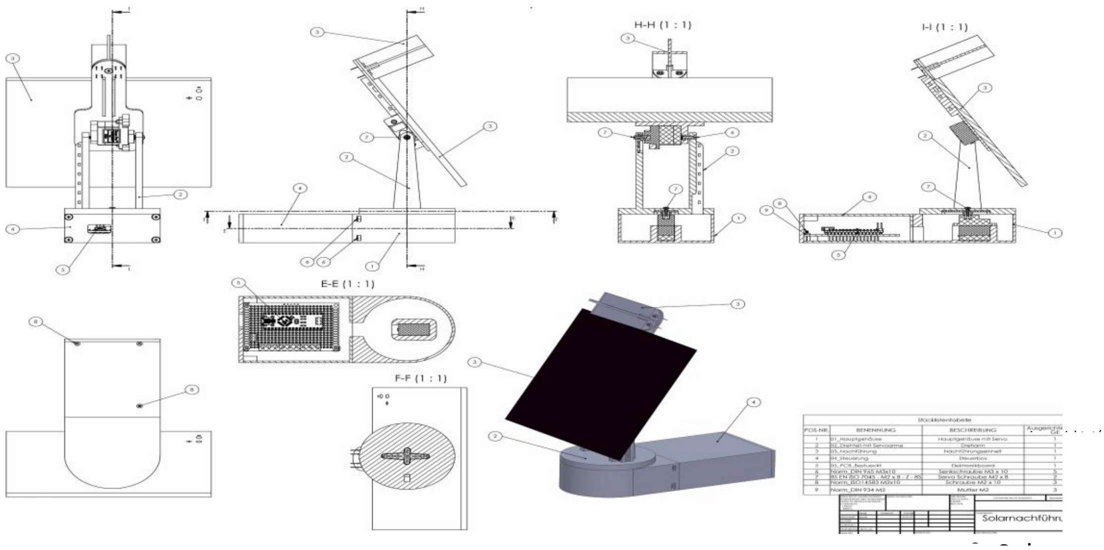


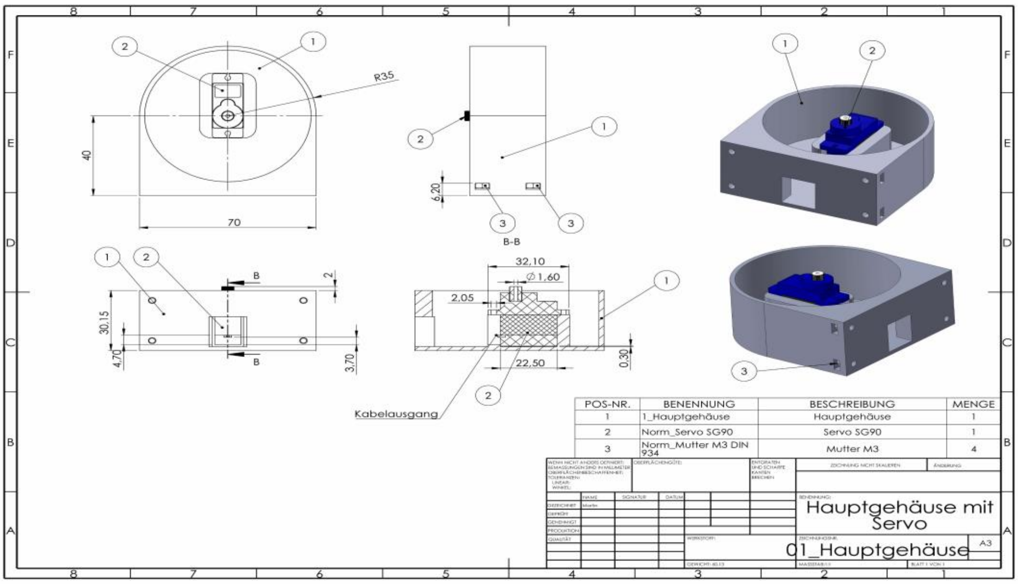
Figure (4) Engineering design of a dual-axis solar tracking device

The appropriate shape of the device was chosen so that it can perform its purpose, which is to move the solar panel in two directions.

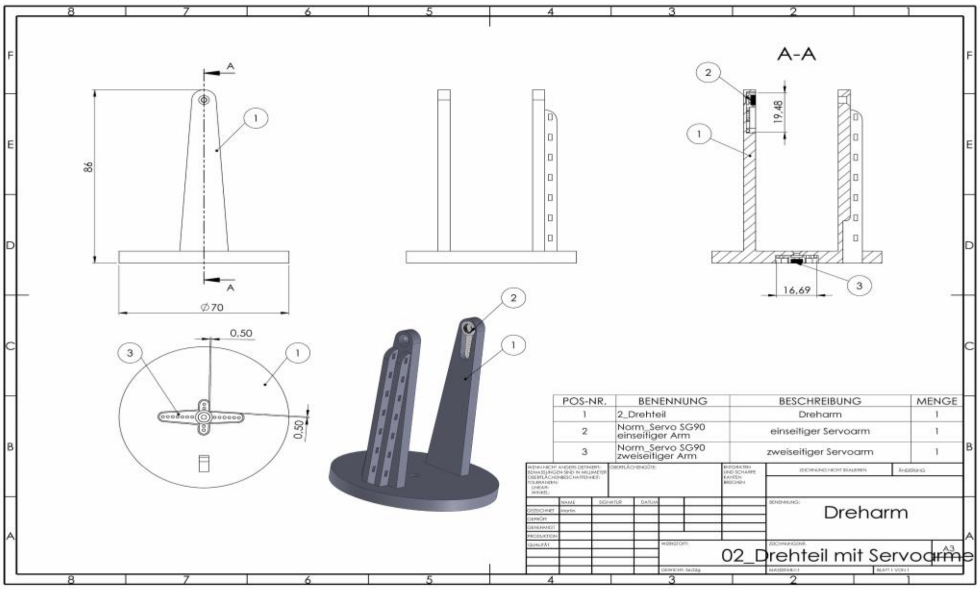
•The initial design of the device has been completed, as in figure (4).

•The measurements of the optical panel and motors were taken to design of the base, horizontal, and vertical axes of the dual-axis solar tracker,, as shown in figures (5a,b, and c).

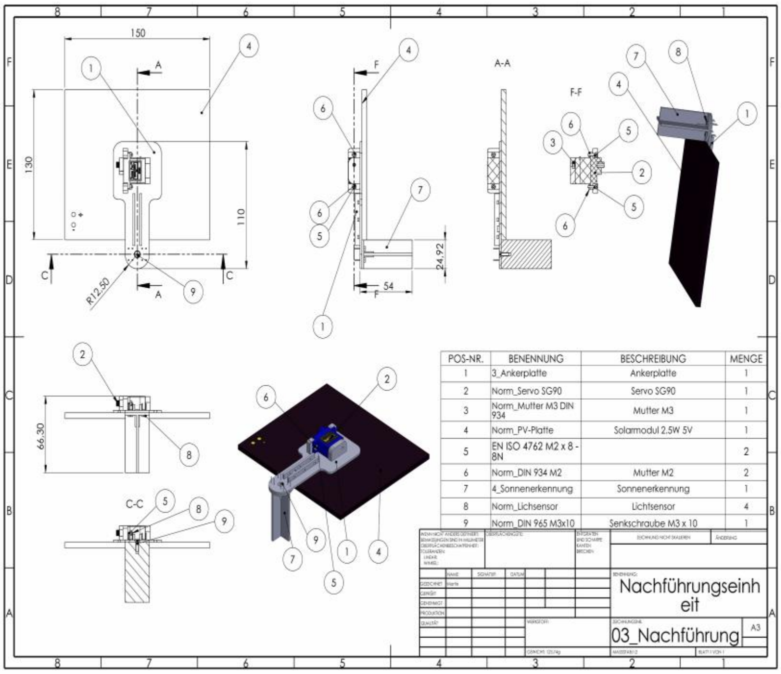
•The final design of the device was implemented using the Tinker Cad program, and printed in 3D using a 3D printer, as shown in figure (6).



(a)

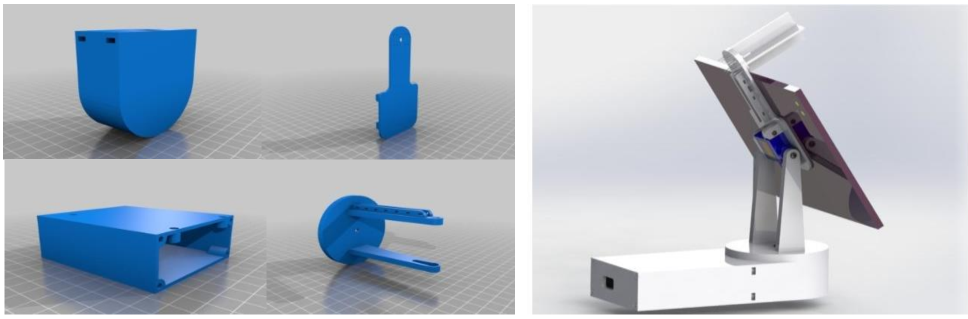


(b)



(c)

Figure (5) Engineering design of: a) the base of the dual-axis solar tracker, b) vertical axis of a dual-axis solar tracker, c) horizontal axis of a dual-axis solar tracking device



(a) (b)

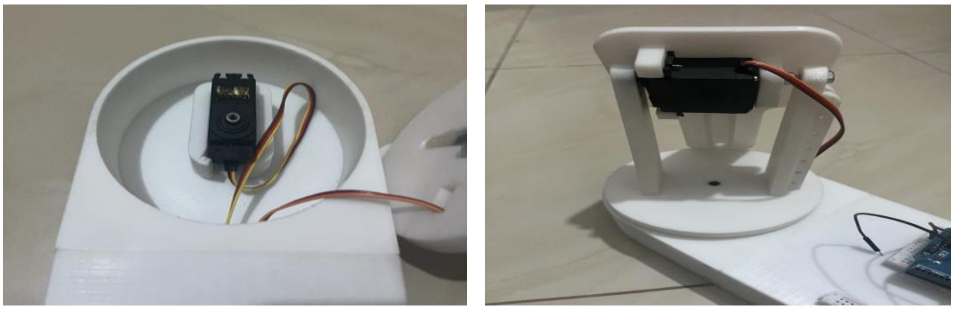
Figure (6) a) Structural parts of a dual axis solar tracker, b) Final design of a dual-axis solar tracker using the Tinker Cad program.

The components were distributed as follows:

- Mechanical structural parts
- Software parts
- Motion electronic devices

The device contains:

- 1 light panel, size (15*20 cm).
- 1 Arduino UNO board.
- 2 servo motors (MG995).
- 1 operating key (0 – 1).
- 1 lithium battery (V9).
- Connecting wires (male/male).



(a) (b)

Figure (7) Bottom motor installation responsible for: a) Azimuth angles, b) Altitude angles

Implementation

- After we finished the design process, the matter became clearer and the implementation process began.
- 3D printed design, as shown in figure (7).
- Preparing the locations of the motors and connecting wires.
- Installing devices on the external structure.
- Connecting the external structure to each other using screws and nuts.
- Connect the device wires to the Arduino board, as shown in figure (8).
- Preparing the system and adjusting the angles of the motors to start operation

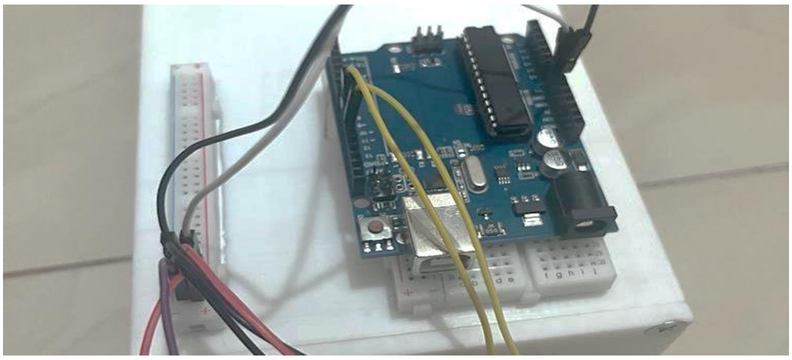


Figure (8) Installing the Arduino and connecting the motor and battery wires

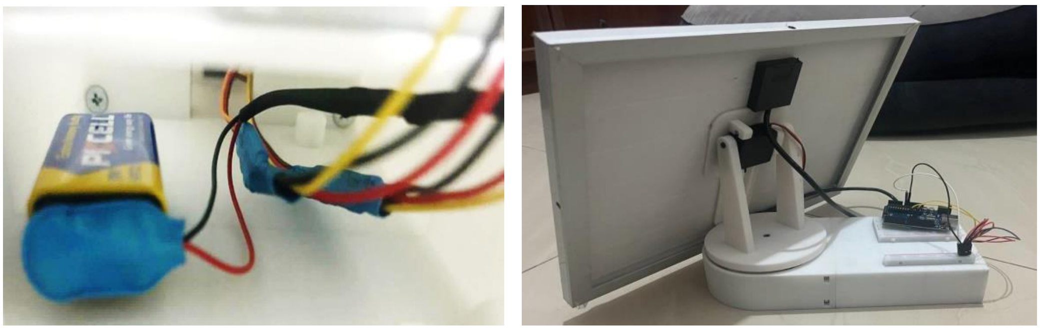


Figure (9) Installing of: a) the battery inside the device, b) the optical panel on the device

3.1 Programming

• We will program the device by listing the Azimuth and Altitude angles of the sun on a specific day of the year, and to obtain this data and angles we have used the (Astronomical Applications Department) program.
• Then specify the location from which you want to measure, specify the day, and specify the time range.
• The website used in programming is the website of the Higher Institute of Engineering Technologies / Tripoli (32.8564299, 13.2609637). [2], [7]
Table (1) Azimuth and Altitude angles used in programming:

Altitude and Azimuth of the Sun N 32° 51', E 13° 16' Tripoli city 2023-12-21 Zone: 2.0 hours East of Greenwich		
Time (h)	**Altitude**	**Azimuth**
07:20	-9.5°	111.9°
07:40	-5.6°	114.4°
08:00	-1.8°	116.9°
08:20	2.2°	119.7°
08:40	5.6°	122.5°
09:00	9.1°	125.5°
09:20	12.4°	128.7°
09:40	15.6°	132.1°
10:00	18.6°	135.7°
10:20	21.4°	139.5°
10:40	24.0°	143.6°
11:00	26.4°	148.0°
11:20	28.4°	152.6°
11:40	30.2°	157.4°
12:00	31.7°	162.5°
12:20	32.7°	167.8°
12:40	33.4°	173.2°
13:00	33.7°	178.7°

13:20	33.6°	184.2°
13:40	33.1°	189.6°
14:00	32.2°	195.0°
14:20	31.0°	200.1°
14:40	29.3°	205.1°
15:00	27.4°	209.8°
15:20	25.2°	214.3°
15:40	22.7°	218.5°
16:00	20.0°	222.5°
16:20	17.0°	226.2°
15:30	24.0°	216.4°
16:40	13.9°	229.7°
15:50	21.4°	220.5°
17:00	10.7°	233.0°
17:20	7.3°	236.0°
17:40	5.6°	237.5°
18:00	0.5°	241.8°
18:20	-3.8°	244.4°
18:40	-9.5°	248.2°
19:00	-11.5°	249.4°

2. Results:

2.1 In the case of a fixed system:

Measuring the voltage and current generated by the solar panels using a fixed tracker using a solar panel with a voltage of 6V, a current intensity of A1.16, and a power of 7W. It was installed at an angle of 300 with the horizontal axis, and the experiment was carried out on Wednesday, 11/15/2023.

2.1.1 Measurement of open circuit voltage (V_{OC}):

In this case, we place a voltmeter between the two ends of the board, and since the resistance of this device is large, the current does not pass and the circuit is considered open. The results recorded in this experiment are recorded in table (2):

Table (2) open circuit voltage (Voc) for fixed tracking system

Open circuit voltage (V_{OC}) (V)	**Time**
6.30	8:00
6.44	9:00
6.52	10:00
6.64	11:00
6.73	12:00
6.80	13:00
7.00	14:00
6.77	15:00
6.64	16:00
6.33	17:00
5.90	18:00
6.52	**المعدل**

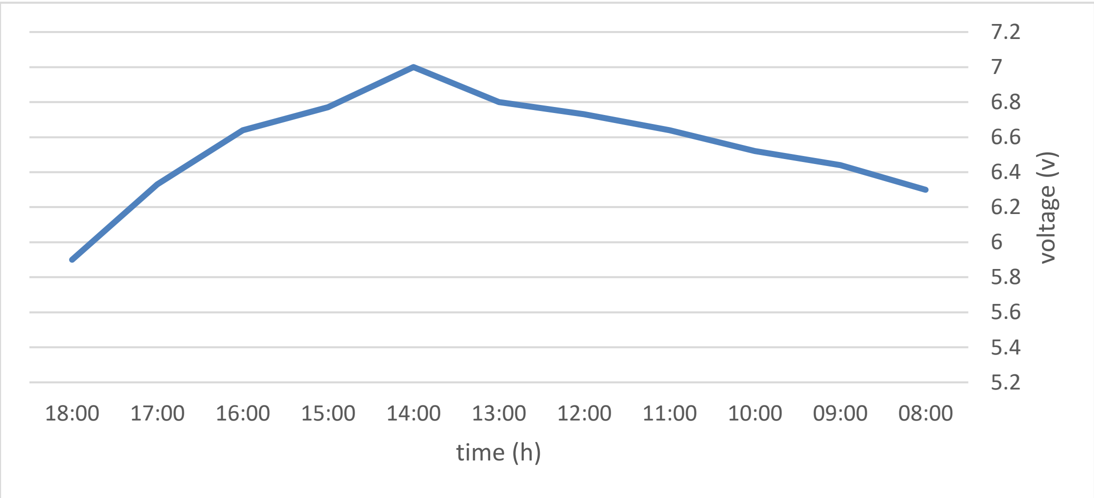


Figure (10) Rate of change of voltage productivity in the fixed tracker

2.1.2 Measuring short circuit current (I_{SC}):

We short the poles of the optical panel using an ammeter to measure the intensity of the shorting current, and the results obtained are recorded in table (3):

Table (3) Short circuit current (Isc) for fixed tracking system

Short circuit current (I_{SC}) (A)	**Time**
0.33	8:00
0.55	9:00
0.62	10:00
0.68	11:00
0.71	12:00
0.86	13:00
0.94	14:00
0.83	15:00
0.66	16:00
0.45	17:00
0.21	18:00
0.62	**المعدل**

Average output in watts (4.0421 watts)

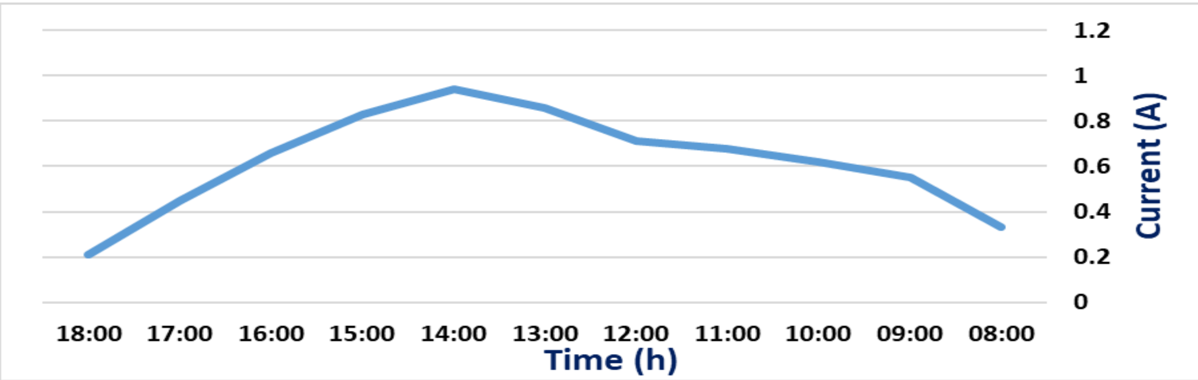


Figure (11) Rate of change of current throughput in the fixed tracer

2.2 In the case of the single-axis system:

Measuring the voltage and current resulting from solar panels using a single-axis tracker using a solar panel with a voltage of 6V, a current intensity of A1.16, and a power of 7W, in which the vertical axis was fixed at 320 with the horizontal axis on Wednesday, 11/15/2023..

2.2.1 Measurement of open circuit voltage (V_{OC}):

In this case, we place a voltmeter between the two ends of the board, and since the resistance of this device is large, the current does not pass and the circuit is considered open. The results recorded in this experiment are recorded in table (4):

Table (4) open circuit voltage (Voc) for single-axis tracking system

Open circuit voltage (V_{OC}) (V)	Time
6.41	8:00
6.50	9:00
6.59	10:00
6.70	11:00
6.81	12:00
6.91	13:00
7.09	14:00
6.85	15:00
6.73	16:00
6.62	17:00
6.56	18:00
6.70	**المعدل**

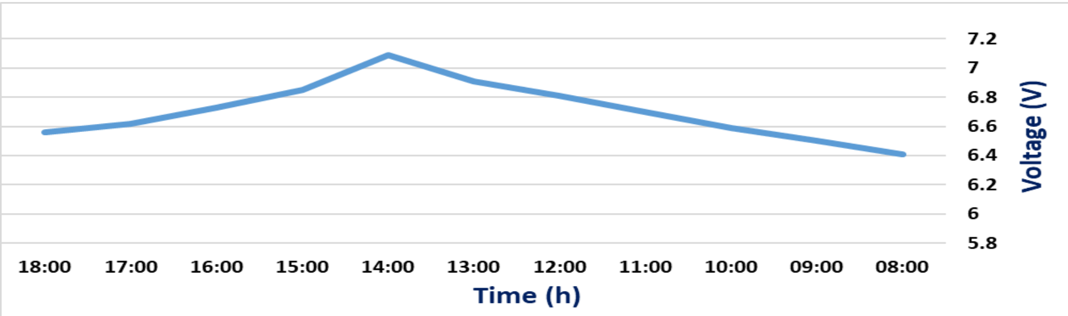


Figure (12) Rate of change of voltage productivity in the single-axis tracker

2.2.2 Measuring short circuit current (I_{SC}): We short the poles of the optical panel using an ammeter to measure the intensity of the shorting current, and the results obtained are recorded in table (5):

Table (5) Short circuit current (Isc) for single-axis tracking system

Short circuit current (I_{SC}) (A)	**Time**
0.41	8:00
0.58	9:00
0.67	10:00
0.81	11:00
0.89	12:00
0.98	13:00
1.04	14:00
0.96	15.00
0.84	16.00
0.73	17.00
0.60	18.00
0.80	المعدل

Average output in watts (5.48 watts)

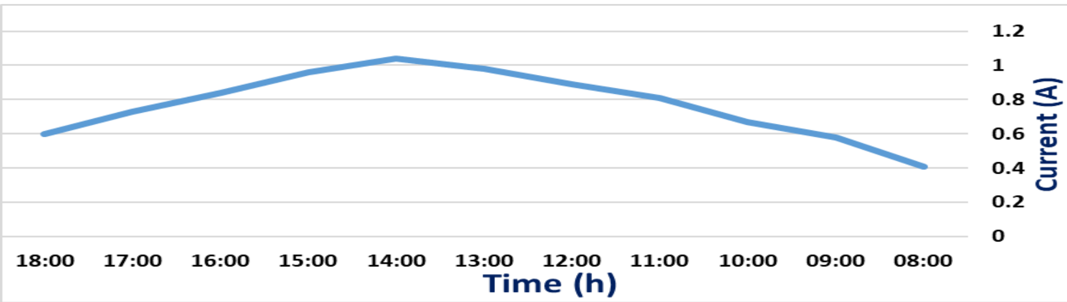


Figure (13) Rate of change of current throughput in the single-axis tracker

2.3 In the case of the dual-axis system:

Measuring the voltage and current resulting from the solar panels using a dual-axis tracker using a solar panel with a voltage of 6V, a current intensity of A1.16, and a power of 7W, which was placed on the project's factory device on Wednesday, 11/15/2023.

4.3.1 Measurement of open circuit voltage (V_{OC}):

In this case, we place a voltmeter between the two ends of the board, and since the resistance of this device is large, the current does not pass and the circuit is considered open. The results recorded in this experiment are recorded in table (6):

Table (6) open circuit voltage (Voc) for dual-axes tracking system

Open circuit voltage (V_{OC}) (V)	Time
6.44	8:00
6.56	9:00
6.64	10:00
6.75	11:00
6.85	12:00
7.03	13:00
7.16	14:00
7.04	15:00
6.92	16:00
6.85	17:00
6.71	18:00
6.88	المعدل

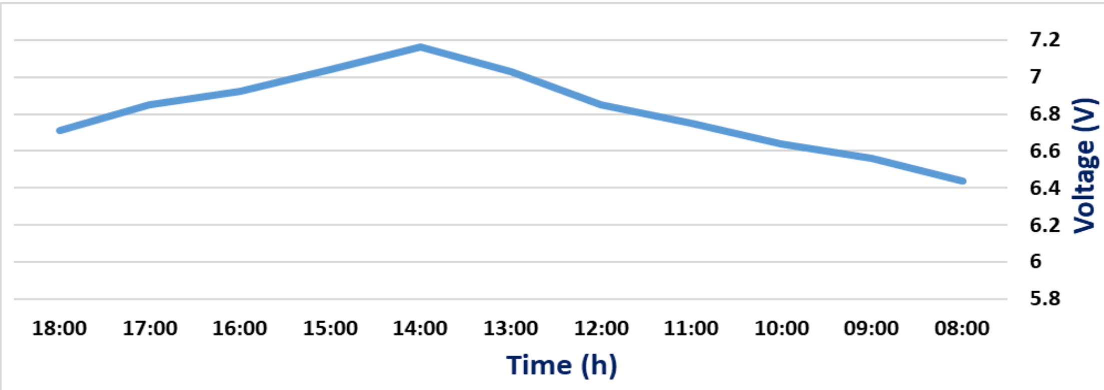


Figure (14) Rate of change of voltage productivity in the dual-axis tracker

4.3.2 Measuring short circuit current (I_{SC}): We short the poles of the optical panel using an ammeter to measure the intensity of the shorting current, and the results obtained are recorded in table (7):

Table (7) Short circuit current (Isc) for dual-axes tracking system

Short circuit current (I_{SC}) (A)	**Time**
0.56	8:00
0.60	9:00
0.73	10:00
0.90	11:00
0.95	12:00
1.05	13:00
1.14	14:00
1.09	15:00
1.01	16:00
0.94	17:00
0.89	18:00
0.89	**المعدل**

Average output in watts (6.1669 watts)

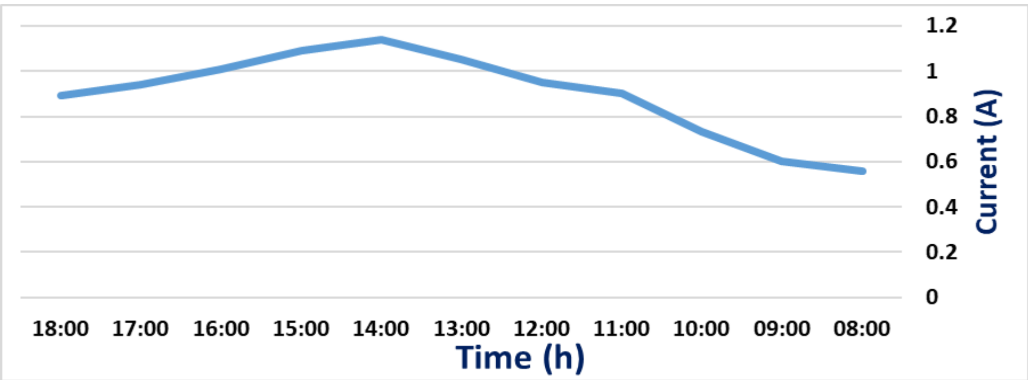


Figure (15) rate of change of current throughput in the dual-axis tracker

2.4 Experiment curves:

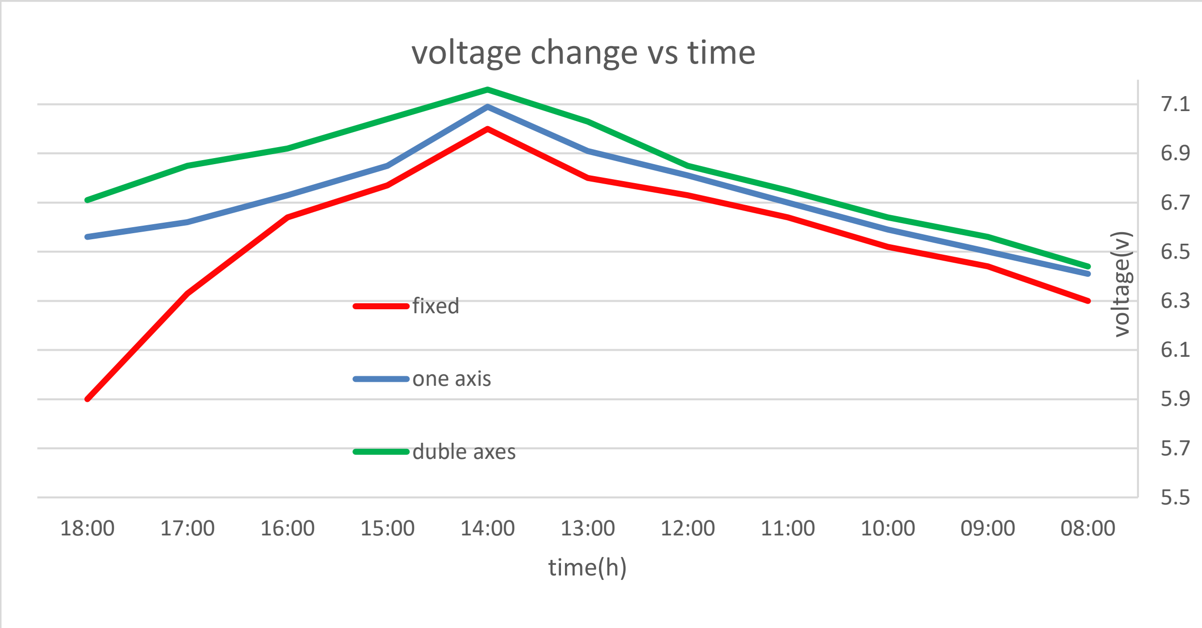


Figure (16) comparing the change in effort productivity according to the tracking system

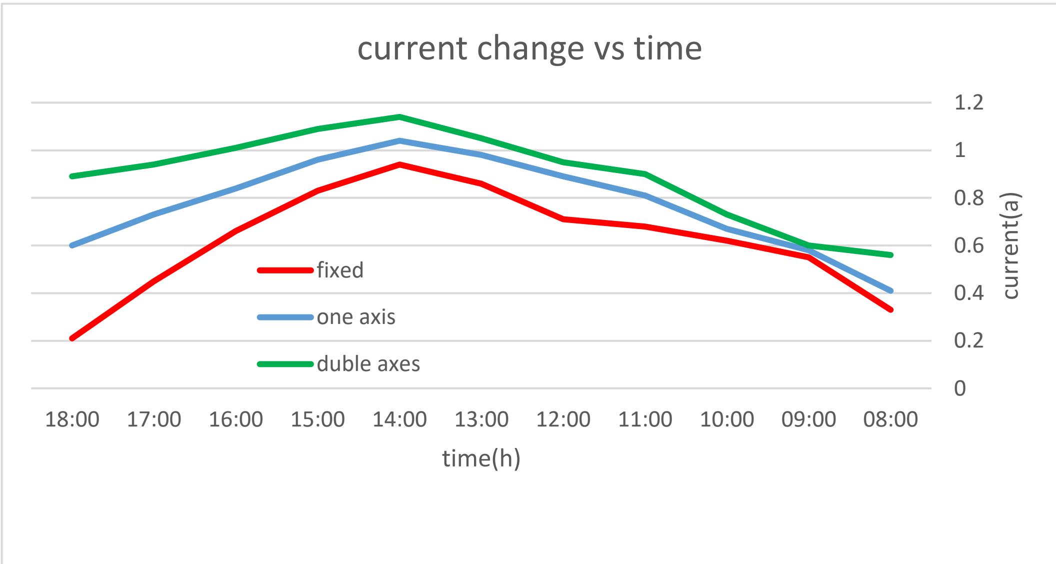


Figure (17) comparing the change in stream productivity according to the tracking system

From figures (16,17), one can note that the power generated (voltage and current) by dual axes tracking system is greater than that generated by one axis tracking system, where the lowest is that generated in the case of fixed one.

Conclusion:

For an open-loop solar tracking system, an electromechanical mechanism was developed. Simulations using azimuth and elevation data from Tripoli, Libya, have shown high effectiveness. The entire system has been designed and implemented successfully. This proposed system tracks the sun with a significant level of precision, repositioning the photovoltaic panel to its original location at the end of each day. The open-loop solar tracking mechanism is based on real data from a specialized table and algorithm. There is no need for feedback, because the open approach eliminates the need to adjust or modify the hardware or software of the system during seasonal changes or cloudy days. This improves the reliability, flexibility and cost effectiveness of the proposed system. The design may include the drive mechanism, which includes motors and solar panels. However, during the design process, it is important to consider the drive mechanism, dimensions and total weight of the solar panels

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