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# Improving the Efficiency of Solar Cells using Arduino-Based Systems

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***Abstract:***
**The sun represents one of the most sustainable and abundant sources of energy. Solar energy can be harnessed through photovoltaic (PV) cells, which convert sunlight directly into electrical energy. However, the energy conversion efficiency of PV cells remains relatively low. This paper explores methods to improve the efficiency of solar panels using an Arduino-based tracking system. The proposed system allows for dynamic adjustment of the solar panel's orientation to maximize solar radiation capture, thereby enhancing overall energy output. Experimental results demonstrate that implementing a tracking system significantly increases the efficiency compared to fixed-angle solar panels.**

***Keywords*: Arduino UNO, Bluetooth module, Solar Panel, Servo Motor, Microcontroller Atmega328, Android device**

## 1. INTRODUCTION

Solar energy is one of the most sustainable and widely available sources of renewable energy. It can be harnessed using photovoltaic (PV) cells that convert sunlight directly into electricity. However, the efficiency of these cells is typically low. One major limitation is that PV cells are highly dependent on the intensity of sunlight, which varies with the sun's position throughout the day.

To address this challenge, this study proposes a solar tracking system based on an Arduino Uno microcontroller. The system enables solar panels to follow the sun's path and continuously orient themselves toward the direction of maximum sunlight, thereby enhancing energy absorption.

The system integrates both hardware and software components. Two light-dependent resistors (LDRs) are employed to detect the direction of the highest light intensity. A servo motor then adjusts the panel's orientation based on LDR input. Additionally, a smartphone can be used to manually or automatically control the panel via Bluetooth.

The performance of this system has been tested and compared to a static solar panel. Results indicate that the tracking system significantly improves the efficiency of the solar panel—by more than 70%, and in some cases, over 100%.

## 2. METHODOLOGY

The proposed solar tracking system was developed using both hardware and software components. The core of the system is an Arduino Uno microcontroller, which serves as the control unit for the tracking mechanism.

### 2.1 Hardware Components

- Light Dependent Resistors (LDRs): Two LDRs were used to detect the intensity of sunlight from different directions. These sensors are placed at appropriate angles to ensure accurate detection of the sun's position.
- Servo Motor: A servo motor was employed to rotate the solar panel based on signals received from the Arduino. The motor adjusts the panel's orientation to align it with the direction of maximum sunlight, as indicated by the LDRs.
- Solar Panel: The solar panel is mounted on a movable frame, which allows it to tilt and rotate in response to motor movements.
- Bluetooth Module: A Bluetooth module (HC-05) was integrated into the system to enable wireless control. This allows the user to manually or automatically adjust the panel's position using a smartphone application.

2.2 Software Components
The Arduino was programmed using the Arduino IDE. The code processes input signals from the LDRs, determines the direction with the highest light intensity, and sends appropriate commands to the servo motor to reposition the solar panel. The software also supports manual control via Bluetooth when needed.

2.3 System Operation
During operation, the LDRs continuously monitor sunlight intensity. When a significant difference is detected between the two sensors, the Arduino calculates the optimal direction and commands the servo motor to rotate the panel accordingly. This ensures the panel remains aligned with the sun throughout the day. The system also allows for manual override via smartphone for testing or custom orientation purposes.

## 3. RESULTS AND DISCUSSION

The performance of the proposed solar tracking system was evaluated by comparing it with a conventional static solar panel under the same environmental conditions. Measurements were recorded for voltage and current output over a typical sunny day.
3.1 Performance Comparison
The tracking system consistently demonstrated a significant increase in energy output compared to the static panel. On average, the Arduino-based tracking system improved solar panel efficiency by more than 70%. In some instances—especially during early morning and late afternoon hours—the efficiency gain exceeded 100%, as the tracking system was able to maintain an optimal angle toward the sun, while the fixed panel received minimal direct sunlight.
This improvement is primarily attributed to the system's ability to follow the sun's movement, thereby maximizing solar irradiance on the panel's surface throughout the day. The continuous realignment allowed the panel to absorb more sunlight, especially during periods when a static panel would otherwise perform poorly.

3.2 Bluetooth Control and Flexibility
The addition of a Bluetooth module enabled convenient manual control of the panel through a smartphone application. This feature allows users to override automatic tracking for testing or to adjust settings remotely, enhancing the system's usability and flexibility.

3.3 Limitations and Considerations
Although the system showed promising results, there are factors that could influence performance. These include weather conditions, the responsiveness of the servo motor, and potential power consumption by the tracking components themselves. However, the energy gained through tracking significantly outweighs the system's power requirements.


Figure (1): Android Application (SolarTracker)

The complete system of the solar tracking is shown in Figure (2) below which consists of ArduinoUno,LDR sensor, servo motor, and solar panel, power supply,buck converter.

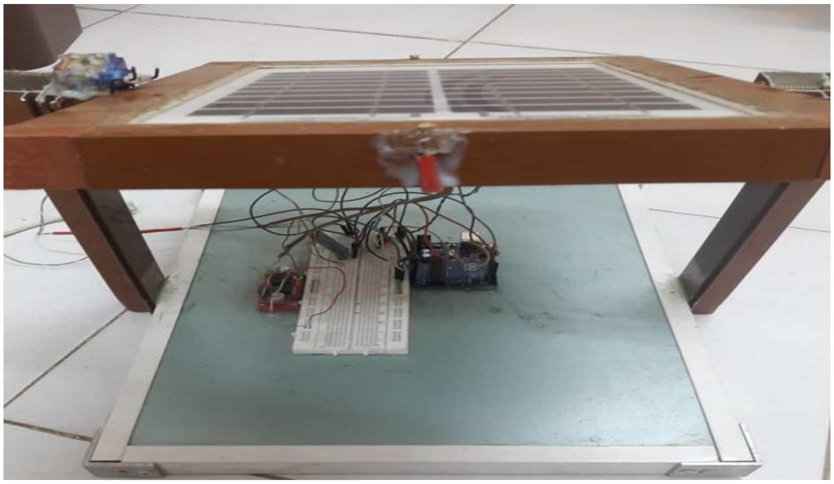

Figure (2) complete system of the solar tracking

## 4- RESULTS AND DISCUSSION

The system was tested at different times of the day under varying sun orientations to evaluate its ability to detect incident light under diverse conditions. The solar panel's movement was adjusted to achieve maximum efficiency based on the detected light. Various scenarios were studied, comparing the performance of the solar panel with and without the tracking system, each under different climatic conditions. Additionally, the temperature was measured at different times using a thermometer to assess its impact on the solar cell's performance.

Scenario1 1

In this scenario, the solar panel system equipped with a tracking mechanism was tested. The tracking system enabled the solar cell to follow the sun's movement from north to south throughout the day, maintaining an optimal angle of incidence for sunlight. This dynamic adjustment ensured that the panel received maximum solar radiation at different times. As a result, the system's output was recorded at regular intervals to evaluate performance improvements due to tracking. The detailed results, including voltage, current, and power output, are presented in Table 3.

Table (3) solar with tracking system

| Time | Temperature | Voltage | Current | Power |
|---|---|---|---|---|
| 9:30AM | 43 | 4.69 | 0.484 | 2.27 |
| 10AM | 41 | 5.1 | 0.464 | 2.36 |
| 10:30AM | 41 | 5.61 | 0.434 | 2.43 |
| 11AM | 39 | 9.69 | 0.49 | 4.94 |
| 11:30AM | 36 | 9.79 | 0.488 | 4.95 |
| 12:00PM | 36 | 9.79 | 0.478 | 4.96 |
| 12:30 PM | 36 | 9.89 | 0.468 | 4.99 |
| 1:00 PM | 41 | 9.79 | 0.484 | 4.74 |
| 1:30 PM | 42 | 9.58 | 0.454 | 4.35 |
| 2:00 PM | 43 | 8.57 | 0.509 | 3.98 |
| 2:30 PM | 40 | 8.46 | 0.393 | 3.33 |
| 3:00 PM | 38 | 7.75 | 0.373 | 2.89 |
| 3:30 PM | 42 | 7.54 | 0.363 | 2.74 |
| 4:00 PM | 40 | 7.14 | 0.353 | 2.52 |

Scenario 2

In this scenario, the solar panel system was tested without the use of a tracking mechanism. The panel remained fixed in a static position throughout the day, without adjusting to the changing position of the sun. As a result, the angle of sunlight incidence varied over time, leading to fluctuations in the amount of solar radiation received by the panel. Measurements of voltage, current, and power output were taken at regular intervals to assess the system's performance under these conditions. The data collected highlights the differences in efficiency compared to the tracking system. Detailed results are presented in Table 4.

Table (4) solar without tracking system

| Time | Temperature | Voltage | Current | power |
|---|---|---|---|---|
| 9:30AM | 40 | 2.14 | 0.515 | 1.1 |
| 10AM | 43 | 2.41 | 0.529 | 1.27 |
| 10:30AM | 41 | 2.57 | 0.526 | 1.35 |
| 11AM | 38 | 3.04 | 0.51 | 1.55 |
| 11:30AM | 39 | 4.75 | 0.538 | 2.56 |
| 12:00PM | 35 | 5.38 | 0.498 | 2.68 |
| 12:30 PM | 34 | 5.85 | 0.483 | 2.82 |
| 1:00 PM | 41 | 6.16 | 0.504 | 3.1 |
| 1:30 PM | 42 | 6 | 0.498 | 2.99 |
| 2:00 PM | 41 | 5.53 | 0.514 | 2.84 |
| 2:30 PM | 42 | 3.97 | 0.504 | 2.004 |
| 3:00 PM | 38 | 3.97 | 0.498 | 1.98 |
| 3:30 PM | 41 | 3.74 | 0.483 | 1.8 |
| 4:00 PM | 40 | 3.27 | 0.451 | 1.47 |

From the tables for the previous scenarios, we found that the solar panels give the maximum electrical power from 12:30 pm to 1:30 pm and also recorded the lowest value from 4 pm.

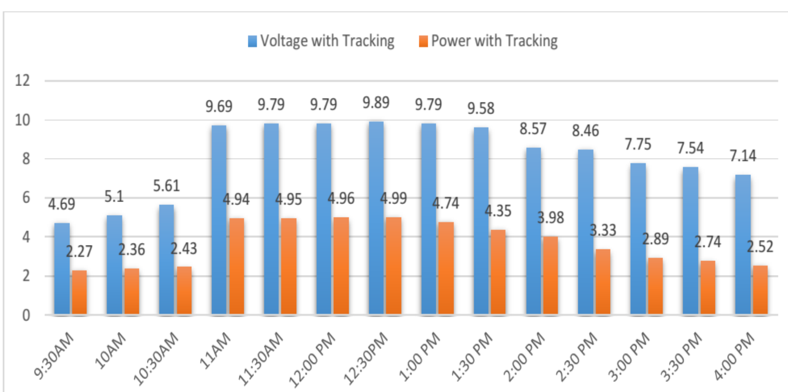


Figure (3) solar voltage and power with tracking system

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Figure (3) shows the effect of temperature changes on the output power and the voltage. At a temperature of 36ºC, it gives 4.99Wand 9.89V respectively, and at a temperature of 44ºC it gives values of the 2.27Wand4.69V.We note that the increase in temperature reduces the output power and voltage values.

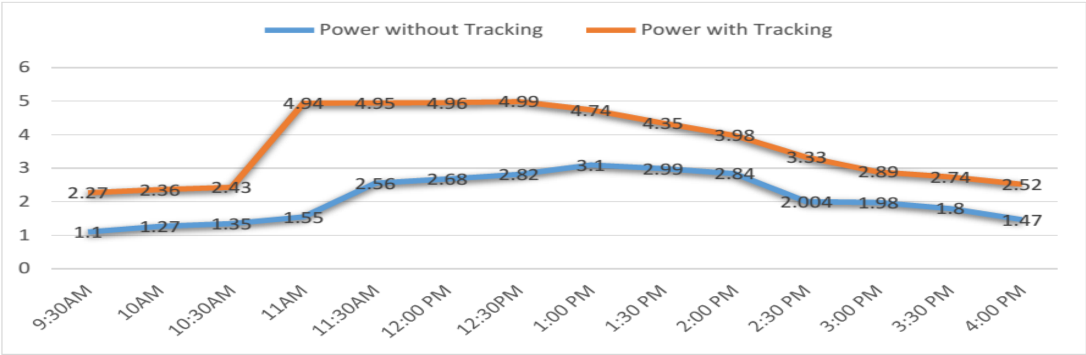


Figure (4) compression between solar power with and without tracking system

The figure (4) shows the Solar tracking system to increase power output by between 25% and 40% than without tracking systems.

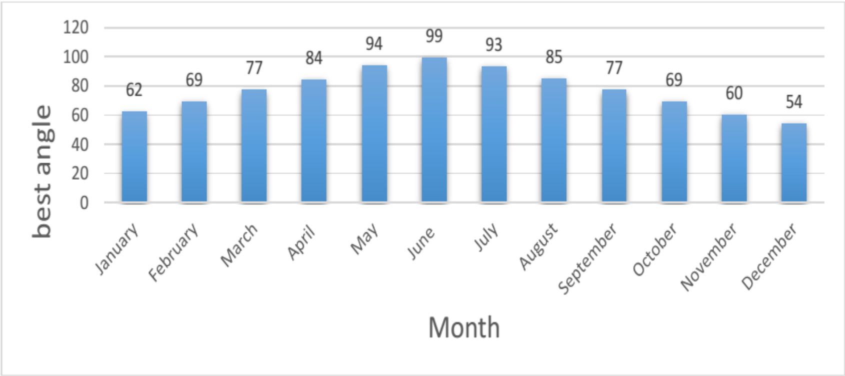


Figure (5) best angle for solar tracking in month

The figure shows that in this design system provides the best angles for tracking the solar cells to get the maximum energy during the year in Sudan in the city of Elobeid.We note that the:
- On the 21st December, the sun will rise 84° east of due south and set 84° west of due south.
- On the 21st March/21st September, the sun will rise 92° east of due south and set 92° west of due south.
- On the 21st June, the sun will rise 95° east of due south and set 95° west of due south

It is also very interesting to note that the efficiency of the solar cell increases considerably. For example at 11 O'clock the efficiency increases by more than 100 %, while at 4 O'clock it is about 70%..

## 5- CONCLUSIONS

The use of a tracking system significantly enhances the efficiency of the solar cell system. This improvement is due to the system's ability to maintain the sunlight incident perpendicularly on the cell surface. As a result, maximizing the intensity of incident solar radiation proves to be one of the most effective factors in increasing solar cell efficiency.

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