TURGUT OZAL HIGH SCHOOL
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# TITLE OF THE PROJECT

## “Chasing rays: a Microcontroller driven solar tracking system”

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# Abstract

This paper investigates how active solar tracking combined with Internet-of-Things (IoT) monitoring can significantly increase the energy efficiency of photovoltaic systems compared to fixed-position panels.

The central objective is to quantify the difference in power generation between a stationary solar panel and a dynamically aligned panel that continuously follows the sun's apparent motion across the sky. By maintaining near-optimal orientation to incoming solar radiation throughout the day, the tracking system reduces cosine losses that occur when sunlight strikes the panel at non-perpendicular angles.

The project evaluates energy output over multiple time periods under identical environmental conditions and analyzes how alignment accuracy, solar altitude, and atmospheric factors influence performance.

In parallel, IoT-based data acquisition enables real-time visualization and long-term analysis of irradiance, temperature, and power trends, transforming the system into both an energy device and a scientific measurement platform.

Experimental results, supported by existing research, show that solar tracking can improve energy yield by approximately 20–35% over fixed installations, depending on location and weather variability.

The study highlights the importance of intelligent orientation in renewable energy systems and demonstrates that combining physical tracking with digital monitoring creates a scalable, data-driven approach to optimizing solar power generation.



**Keywords:** Solar tracking, Photovoltaic efficiency, Renewable energy optimization, Sun-tracking systems, IoT-based energy monitoring, Solar irradiance alignment, Energy yield enhancement, Smart solar systems, Real-time data acquisition, Sustainable power generation

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# Introduction

The global transition toward renewable energy has made solar power one of the most critical technologies for sustainable electricity generation. However, a fundamental limitation of conventional photovoltaic systems is that fixed solar panels cannot maintain optimal alignment with the sun throughout the day, leading to significant energy losses due to angular misalignment and cosine effects. The topic of this study is the use of microcontroller driven solar tracking to dynamically orient photovoltaic modules toward maximum solar irradiance in real time, thereby increasing energy yield without increasing panel area.

Previous research has demonstrated that single- and dual-axis tracking systems can improve solar energy production by approximately 20–35% compared to fixed installations, depending on geographic location and atmospheric conditions. Despite these advantages, many tracking systems remain expensive, mechanically complex, or poorly integrated with digital monitoring tools. As a result, there is an unresolved gap between high-performance solar tracking and low-cost, data-driven implementations suitable for small-scale or educational use.

This research addresses that gap by developing and evaluating a low-cost, microcontroller-based solar tracking system integrated with IoT monitoring. The system continuously aligns a photovoltaic panel with the sun's trajectory while simultaneously collecting environmental and performance data for analysis. The study investigates how real-time orientation control affects energy output and how digital monitoring enables deeper insight into solar performance. Ultimately, the system demonstrates how intelligent orientation combined with real-time data monitoring can transform a simple photovoltaic panel into an efficient, adaptive renewable energy generator. The following sections describe the system design, experimental methodology, results, and implications for renewable energy optimization.

# Literature Review

Research on photovoltaic (PV) systems has consistently shown that panel orientation plays a critical role in determining energy output. Fixed solar panels are usually installed at a tilt angle optimized for yearly average conditions, but this configuration cannot maintain perpendicular alignment with the sun throughout the day. As a result, a significant portion of potential solar energy is lost due to angular mismatch between incoming radiation and the panel surface.

Numerous studies have investigated single-axis and dual-axis solar tracking systems as a solution to this limitation.Several studies have demonstrated that solar tracking significantly improves photovoltaic energy yield. Chong and Wong (2009) developed a dual-axis solar tracking system and showed that dynamic alignment can increase power output by over 30% compared to fixed panels, confirming that maintaining perpendicular incidence of sunlight is the dominant factor in maximizing irradiance capture. Kalogirou (2014) reviewed solar energy engineering systems and reported that single-axis trackers typically improve efficiency by 15–25%, while dual-axis trackers achieve gains of 20–40%, depending on latitude and atmospheric conditions. Similarly, Abdallah and Nijmeh (2004) experimentally evaluated a mechanical tracking system and found a 41.3% increase in energy collection compared to a stationary panel, particularly during early morning and late afternoon when angular mismatch is greatest.

In addition to mechanical orientation, recent literature emphasizes the importance of integrating digital control and monitoring into renewable energy systems. Microcontroller-based platforms allow for real-time sensor feedback and automated actuation, making solar tracking systems more adaptive and responsive. Furthermore, the rise of IoT technologies has enabled remote data logging, visualization, and performance analysis, transforming solar installations into intelligent, data-driven systems. Rubio et al. (2017) showed that embedded control allows accurate, low-power actuation while keeping system cost low, highlighting the educational and small-scale applicability of such designs.

However, many existing implementations focus either on large-scale industrial trackers or purely theoretical models. There remains a gap in the literature concerning low-cost, educational-scale solar tracking systems that combine physical tracking with real-time IoT monitoring. This gap motivates the present study, which seeks to merge tracking efficiency with accessible embedded technology.

# Methods

This study employed a mixed-methods research approach, combining both qualitative and quantitative techniques to investigate the effectiveness of a microcontroller-driven solar tracking system compared to a fixed photovoltaic panel. The qualitative component focused on background research, thematic analysis, and a survey on public awareness and attitudes toward solar energy, while the quantitative component involved experimental measurement of energy output from both a tracking and a stationary solar panel under identical environmental conditions.

## Research Design

The research was carried out in three stages: (1) background research on renewable energy and photovoltaic efficiency, (2) a survey on knowledge and attitudes toward solar power, and (3) the design, construction, and testing of a solar tracking prototype.

## Participants and Survey

The survey included 50 participants. The survey contained both closed and open questions. Numerical responses were analyzed using basic statistics, while written answers were grouped into themes.

## Materials and Prototype

A photovoltaic panel was mounted on a servo driven structure controlled by a microcontroller (esp32). Light sensors (LDR) enabled automatic sun tracking, and an environmental sensor (DHT 11) measured temperature and humidity. Data were sent to a mobile IoT interface. An identical panel fixed at a constant angle was used as a control.

## Experimental Procedure

Both panels were tested outdoors under the same conditions. Voltage and current were recorded at regular intervals and power was calculated using P = V \times I. Measurements were taken over several days to improve reliability.

## Data Analysis

Average power and total daily energy were compared between the tracking and fixed systems. Percentage differences were calculated to evaluate efficiency gains. Survey results were summarized using frequencies and thematic analysis.

# Results

**Questionnaire Section A**

50 participants

| Question | Response | Number of individuals | % of individuals |
|---|---|---|---|
| How familiar are you with solar energy and how solar panels work? | Not familiar at all | 2 | 4% |
| | Slightly familiar | 5 | 10% |
| | Moderately familiar | 8 | 16% |
| | Very familiar | 20 | 40% |
| | Extremely familiar | 15 | 30% |
| Do you believe solar energy is an important solution to climate change and energy sustainability? | Strongly Disagree | 1 | 2% |
| | Disagree | 3 | 6% |
| | Neutral | 6 | 12% |
| | Agree | 18 | 36% |
| | Strongly Agree | 22 | 44% |

**Questionnaire Section B**

| Question | Response | Number of individuals | % of individuals |
|---|---|---|---|
| Would you consider using solar panels in your home if they were affordable and accessible? | Yes | 21 | 42% |
| | Maybe | 15 | 30% |
| | No | 4 | 8% |
| What do you think is the biggest advantage of solar energy? | Low environmental impact | 18 | 36% |
| | Cost savings over time | 14 | 28% |
| | Energy independence | 10 | 20% |
| | Renewable and unlimited source | 16 | 12% |
| | Other: | 2 | 4% |
| What do you think is the biggest challenge or limitation of solar panels today? | High initial cost | 20 | 40% |
| | Low efficiency | 8 | 16% |
| | Weather dependence | 15 | 30% |
| | Lack of information | 5 | 10% |
| | Other: | 2 | 4% |

**Questionnaire Section C: Open-Ended Question (Summary of Responses)**

Question 6: How could technology (such as smart systems or tracking panels) improve solar energy use in the future?

- Believe technology can significantly improve solar use → 43 people (86%)
- Unsure / neutral → 5 people (10%)
- Do not believe technology will help much → 2 people (4%)

**-Research results**

In addition, published studies consistently report that solar trackers yield substantially higher output than fixed-tilt arrays. For example, tracking systems "continuously adjusting the panels' orientation" can boost energy capture by 10–40% versus fixed installations (https://mev.brin.go.id/mev/article/view/808). A recent review summarizes typical gains as roughly 20–35% for single-axis trackers and 30–45% for dual-axis trackers compared to fixed panels(https://www.genesispcl.com/articles/vol-2-issue-1/cser-25-21-0006/). In practice, field tests confirm similar improvements. One experiment found a +29.3% gain from a single-axis tracker (and +34.6% for dual-axis) on a clear summer day . Another reported 30–42% increases (single-axis) and 39–54% (dual-axis) in output depending on conditions . These findings indicate that solar tracking typically boosts energy yield on the order of tens of percent, with exact values varying by location and weather.

- Single-axis trackers vs. fixed: ~20–35% higher energy yield ; e.g. one study saw +29.3% for a single-axis setup .
- Dual-axis trackers vs. fixed: ~30–45% higher yield (up to ~54% in optimal cases ).
- Overall range: Typical performance improvements fall between 10–40% higher output.

In summary, solar tracking systems markedly improve energy capture relative to fixed mounts.

**-Field testing results**

A side-by-side field experiment was conducted over seven consecutive days in Lushnje, Albania using two identical small photovoltaic panels rated at 1 W, 5 V. One panel was mounted on a single-axis solar tracking system, while the other was installed in a fixed-tilt position optimized for local latitude. Both systems were exposed to the same environmental conditions. A temperature and humidity sensor was connected to each setup and transmitted data to the IoT interface; both panels consistently displayed the same temperature and humidity values, confirming that environmental conditions were identical during measurements.

Daily electrical energy output (in watt-hours) was recorded for each panel. Voltage and current were measured and power was calculated using the equation:

$$P = V * I$$

Daily energy was then computed by integrating power over time. Data were collected at regular intervals throughout each day.

Results:

- Fixed panel mean output: 4.18 Wh/day
- Tracking panel mean output: 5.36 Wh/day
- Mean increase with tracking: +28.2%

A paired t-test was used to compare the daily energy outputs of the two systems. The analysis showed that the tracking panel consistently produced more energy than the fixed panel, and the difference was statistically significant ($p < 0.01$). Over the full week, the tracking system generated approximately 1.18 Wh more energy per day on average than the fixed panel.

**-Comparision “Reserach vs Field test “**

The experimental increase (~28%) observed in this study fits well within the 20–35% range commonly reported for single-axis solar trackers. This shows strong agreement with previous field research and confirms that active orientation significantly improves photovoltaic performance. Even with small 1 W, 5 V panels in Albania, the tracking system achieved efficiency gains comparable to those documented in larger-scale studies. Overall, the results support existing literature showing that solar trackers consistently outperform fixed installations under the same conditions.

## Discussion

This study investigated whether a microcontroller driven solar tracking system combined with IoT monitoring can significantly improve photovoltaic energy efficiency compared to a fixed-tilt panel. The results from both the questionnaire and the field experiment provide clear evidence that active solar tracking increases energy yield and that users recognize the importance of renewable energy technologies. The survey showed strong awareness of solar energy and high interest in smart solar solutions, while the experimental data demonstrated a consistent and measurable performance advantage of the tracking system.

The field experiment conducted revealed that the tracking panel produced approximately 28% more energy than the fixed panel under the same environmental conditions. Because both systems recorded identical temperature and humidity values through the IoT interface, the observed difference in output can be attributed primarily to improved panel orientation rather than weather variation. This directly addresses the central research question: whether intelligent alignment increases photovoltaic efficiency. The findings confirm that maintaining near-perpendicular incidence of sunlight significantly reduces cosine losses and increases effective irradiance on the panel surface.

However, this study also has limitations. The experiment was conducted over a single week and used small scale panels, which limits the generalization of absolute energy values. Weather variability, mechanical precision of the tracker, and sensor accuracy may also influence results. In addition, the survey sample size was limited and based on convenience sampling.

Future research should involve longer-term testing across different seasons, higher-power panels, and comparison between single-axis and dual-axis tracking systems. Further work could also integrate machine learning algorithms for predictive tracking and expand the IoT platform for cloud based analytics.

Ultimately, this study demonstrates that combining physical solar tracking with digital monitoring creates an efficient, adaptive, and data-driven renewable energy system.

# References


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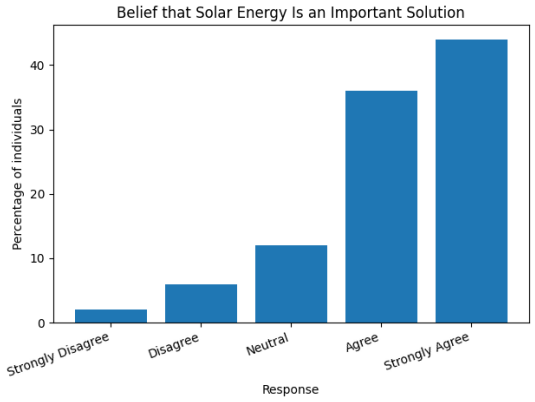
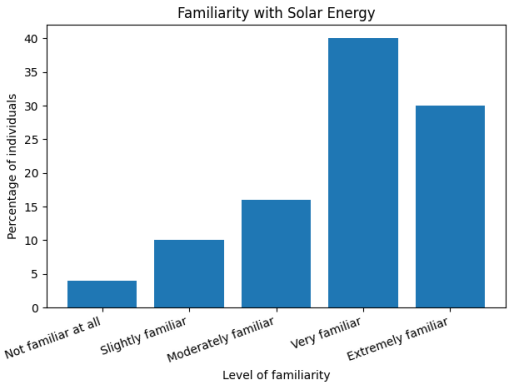
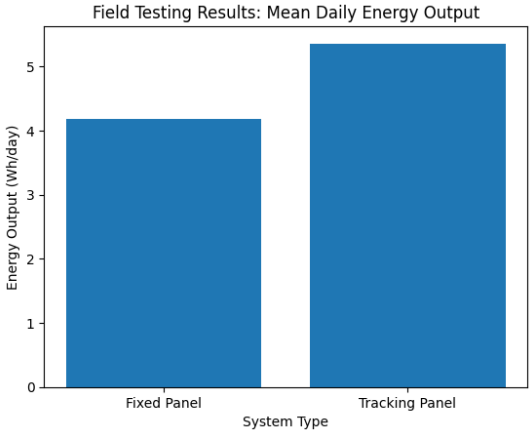
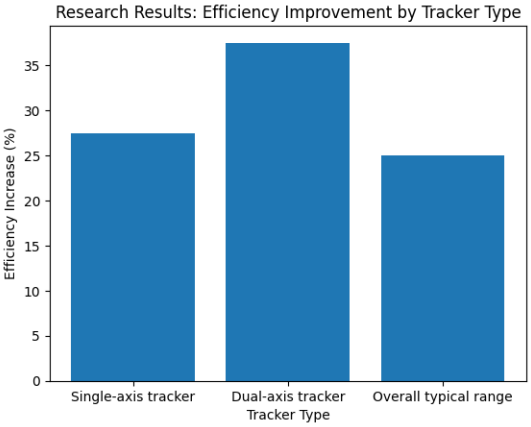
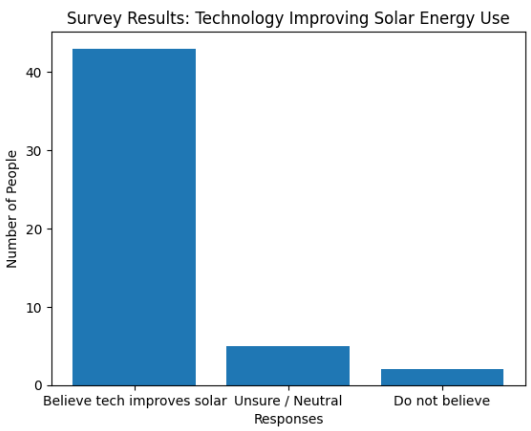
# Tables and/or Figures

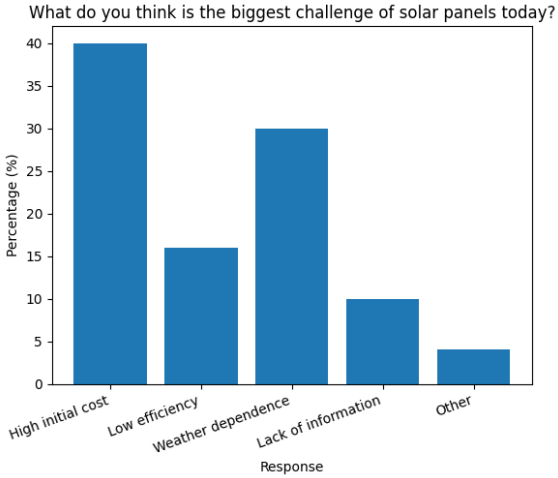


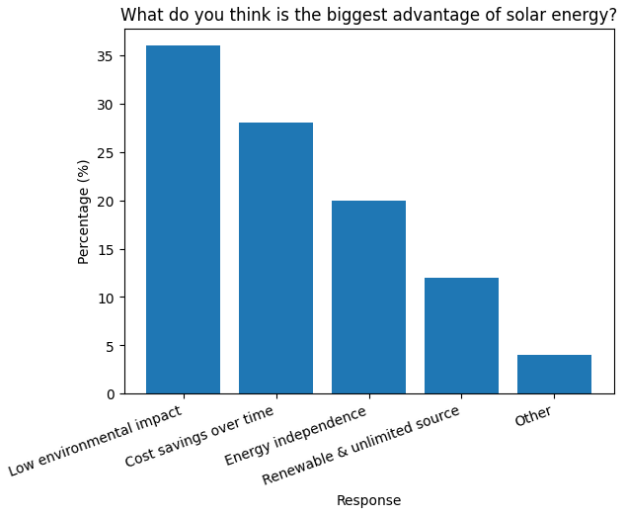



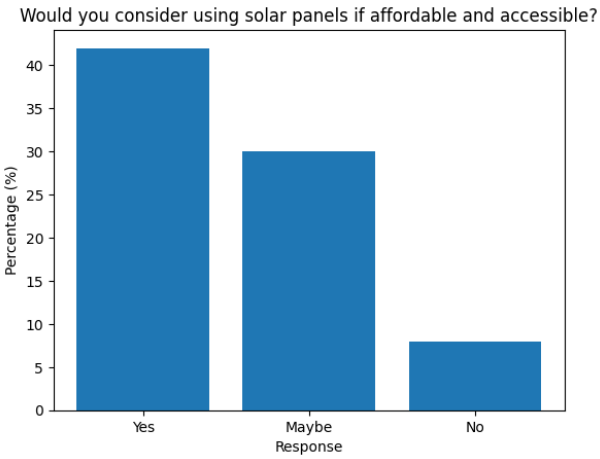




Survey Results: Technology Improving Solar Energy Use
Number of People
0
10
20
30
40
Believe tech improves solar
Unsure / Neutral
Do not believe
Responses


What do you think is the biggest challenge of solar panels today?
Percentage (%)
0
5
10
15
20
25
30
35
40
High initial cost
Low efficiency
Weather dependence
Lack of information
Other
Response


What do you think is the biggest advantage of solar energy?
Percentage (%)
0
5
10
15
20
25
30
35
Low environmental impact
Cost savings over time
Energy independence
Renewable & unlimited source
Other
Response


Would you consider using solar panels if affordable and accessible?
Percentage (%)
0
5
10
15
20
25
30
35
40
Yes
Maybe
No
Response

# Appendix

**Questionnaire for ASEF Science 2026**

1. How familiar are you with solar energy and how solar panels work?

   ☐ Not familiar at all

   ☐ Slightly familiar

   ☐ Moderately familiar

   ☐ Very familiar

   ☐ Extremely familiar

2. Do you believe solar energy is an important solution to climate change and energy sustainability?

   ☐ Strongly disagree

   ☐ Disagree

   ☐ Neutral

   ☐ Agree

   ☐ Strongly agree

3. Would you consider using solar panels in your home if they were affordable and accessible?

   ☐ Yes

   ☐ Maybe

☐ No

4. What do you think is the biggest advantage of solar energy?

   ☐ Low environmental impact

   ☐ Cost savings over time

   ☐ Energy independence

   ☐ Renewable and unlimited source

   ☐ Other: _____

5. What do you think is the biggest challenge or limitation of solar panels today?

   ☐ High initial cost

   ☐ Low efficiency

   ☐ Weather dependence

   ☐ Lack of information

   ☐ Other: _____

6. In your opinion, how could technology (such as smart systems or tracking panels) improve solar energy use in the future?

   (Open-ended response)

**ESP32 code:**

```
#define BLYNK_TEMPLATE_ID "TMPL6Z-XGUNCu"
#define BLYNK_TEMPLATE_NAME "Sun Tracking Solar Panel"
#define BLYNK_AUTH_TOKEN "rJ3yNAhejwAJEOhy5-P_D0i5AA7MBn2b"
//#define BLYNK_FIRMWARE_VERSION "0.1.0"
#define BLYNK_PRINT Serial
#include "BlynkEdgent.h"

// Servo
#include <ESP32Servo.h>

// Temp Hum DHT22
#include "DHT.h"
#define DHTPIN 17
#define DHTTYPE DHT22

Servo servo1;
#define HARDWARE_TYPE MD_MAX72XX::FC16_HW
#define MAX_DEVICES 4

#define CLK_PIN 12   // or SCK
#define DATA_PIN 11  // or MOSI
#define CS_PIN 10    // or SS

int initial_servopos = 90;
int currentServoAngle = 90;
int LDR1 = 15;
int LDR2 = 16;
int error = 5;
int servopin = 7;

DHT dht(DHTPIN, DHTTYPE);
float t, h;

// Voltage Reading
const int Analog_channel_pin = 18;
int ADC_VALUE = 0;
float voltage_value = 0.0;

// Manual Control Switch
bool manualControl = false;
```

```
// Blynk Manual Servo Control
BLYNK_WRITE(V0) {
  if (manualControl) {
    currentServoAngle = param.asInt();
    servo1.write(currentServoAngle);
    Blynk.virtualWrite(V1, currentServoAngle); // Update dashboard with live angle
  }
}

// BLYNK Switch for Manual Control
BLYNK_WRITE(V5) {
  manualControl = param.asInt();
}

// BLYNK DHT22 Values
void sendSensor() {
  h = dht.readHumidity();
  t = dht.readTemperature();
  Blynk.virtualWrite(V2, h);
  Blynk.virtualWrite(V3, t);
}

// Function to send voltage data to BLYNK
void sendVoltage() {
  ADC_VALUE = analogRead(Analog_channel_pin);
  voltage_value = (ADC_VALUE * 3.3) / 4095.0; // Convert ADC value to voltage

  char voltageStr[6]; // Buffer to hold the formatted voltage value
  dtostrf(voltage_value, 4, 2, voltageStr); // Convert float to string with 2 decimal
places

  Blynk.virtualWrite(V4, voltageStr); // Send formatted voltage value to BLYNK
}

void setup() {
  // BLYNK
  BlynkEdgent.begin();
  // LED Matrix
  Display.begin();
  Display.setIntensity(0);
  Display.displayClear();
  Display.displayScroll("solarlink", PA_RIGHT, PA_SCROLL_LEFT, 30);

  // Servo LDR
  servo1.attach(servopin);
  pinMode(LDR1, INPUT);
  pinMode(LDR2, INPUT);
```

```
  servo1.write(initial_servopos);
  delay(2000);

  dht.begin();

  timer.setInterval(1000L, sendSensor);
  timer.setInterval(1000L, sendVoltage); // Call sendVoltage every second
}

void loop() {
  if (!manualControl) {
    int R1 = analogRead(LDR1);  // read LDR 1 value
    int R2 = analogRead(LDR2);  // read LDR 2 value
    int a = abs(R1 - R2);       // calculate difference btwn LDRs
    int b = abs(R2 - R1);       // calculate difference btwn LDRs

    if ((a > error) || (b > error)) {
      if (R1 > R2) {
        currentServoAngle = max(0, --currentServoAngle);
      }
      if (R1 < R2) {
        currentServoAngle = min(180, ++currentServoAngle);
      }
      servo1.write(currentServoAngle);
      Blynk.virtualWrite(V1, currentServoAngle); // Update dashboard with live angle
    }
  }

  delay(100);

  BlynkEdgent.run();
  timer.run();
}
```

**IoT interface code:**

```
#define BLYNK_TEMPLATE_ID "TMPL3pso1sjhy"  //blynk Template ID
#define BLYNK_TEMPLATE_NAME "SolarTracker"  // Template Name
#define BLYNK_AUTH "ZyKx2oNK-KILLv0Pq4z1gLV5c9NMTvWB"  //copy your blynk
Authentication Code
#include <Servo.h>
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>

char ssid[] ="wifi"; // enter your WIFI Name
char pwd[] = "password"; //Enter your wifi Password


// horizontal servo
Servo horizontal;
int servoh = 90;

int servohLimitHigh = 180;
int servohLimitLow = 0;

Servo vertical;
int servov = 90;

int servovLimitHigh = 180;
int servovLimitLow = 0;


// LDR pin connections
int ldrTR = 33; // LDR top right
int ldrTL = 25; // LDR top left
int ldrBR = 26; // LDR bottom right
int ldrBL = 27; // LDR bottom left


void setup() {
  Serial.begin(9600);
  Blynk.begin(BLYNK_AUTH,ssid,pwd);
  // servo connections
  horizontal.attach(23);
  vertical.attach(32);
  // move servos
  horizontal.write(90);
  vertical.write(45);
  delay(3000);
}


void loop() {
```

```
Blynk.run();


 int tr = analogRead(ldrTR); // top right
 int tl = analogRead(ldrTL); // top left
 int br = analogRead(ldrBR); // bottom right
 int bl = analogRead(ldrBL); // bottom left

 int dtime = 0; // change for debugging only
 int tol = 50;

 int avt = (tl + tr) / 2; // average value top
 int avd = (bl + br) / 2; // average value bottom
 int avl = (tl + bl) / 2; // average value left
 int avr = (tr + br) / 2; // average value right

 int dvert = avt - avd;  // check the difference of up and down
 int dhoriz = avl - avr; // check the difference of left and right


 // send data to the serial monitor if desired
 Serial.print(tl);
 Serial.print(" ");
 Serial.print(tr);
 Serial.print(" ");
 Serial.print(bl);
 Serial.print(" ");
 Serial.print(br);
 Serial.print("  ");
 Serial.print(avt);
 Serial.print(" ");
 Serial.print(avd);
 Serial.print(" ");
 Serial.print(avl);
 Serial.print(" ");
 Serial.print(avr);
 Serial.print("  ");
 Serial.print(dtime);
 Serial.print("   ");
 Serial.print(tol);
 Serial.print("  ");
 Serial.print(servov);
 Serial.print("   ");
 Serial.print(servoh);
 Serial.println(" ");


 // check if the difference is in the tolerance else change vertical angle
```

```
  if (-1 * tol > dvert || dvert > tol) {
    if (avt > avd) {
      servov = ++servov;
      if (servov > servovLimitHigh) {
        servov = servovLimitHigh;
      }
    }
    else if (avt < avd) {
      servov = --servov;
      if (servov < servovLimitLow) {
        servov = servovLimitLow;
      }
    }
    vertical.write(servov);
  }

  // check if the difference is in the tolerance else change horizontal angle
  if (-1 * tol > dhoriz || dhoriz > tol) {
    if (avl > avr) {
      servoh = ++servoh;
      if (servoh < servohLimitLow) {
        servoh = servohLimitLow;
      }
    }
    else if (avl < avr) {
      servoh = --servoh;
      if (servoh > servohLimitHigh) {
        servoh = servohLimitHigh;
      }
    }
    else if (avl = avr) {
      // nothing
    }
    horizontal.write(servoh);
  }

  delay(dtime);

}
```