CSE2006 Microprocessor and Interfacing

Title : Sun Tracking Solar System Using Solar Angles

Vellore Institute of Technology
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1. Abstract:

Solar panels are widely used as a renewable energy source for generating electricity. Maximizing the efficiency of solar panels requires optimizing their orientation towards the sun to capture the maximum amount of sunlight. In this project, a sun tracking solar panel system based on the time of day of the year using azimuthal and zenith angles is proposed.

The system utilizes astrometric formulae to measure the azimuthal and zenith angles of the sun, which represent the horizontal and vertical angles between the sun and the solar panel, respectively. These angles are calculated based on the geographic location and time of day of the year. The azimuthal angle determines the panel's orientation in the east-west direction, while the zenith angle determines the panel's tilt angle in the vertical direction.

2. Introduction:

To achieve maximum solar energy capture, solar panels need to be aligned with the sun's position in the sky, which changes throughout the day and year due to the Earth's rotation and orbit. Fixed solar panels, which are typically set at a fixed tilt angle and orientation, may not always be perfectly aligned with the sun, resulting in suboptimal energy capture. This has led to the development of sun tracking solar panel systems that dynamically adjust the panel's orientation to track the sun's movement and maximize solar energy capture.

One approach to sun tracking is based on the azimuthal and zenith angles of the sun, which represent the horizontal and vertical angles between the sun and the solar panel, respectively. The azimuthal angle determines the panel's east-west orientation, while the zenith angle determines the panel's tilt angle in the vertical direction. By continuously monitoring and adjusting these angles, a solar panel can maintain an optimal orientation towards the sun, resulting in increased energy capture.

In this project, a sun tracking solar panel system based on the time of day of the year using azimuthal and zenith angles is proposed. The system incorporates mathematical logic to measure the azimuthal and zenith angles of the sun, and a microprocessor to process the data and control the movement of the solar panel with the help of servo motors. The system aims to optimize the solar panel's orientation in real-time to track the sun's movement and maximize solar energy capture. The performance of the system is evaluated through simulations and experiments to assess its effectiveness in improving solar panel efficiency. The findings of this study may contribute to the development of more efficient solar panel systems that can harness solar energy more effectively for electricity generation.

3. Motivation:

The motivation for choosing a sun tracking solar panel using astronomical equations is to maximize the amount of energy that the solar panel can generate. By continuously tracking the movement of the sun, the solar panel can be positioned to receive the maximum amount of sunlight possible throughout the day, which increases the energy output of the panel.

Sun tracking solar panels are designed to track the movement of the sun across the sky throughout the day. This is done by adjusting the angle and orientation of the solar panel to maximize the amount of sunlight that it receives. As the sun moves across the sky, the solar panel adjusts its position in real-time, ensuring that it is always directly facing the sun and receiving the maximum amount of solar radiation possible.

Astronomical equations are used to calculate the precise position of the sun based on the time of day and the location of the solar panel. These equations take into account factors such as the tilt of the Earth's axis and the curvature of the Earth's surface. By using these equations, the solar panel can be programmed to adjust its position with extreme precision, ensuring that it is always facing the sun directly and receiving maximum solar radiation.

One of the main advantages of using astronomical equations is that they are extremely accurate. While sensors and GPS can be affected by factors such as cloud cover or atmospheric conditions, astronomical equations are based on fundamental principles of astronomy and are not affected by these factors. This means that sun tracking solar panels that use astronomical equations can operate with a high degree of accuracy and reliability.

Another advantage of using sun tracking solar panels is that they can generate more energy than fixed solar panels. By tracking the movement of the sun, sun tracking solar panels can receive up to 40% more solar radiation than fixed solar panels that are angled towards the sun based on the latitude and season. This increased energy output can make sun tracking solar panels a more cost-effective option over the long term, as fewer panels may be needed to generate the same amount of energy.

In summary, the motivation for choosing sun tracking solar panels using astronomical equations is to increase the efficiency and effectiveness of solar energy systems. By tracking the movement of the sun with extreme precision, these panels can generate more energy and operate with a high degree of accuracy and reliability.

4. Related Work (Literature Review):

S.No.	Title	Authors	Methodology	Drawbacks
1.	Solar Tracking System - A Review	K, Rajan. (2016). Solar Tracking System - A Review. International Journal of Sustainable Engineering, 9(3), 177-190. doi: 10.1080/19397038.2016.1267816.	Provides a comprehensive review of various solar tracking systems, their types, and their advantages and disadvantages. The author discusses the different types of solar trackers, such as single-axis and dual-axis trackers, and their corresponding advantages and disadvantages. The article also covers the latest technologies used in solar tracking systems, including computer-based control systems, and discusses their potential benefits. They conclude that solar tracking systems can significantly improve the efficiency of solar energy systems, particularly in areas with high solar irradiance. However, the cost and complexity of these systems should be carefully considered before implementation.	Does not provide a detailed comparison of the performance and efficiency of different solar tracking systems. While the article describes the various types of solar trackers and their advantages and disadvantages, it does not provide specific data on their energy output or cost-effectiveness. Additionally, the article focuses primarily on the technical aspects of solar tracking systems and does not address other factors that may impact their feasibility, such as environmental considerations or local regulations. As such, readers interested in implementing solar tracking systems may need to seek additional information beyond what is provided in the article.
2.	A low-cost dual-axis solar tracking system based on digital logic design: Design and implementation.(2020)	Jamroen, C., Komkum, P., Kohsri, S., Himananto, W., Panupintu, S., & Unkat, S. (2020). A low-cost dual-axis solar tracking system based on digital logic design: Design and implementation. Sustainable Energy Technologies and Assessments, 37, 100618. doi:10.1016/j.seta.2019.100618	The paper discusses the design and implementation of the solar tracker, including the use of off-the-shelf components and the performance tests carried out to evaluate its accuracy and efficiency. Demonstrate the feasibility of developing a low-cost solar tracking system with high accuracy and potential for small-scale solar energy applications in remote or off-grid locations.	The experimental results were obtained under controlled laboratory conditions and may not be representative of real-world situations. Additionally, the article does not provide detailed information on the cost and availability of the components used in the system, which may limit its practicality in some locations. Finally, the paper does not compare the performance of the proposed system with other solar tracking systems, leaving readers with limited information to evaluate its advantages and disadvantages compared to other solutions..

3.	Review on sun tracking technology in solar PV system.	Awasthi, A., Shukla, A. K., S.R., M. M., Dondariya, C., Shukla, K. N., Porwal, D., & Richhariya, G. (2020). Review on sun tracking technology in solar PV system. Energy Reports, 6, 392–405. doi:10.1016/j.egyr.2020.02.004	The paper extensively reviews sun-tracking technologies for solar photovoltaic systems.It provides an overview of various sun-tracking systems and their performance analysis based on simulation and experimental results. Overall, the paper provides a comprehensive guide for selecting and designing sun tracking systems for solar PV applications.	the authors do not provide a critical evaluation of the literature reviewed, which may lead to bias in their conclusions. Additionally, the paper focuses mainly on technical aspects of sun tracking systems and does not consider other important factors that may influence their performance, such as environmental and economic factors. Finally, the paper does not provide a detailed analysis of the cost-effectiveness of different sun tracking systems, which may limit its usefulness for decision-makers and practitioners in the field.
4.	Performance evaluation of large solar photovoltaic power plants in Spain	Martín-Martínez, S., Cañas-Carretón, M., Honrubia-Escribano, A., & Gómez-Lázaro, E. (2017). Performance evaluation of large solar photovoltaic power plants in Spain. Renewable and Sustainable Energy Reviews, 80, 386-395. doi:10.1016/j.rser.2017.05.267	Evaluates the performance of large solar photovoltaic (PV) power plants in Spain based on the analysis of operational data from 2007 to 2014. The study provides a detailed analysis of the energy production, availability, and performance ratios of the solar PV plants, highlighting the impact of various factors such as weather conditions, plant location, and type of technology on their performance. The authors also provide recommendations for optimizing the performance of solar PV plants based on their findings. Overall, the paper provides valuable insights into the performance of large solar PV power plants, which can inform future developments and policy decisions in the field.	One potential drawback of the paper is that it focuses solely on the performance of large solar photovoltaic power plants in Spain, and thus its findings may not be generalizable to other countries or regions with different environmental, regulatory, and market conditions. Additionally, the study is based on a relatively short period of operational data, which may limit its ability to capture longer-term trends and variations in the performance of the solar PV plants. Finally, the paper does not provide a detailed cost-benefit analysis of the solar PV plants, which could be useful for decision-makers considering investment in this technology.
5.	A low-cost dual-axis solar tracking system based on digital logic design: Design and implementation.	AL-Rousan, N., Mat Isa, N. A., & Mat Desa, M. K. (2019). Efficient single and dual axis solar tracking system controllers based on adaptive neural fuzzy inference system. Renewable Energy,	Proposes an adaptive neural fuzzy inference system (ANFIS) approach for designing efficient controllers for single and dual-axis solar tracking systems. The ANFIS-based controllers are designed to adapt to different weather conditions and to optimize the energy output of the solar tracking systems. The authors demonstrate the effectiveness of	The proposed ANFIS-based controllers were evaluated only through simulation studies, and the authors did not provide any experimental results to support the effectiveness of their approach. Furthermore, the study was limited to a specific type of solar panel, and the proposed controllers may not

		135, 47-59. doi:10.1016/j.renene.2018.12.045.	their approach through simulation studies and show that the ANFIS-based controllers can outperform traditional controllers in terms of energy efficiency and tracking accuracy.	be applicable to other types of solar panels or solar tracking systems. Additionally, the paper does not address the cost-effectiveness of implementing ANFIS-based controllers compared to traditional controllers, which could be an important consideration for practical applications.

5. Description:

Azimuthal and Zenith angles are required to accurately estimate the position of the sun at a given time of the year in a given location. These angles are dependent on the latitude, longitude and the time. Hour angle and declination angles are required for the calculation.

The hour angle (h) is defined as the longitude of the sun, which is calculated as: t is the fractional GMT time

$$\boxed{h = -\frac{t - 12}{12}}$$

Solar declination angle is calculated as: where J is day of the year.

$$\boxed{\delta = -23.45\cos\left(\frac{2\pi J}{365} + \frac{20\pi}{365}\right)}$$

Solar zenith angle is calculated as : phi is the latitude of the place, h is hour angle

$$\boxed{\cos\theta_o = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos h}$$

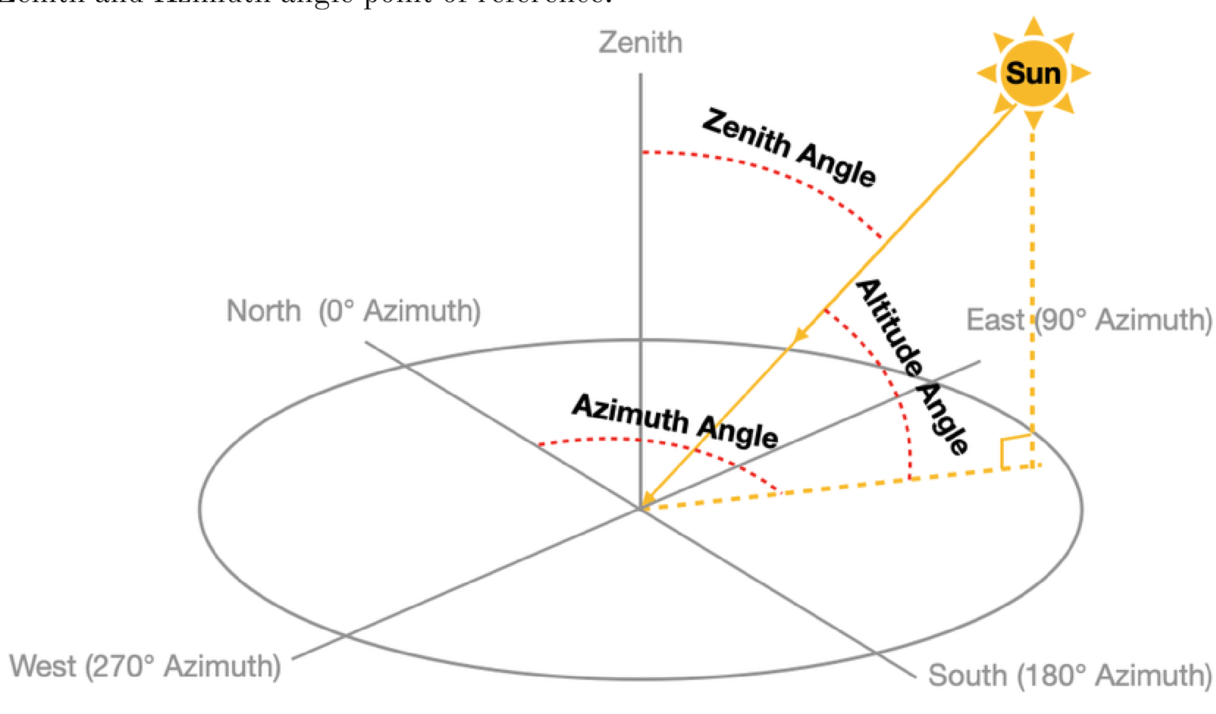
Solar azimuth angle is calculated as: where a is altitude angle, L is latitude, and D is declination angle.

$$\boxed{\cos(A) = \frac{[Sin(a) * \sin(L)] - \sin(D)}{\cos(a) * \cos(L)}}$$

altitude angle a is given as: L is latitude, D is declination angle, omega is the hour angle.

$$\boxed{\sin a = [\cos(L) * \cos(D)] * \cos(\omega)] + [\sin(L) * \sin(D)]}$$

Zenith and Azimuth angle point of reference:



6. Methodology:

Processes involved include:-

1. Input: The latitude and fractional GMT (Greenwich Mean Time) of the location where the solar panel system is installed.

2. Azimuthal and Zenith Angle Calculation: The program calculates the azimuthal and zenith angles using mathematical formulas based on the latitude and fractional GMT time. The zenith angle is determined by calculating the solar hour angle, which is the difference between the local solar time (based on fractional GMT time) and the solar noon time (which varies depending on the location's longitude). The azimuthal angle is calculated based on the latitude and the declination angle, which is the angle between the sun and the Earth's equatorial plane.

3. Register Storage: The calculated azimuthal and zenith angles are stored in registers or variables within the program for further processing. These angles represent the position of the sun relative to the solar panel and are used to determine the optimal orientation of the solar panel to maximize solar energy capture.

4. Conditional Statements for Pulse Width Variation: The program uses conditional statements to determine the pulse width of the control signal that will be sent to the servo motors. The pulse width is typically specified in milliseconds and determines the position of the servo motors, which are responsible for changing the orientation of the solar panel. The conditional statements take into account the calculated azimuthal and zenith angles to determine the appropriate pulse width for the servo motors.

5. Control Signal Transmission: The program sends the calculated pulse width through a control line to the servo motors. The servo motors receive the control signal and adjust their position accordingly to align the solar panel with the sun based on the azimuthal and zenith angles. The servo motors may be connected to mechanical mechanisms that adjust the tilt and orientation of the solar panel to track the sun's movement throughout the day and year.

6. Sun Tracking and Energy Capture: With the servo motors continuously adjusting the orientation of the solar panel based on the calculated azimuthal and zenith angles, the solar panel is able to effectively track the sun's movement and maintain optimal alignment for maximum solar energy capture. This allows the solar panel to capture more sunlight, resulting in increased energy generation compared to fixed solar panels that do not adjust their orientation.

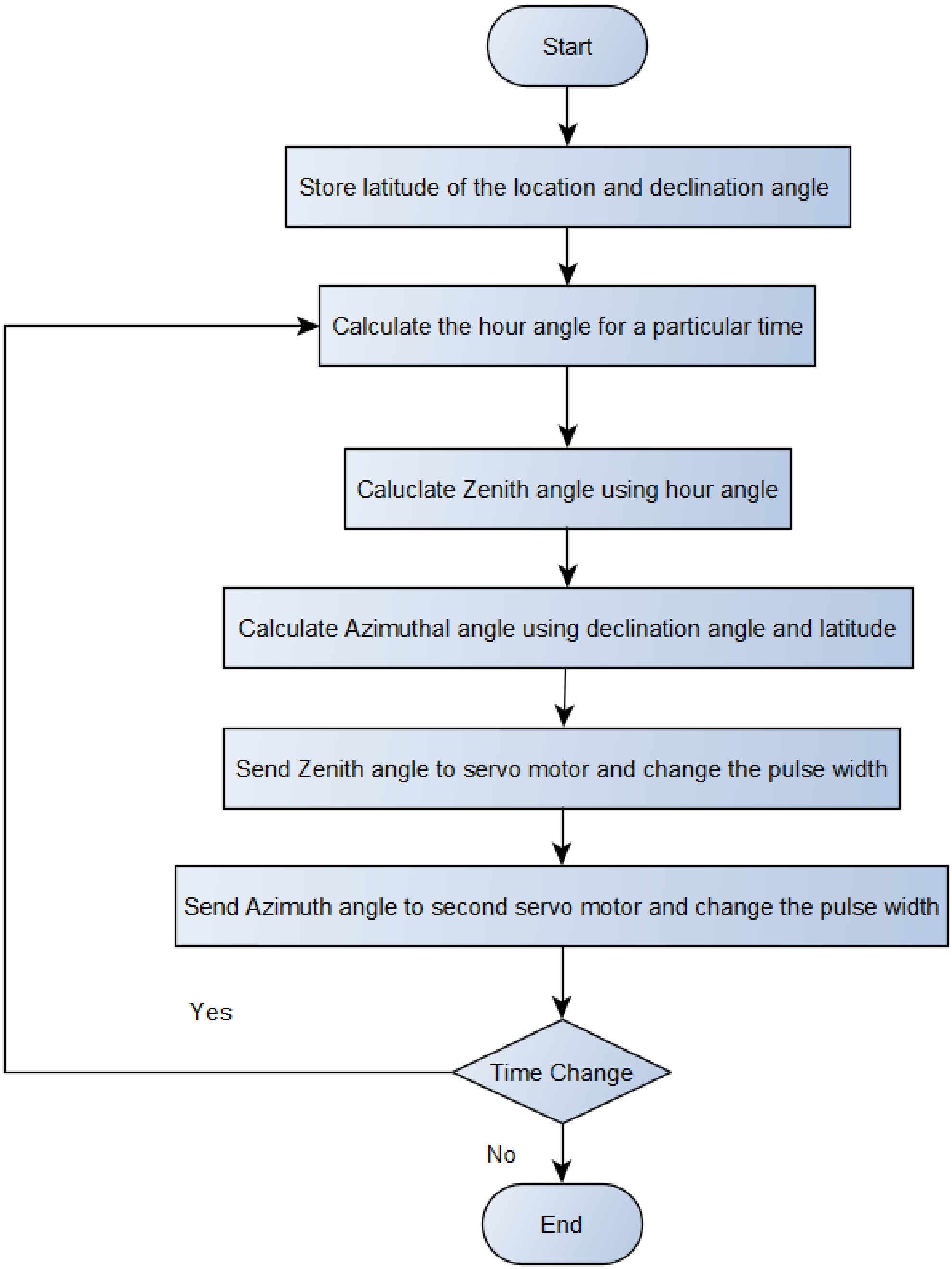
Overall, this methodology involves using input, mathematical calculations, register storage, conditional statements, and control signal transmission to dynamically adjust the orientation of a solar panel based on the time of day of the year using azimuthal and zenith angles. This enables the solar panel to effectively track the sun's movement and maximize solar energy capture, potentially improving the efficiency of the solar panel system.

Algorithm:

1. Initialize variables and constants.
    - Set the starting address of the program to 0x00.
    - Set the declination angle to 0x18.
    - Set the latitude to 0x0D.
2. Calculate the hour angle.
    - Load the current time into register R3.
    - Subtract 12 from the current time.
    - Divide the result by 12 and store the quotient in register R0.
3. Calculate the zenith angle.
    - Multiply the sine of latitude and declination angle and store the result in register R2.
    - Multiply the sine of current hour angle, declination angle, and sine of latitude and store the result in register R3.
    - Add the values in R2 and R3 and store the result in R2.
    - We get the zenith angle to 0x24.
4. Calculate the azimuthal angle.
    - Multiply the sin latitude and declination angle and store the result in register R2.
    - Multiply the cosine current hour angle and declination angle and store the result in register R4.
    - Add the values in R2 and R4 and store the result in R4.
    - We get the azimuthal angle to 0x46.
5. Move the servo motors to track the zenith angle position of the sun.
    - Load Timer 0 with mode 1.
    - Call the zero_degrees function to move the servo motors to the starting position.
    - Call the delay function to wait for 1 second.
    - Call the req function to move the servo motors to the zenith angle position of the sun.
    - Call the delay function to wait for 1 second.
    - Call the one_eighty_degrees function to move the servo motors to the opposite side.
    - Call the delay function to wait for 1 second.
    - Return from the main function.

6. Move the servo motors to track the azimuth angleposition of the sun.
    - Load Timer 0 with mode 1.
    - Call the zero_degrees1 function to move the servo motors to the starting position.
    - Call the delay1 function to wait for 1 second.
    - Call the req1 function to move the servo motors to the azimuthal angle position of the sun.
    - Call the delay1 function to wait for 1 second.
    - Call the one_eighty_degrees1 function to move the servo motors to the opposite side.
    - Call the delay1 function to wait for 1 second.
    - Return from the function.

Flowchart:


Start
Store latitude of the location and declination angle
Calculate the hour angle for a particular time
Caluclate Zenith angle using hour angle
Calculate Azimuthal angle using declination angle and latitude
Send Zenith angle to servo motor and change the pulse width
Send Azimuth angle to second servo motor and change the pulse width
Yes
Time Change
No
End

7. ALP Code:

```
ORG 00H //Start the program
;angles
MOV R1,#18H   ;DECLINATION ANGLE WHEN THE DAY OF YEAR IS 103
MOV R6,#24H  ;zenith angle of 36 degree with the perpendicular as the reference at 10am
MOV R7,#46H    ;Azimuthal angle of 70 degree from north as point of reference

;hour angle calc
MOV R3,#0CH
MOV A,R3
SUBB A,#0CH
MOV B,#0CH
DIV AB
MOV R0,A  ;hour angle

;zenith angle calculation
MOV R3,#0DH   ;LATITUDE 13 degree for vellore
MOV A,R3
MOV B,R1
MUL AB
MOV R2,A
MOV A,#0DH
MOV B,R1
MUL AB
MOV B,R0
MUL AB
MOV R3,A
MOV A,R2
ADD A,R3
MOV R2,A
JMP ZEN

;azimuthal angle calculation
MOV R3,#0DH
MOV A,R3
MOV B,R1
MUL AB
MOV B,R0
MUL AB
MOV R4,A
MOV A,#0DH
```

```
MOV B,R1
MUL AB
ADD A,R4
MOV R4,A
JMP AZI


;Code to move motor for zenith angle
;The motor moves from 0 degree (start of day)
;to the calculated angle at 10am
;to 180 degree at the end of the day
;and this is repeated in a loop
ZEN:
MOV TMOD, #01H ;using Timer 0 in Mode 1
LCALL zero_degrees ;Function to move to position = 0 deg
LCALL delay ;Function to create a delay of 1 sec
LCALL req ;Function to move to the zenith angle  position of sun
LCALL delay
LCALL one_eighty_degrees ;Function to move to position = 180 deg
LCALL delay ;Function to create a delay of 1 sec
RET

zero_degrees: //To create a pulse of 1ms
MOV TH0, #0FCH //(FFFF - 03E7 + 1)H = (FC19)H
MOV TL0, #19H //equal TO (1000)D = 1ms
SETB P2.0 ;Make P2.0 HIGH
SETB TR0 ;Start the timer 0
WAIT1:JNB TF0, WAIT1 ;Wait till the TF0 flag is set
CLR P2.0 ;Make P2.0 LOW
CLR TF0 ;Clear the flag manually
CLR TR0 ;Stop the timer 0
RET

;a pulse of 1.2ms is required to move the servo motor to the zenith angle
req: //To create a pulse of 1.2ms
MOV TH0, #0FBH //(FFFF - 04B0 + 1)H = (FB51)H
MOV TL0, #51H //equal TO (1200)D = 1.2ms
SETB P2.0 ;Make P2.0 HIGH
SETB TR0 ;Start the timer 0
WAIT2:JNB TF0, WAIT2 ;Wait till the TF0 flag is set
CLR P2.0 ;Make P2.0 LOW
CLR TF0 ;Clear the flag manually
CLR TR0 ;Stop the timer 0
```

```
RET
one_eighty_degrees: //To create a pulse of 2ms
MOV TH0, #0F8H //(FFFF - 07CF + 1)H = (F831)H
MOV TL0, #31H //equal to (2000)D = 2ms
SETB P2.0 ;Make P2.0 HIGH
SETB TR0 ;Start the timer 0
WAIT4:JNB TF0, WAIT4 ;Wait till the TF0 flag is set
CLR P2.0 ;Make P2.0 LOW
CLR TF0 ;Clear the flag manually
CLR TR0 ;Stop the timer 0
RET


delay: //To create a delay of 1sec
MOV R4,#64H ;100us * 100us * 100us = 1s
LOOP1:MOV R3,#64H
LOOP2:MOV R2,#64H
LOOP3:DJNZ R2,LOOP3
DJNZ R3,LOOP2
DJNZ R4,LOOP1


;Code to move motor for azimuth angle
;The motor moves from 0 degree (start of day)
;to the calculated angle for day 103
;to 180 degree at the end of the day
;and this is repeated in a loop
AZI:
MOV TMOD, #01H ;using Timer 0 in Mode 1

LCALL zero_degrees1 ;Function to move to position = 0 deg
LCALL delay1 ;Function to create a delay of 1 sec
LCALL req1  ;Function to move to the azimuth angle of sun
LCALL delay1
LCALL one_eighty_degrees1 ;Function to move to position = 180 deg
LCALL delay1 ;Function to create a delay of 1 sec
RET

zero_degrees1: //To create a pulse of 1ms
MOV TH0, #0FCH //(FFFF - 03E7 + 1)H = (FC19)H
```

```
MOV TL0, #19H //equal TO (1000)D = 1ms
SETB P2.1 ;Make P2.0 HIGH
SETB TR0 ;Start the timer 0
WAIT11:JNB TF0, WAIT11 ;Wait till the TF0 flag is set
CLR P2.1 ;Make P2.0 LOW
CLR TF0 ;Clear the flag manually
CLR TR0 ;Stop the timer 0
RET

;a pulse of 1.39ms is required to move the servo motor to the azimuth angle
req1: //To create a pulse of 1.39ms
MOV TH0, #0FAH //(FFFF - 056E + 1)H = (FA93)H
MOV TL0, #93H //equal TO (1390)D = 1.39ms
SETB P2.1 ;Make P2.0 HIGH
SETB TR0 ;Start the timer 0
WAIT22:JNB TF0, WAIT22 ;Wait till the TF0 flag is set
CLR P2.1 ;Make P2.0 LOW
CLR TF0 ;Clear the flag manually
CLR TR0 ;Stop the timer 0
RET
one_eighty_degrees1: //To create a pulse of 2ms
MOV TH0, #0F8H //(FFFF - 07CF + 1)H = (F831)H
MOV TL0, #31H //equal to (2000)D = 2ms
SETB P2.1 ;Make P2.0 HIGH
SETB TR0 ;Start the timer 0
WAIT44:JNB TF0, WAIT44 ;Wait till the TF0 flag is set
CLR P2.1 ;Make P2.0 LOW
CLR TF0 ;Clear the flag manually
CLR TR0 ;Stop the timer 0
RET


delay1: //To create a delay of 1sec
MOV R4,#64H ;100us * 100us * 100us = 1s
LOOP11:MOV R3,#64H
LOOP22:MOV R2,#64H
LOOP33:DJNZ R2,LOOP33
DJNZ R3,LOOP22
DJNZ R4,LOOP11
RET

END
```

8. Results:

Criteria	**Sun Tracking Solar Panel**	**LDR-Based Solar Panel**
Energy Capture	Captures maximum sunlight by continuously adjusting orientation to face the sun	Relies on light intensity falling on LDR, which may vary due to shading and other environmental factors
Efficiency	Operates at higher efficiency levels due to optimal alignment with the sun	May experience reduced efficiency due to changes in light intensity and shading effects on LDR
Flexibility and Adaptability	Adaptable to different geographical locations and time of day/year based on latitude and fractional GMT time	Relies solely on light intensity falling on LDR, less adaptable to changing conditions

Potential for Higher Output	Higher energy output due to increased sunlight capture and higher efficiency	Lower energy output compared to sun tracking panels
Cost	Typically more complex and expensive, requiring additional sensors, microcontrollers, and servo motors	Relatively simpler and more cost-effective
Maintenance	May require maintenance of servo motors and other tracking components	Generally low maintenance
Operational Expenses	Higher operational expenses due to complexity and additional components	Lower operational expenses
Return on Investment	Potential for higher returns over the long term due to increased energy generation	Lower returns compared to sun tracking panels

In conclusion, sun tracking solar panels based on azimuthal and zenith angles offer several advantages over traditional LDR-based solar panels. They have the potential to capture more sunlight, operate at higher efficiency, and adapt to changing solar conditions based on the latitude and time of day/year. However, they are typically more complex and expensive, requiring additional components and maintenance. On the other hand, LDR-based solar panels are simpler and more cost-effective, but may have limitations in terms of adaptability and efficiency.

Link:https://drive.google.com/drive/folders/1ciEc8tA6GhYxA7dlHBZz42NEVA4yMiAw

9. Conclusion:

In conclusion, sun tracking solar panels based on azimuthal and zenith angles offer significant advantages in terms of energy capture, efficiency, and adaptability. By continuously adjusting their orientation to face the sun, these panels can optimize the angle of incidence and capture maximum sunlight throughout the day and year. This results in higher energy generation and potential for increased efficiency compared to traditional fixed solar panels.

Furthermore, sun tracking solar panels can be customized to specific geographical locations by considering the latitude and time of day/year, allowing for optimal performance based on local solar conditions. While they may be more complex and expensive compared to other solar panel technologies, the potential for higher energy output and efficiency can lead to improved returns on investment over the long term.

Overall, sun tracking solar panels based on azimuthal and zenith angles offer a promising solution for maximizing solar energy capture and efficiency, particularly in locations with varying solar conditions. Proper evaluation and analysis of project requirements and constraints are crucial in determining the most appropriate solar panel system for a specific application.

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