Autonomous Solar Panel System with Dual Axis Rotation

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***Abstract*: Conventional solar panels are generally based on either fixed axis or single axis because of which solar energy is not optimally converted into electrical energy. To overcome this issue dual axis solar panels can be implemented which can track sun position throughout the day as well as throughout the year based on sensors or sensor less. Sensor based sun position tracking can cause unnecessary rotations during rainy or cloudy days and may lead to wastage of power for rotating the panel. Sensor less tracking can be the solution for all these issues. Also, for easier installation of the system, we have developed an Android application that interfaces with the microcontroller. Our project, Autonomous Solar Panel includes sensor less solar tracking.**

***Keywords*: Solar tracker, Dual axis, Azimuth angle, Zenith angle, Android application, Charge controller circuit.**

1. Introduction

The major issue today's world is facing is increase in the demand of energy and failing to fulfill it. This has led to the increase of energy crisis. To overcome this issue, renewable energy technology is the optimum solution. Sun is the prime source of the energy. Numerous operations are carried out using solar energy. In domestic level applications the solar energy is converted into electrical energy and is used to operate different appliances like heating water, to power electrical devices like bulb, tube light etc. There are main three types of solar tracker: Fixed axis, single axis and dual axis. A fixed axis solar panel positions the modules at a fixed tilt and orientation, while solar tracker systems automatically adjust the positions of the solar panel so that they consistently track the sun throughout the day. Compared to fixed-tilt systems, single or dual-axis tracking systems help to increase the energy production for the same size array.

Single-axis trackers are the most common tracking systems installed today. Although single-axis trackers can increase total energy production by 10-15% above a fixed-axis tracker, fixed-axis trackers are more cost-effective. In addition, the solar energy is not completely utilized in case of both single & fixed axis solar panels. Sun path keeps on changing throughout the day & year. Hence some amount of solar energy gets wasted in current solar panel systems.

In this paper, we have implemented an improved overall system which precisely tracks the sun position throughout the day & increases output efficiency of the system.

2. Literature Review

The papers named as "*Auto Solar Tracking*" [1] and "*Design and Construction of Automatic Solar Tracking*" [2] are based on the principle of sensor based solar tracking, first paper includes use of six light dependent resistors and second one includes use of two photo resistors. In both the cases, the difference between outputs given by photo resistors is calculated by microcontroller and motors are rotated by certain amount of degree as per the decision of microcontroller.

The paper named as "*Sensor less Solar Tracker Based on Sun Position for Maximum Energy Conversion*" [3] includes sensor less sun tracking. The data of sunrise and sunset is stored. Latitude and longitude are calculated by using linear interpolation equations used. The paper named as "*Sun Position Algorithm for Sun Tracking Applications*" [4], includes various equations based on longitude, latitude, time zone, etc. Calculated azimuth angle, elevation angle are used for further decision to rotate the panel. Result includes 0.22 degree difference in azimuth angle and 0.4 degree difference in elevation angle.

The paper named "*Comparison of Solar Trackers and Application of a Sensor less Dual Axis Solar Tracker"* [5] gives us information about how dual axis solar tracking is better than fixed & single axis systems. The paper also states that sensor less trackers are more efficient than trackers that use sensors. Sensor less tracking helps to increase the overall efficiency & reduces the cost of system.

The paper "*A review of solar tracker patents in Spain*" [6] gives us insight about how dual axis solar trackers are beneficial compared to fixed & single axis solar trackers. It also talks about the development in solar trackers happening in Spain.

3. Proposed methodology and Operating principle

A. Mechanical Model

Assembling the mechanical system is the most challenging part of this system because the objective is to make an energy efficient solar tracking system which demands minimum power consumption of motors. One of these motors is used for horizontal tracking (east-west motion) and other for making a vertical tracking (north-south motion) as it is a dual axis tracker system.

B. Solar Tracking System

In this design we are implementing dual axis tracking system. The microcontroller used here is *STM32f103C*. The main advantage of STM32 over any other microcontroller is its hardware compatibility with other MCU of different. *Arduino Uno* which is commonly used for these kinds of projects can execute code only 16 MIPS (Million Instructions Per Cycle) while STM32 series can execute code up to 32 MIPS. We have also designed charge controller circuit to increase the life span of the battery by protecting it from getting overcharged by solar arrays and over discharged by the heavy load. There is also a motor driver circuit for speed and direction control of two DC motors. Information about every individual module of the system is given below:

- *Bluetooth Application:*

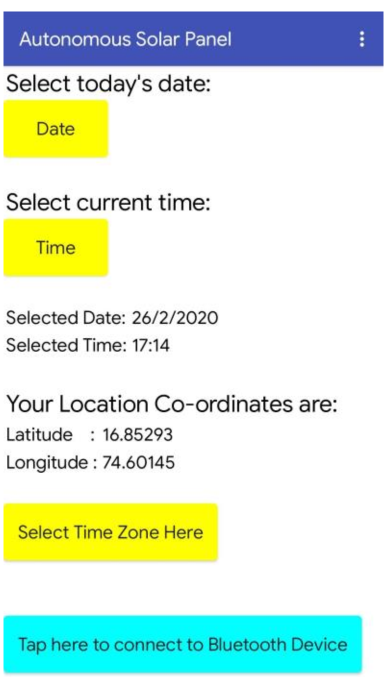

Fig. 1. Android Application

Bluetooth application is created using "MIT app inventor" app development platform. In this we take latitude and longitude of the given position using different modules. We have latitude, longitude, date and time as an input to the microcontroller STM32. The name of this application is ASP (Autonomous Solar Panel).

As shown in Fig. 1, this application lets user input the required values in order to initiate the system. Date, Time, Longitude, Latitude, & Time zone are inputted and these values and are then sent to microcontroller via Bluetooth.

- *HC-05 & STM32 Interfacing*

A Bluetooth module HC-05 is used for communication between Android application and STM32 microcontroller. First, we select date, time and time zone on the app. Latitude and longitude is calculated automatically based on the GPS of the Smartphone. Then these values are given as input to the STM32 microcontroller through HC-05 module. These values are given as a user defined input in the code through the STM32.

- *Motor Driver Circuit*

L298N Motor Driver IC is a 15-lead high voltage, high current Motor Driver IC with two full H-bridge drivers. The logic levels of L298N IC are compatible with standard TTL and IC can be used to drive different inductive loads like DC Motors, Stepper Motors, Relay, etc. Here we are using two 12V DC worm geared motors. The output of the STM32 microcontroller is given as the input to L289N IC. This rotates the motors as per the given input in horizontal and vertical direction respectively.

- *Charge Controller Circuit*

It protects the battery from being overcharged. The solar charge controller monitors the voltage of the battery and when the battery voltage reaches to the certain level it opens the circuit and the charging of the battery from the panels gets stopped. It also blocks the reverse current from flowing back to the solar panels, during night when there is no sunlight. The solar charge controller detects when no energy is coming from the solar panels, it opens the circuit and disconnects the batteries from the panels hence avoids the reverse flow of the current.

C. Angle calculation

The crux part of the project is its code and the equations of various aspects of the sun. The programming language we are using here is C language and the platform to compile and execute the code is Arduino IDE. There are various properties of sun which should be considered while building a solar tracker. With the help of these properties we get equations through which we are able to rotate the panel in dual axis according to the position of the sun. The equations that we have used in the code are given below:

- *Local Solar Time (LST)*

Twelve noon local solar time (LST) is defined as when the sun is highest in the sky. Local time (LT) usually varies from LST because of the eccentricity of the Earth's orbit, and because of human adjustments such as time zones and daylight saving.

- *Local Standard Time Meridian (LSTM)*

The Local Standard Time Meridian (LSTM) is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time. The LSTM is illustrated below (1).

The (LSTM) is calculated according to the equation:

$$LSTM=15°\Delta T_{UTC} \quad (1)$$

Where ΔT_{UTC} is the difference of the Local Time (LT) from Universal Coordinated Time (UTC) in hours. ΔT_{UTC} is also equal to the time zone. 15°= 360°/24 hours. For instance, Sydney Australia is UTC +10.

- *Equation of Time (EoT):*

The equation of time (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit & the Earth's axial tilt. Approximate accuracy within ½ minute is:

$$EoT = 9.87sin(2B) - 7.53cos(B) - 1.5sin(B) \quad (2)$$

Where, $B=360/365(d-81)$ in degree and *d* is the number of days since the start of the year.

- *Time Correction Factor(TC)*

The net Time Correction Factor (in minutes) accounts for the variation of the Local Solar Time (LST) within a given time zone due to the longitude variations within the time zone and also incorporates the EoT above (3).

$$TC= 4\ (Longitude - LSTM) + EOT \quad (3)$$

The factor of 4 minutes comes from the fact that the Earth rotates 1° every 4 minutes.

- *Local Solar Time (LST)*

The Local Solar Time (LST) can be found by using the previous two corrections to adjust the local time (LT) (4).

$$LST = LT + (TC/60) \quad (4)$$

- *Hour Angle (HRA)*

The Hour Angle converts the local solar time (LST) into the number of degrees which the sun moves across the sky. By definition, the Hour Angle is 0° at solar noon. Since the Earth rotates 15° per hour, each hour away from solar noon corresponds to an angular motion of the sun in the sky of 15°. In the morning the hour angle is negative, in the afternoon the hour angle is positive (5).

$$HRA= 15°\ (LST-12) \quad (5)$$

- *Declination angle (DA)*

The declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0° (6).

$$DA = 23.45°*sin\ (360*(d+284)/365)) \quad (6)$$

- *Elevation angle*

The elevation angle (used interchangeably with altitude angle) is the angular height of the sun in the sky measured from the horizontal. Confusingly, both altitude and elevation are also used to describe the height in meters above sea level. The elevation is 0° at sunrise and 90° when the sun is directly overhead (which occurs for example at the equator on the spring and fall equinoxes) (7).

$$e=(1/sin(sin(da)*sin(t)+cos(da)*cos(t)*cos(h))) \quad (7)$$

- *Zenith Angle*

The zenith angle is the angle between the sun and the vertical. The zenith angle is similar to the elevation angle but it is measured from the vertical rather than from the horizontal, thus making the zenith angle = 90° - elevation (8).

$$z=90-e \quad (8)$$

- *Sunrise (SR) and Sunset (SS):*

$$sr=12-(1/15°)*(1/cos(-tan(t)*tan(da)))-(tc/60) \quad (9)$$
$$ss=12+(1/15°)*(1/cos(-tan(t)*tan(da)))-(tc/60) \quad (10)$$

- *Azimuth angle*

The azimuth angle is the compass direction from which the sunlight is coming. At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day as shown in the animation below. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles 90° at sunrise and 270° at sunset. In general, however, the azimuth angle varies with the latitude and time of year and the full equations to calculate the sun's position (11).

$$A=(1/cos((sin(da)*cos(t)*-cos(da)*sin(t)*cos(h))/cos(e))) \quad (11)$$

D. Algorithm

1) Start
2) Input variables through mobile application, the variables are Latitude, Longitude, Time, Date, and Time zone.
3) Calculation of various values based on input variables.
4) Store the output values obtained from mathematical equations of azimuth angle, elevation angle, sunset time.
5) Calculate Azimuth and Elevation angles after certain delay.
6) Rotate the motors as per calculated angles with the help of

gyroscope.
7) After sunset, rotate the panel to home position.
8) Calculate sunrise time of next day and calculate all possible azimuth and elevation angles of next day and store them.
9) Compare Real Time Clock value with calculated Sunrise Time until they match and after matching set the panel as per calculated angles.
10) Repeat the step number 7, 8 & 9.
11) End.

E. Mechanical Assembly

The solar panel will be fixed in a frame which is attached to the rotatable shaft. The shaft is connected with the geared DC motor. Fig. 2 represents the position of solar panel during day time.

As shown in Fig. 3, when motor A is ON, the shaft rotates and that makes the solar panel to rotate according to the given Azimuth angle. Motor B rotates that makes the solar panel to rotate according to the Elevation angle. The panel frame is fixed with the shaft which is fixed on Motor B (Fig. 3) using ball bearings in order to make the rotation smooth and free.

Fig. 2. Hardware implementation of autonomous solar panel

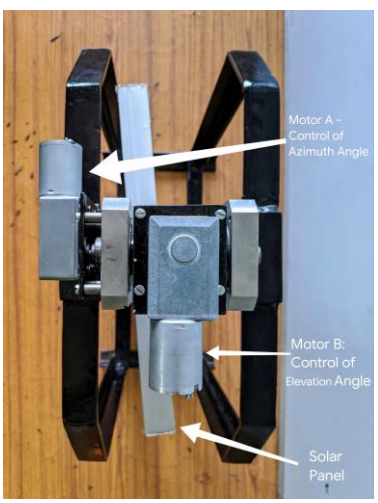

Fig. 3. Arrangement of motors for dual axis movement

Fig. 4. Worm gear DC motor

As the DC motors that are used have worm gear, the shaft automatically gets locks when no supply is given to motors. This ensures the panel is on its correct position even when supply is cut off (Fig. 4).

4. Results and Discussion

The proposed method of & implementation presents an efficient system to harness solar energy which ensures 25.9% more energy conversion than the existing static solar module system (Table 1). The hardware implementation of the Autonomous Solar Panel is shown in Fig. 2, 3.

Table 1
Observation of fixed & dual axis solar panel systems

Time (Hour)	Fixed Axis			Dual Axis		
	Voltage (V)	Current (A)	Power (Watt)	Voltage (V)	Current (A)	Power (Watt)
6:00	8.0	0.0	0.0	8.2	0.0	0.0
7:00	11.2	0.376	4.222	16.7	0.38	6.58
8:00	19.6	0.41	6.18	20.8	0.362	7.548
9:00	21.1	0.357	7.545	21.8	0.386	8.418
10:00	21.0	0.401	8.433	21.4	0.431	9.213
11:00	21.6	0.43	9.288	21.9	0.50	10.95
12:00	21.4	0.46	9.844	21.6	0.53	11.44
13:00	21.3	0.43	9.159	21.3	0.51	10.86
14:00	21.5	0.39	8.385	21.6	0.47	10.15
15:00	21.0	0.29	6.09	21.3	0.38	8.094
16:00	21.7	0.21	4.557	22.3	0.36	8.028
17:00	21.4	0.20	4.28	21.9	0.31	6.789
18:00	12.3	0.0	0.0	12.3	0.0	0.0

The proposed system consists of a less complicated control circuit which is supplied with the output of solar tracking algorithm and based upon these inputs it controls the operation of the geared motors. As worm geared DC motors are used, no power is consumed while holding the solar panel at a stationary position. The circuit consumes less power and is easy to implement with readily available electronic components. The experimental validation of the proposed system energy conversion over fixed system is shown in Fig. 4.

By observing the outputs from Table 1, we get to know that between fixed & dual axis solar panel systems, the output voltage is having less difference than that of output current of the system. In dual axis solar panels system, output current is consistently greater than the fixed system by a higher margin which further leads to greater power output of the system.

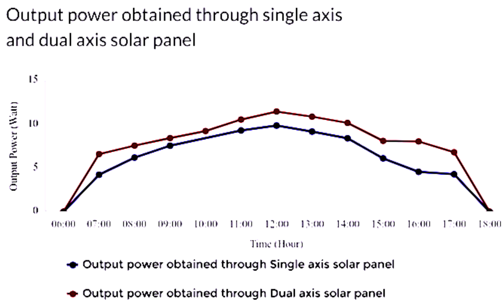

Fig. 5. Comparative graphs of output power obtained from fixed & dual axis solar panels throughout the day

5. Conclusion

With the help of optimized algorithm and use of proper mechanical structure, the proposed dual axis solar panel system ensures to increase the solar energy conversion efficiency by 25.9% compared to the fixed axis solar panel systems. Also it is easier to setup the solar panel system even by the end consumer thanks to the Android Application & the microcontroller system.

This system can be further modified according the required solar panel size while keeping the principle of working unchanged.

References

[1] Rana Liaqat Ali, Muhammad Faheem Khan "Automatic sun tracking system", Air University, Islamabad, Pakistan, May 2005.

[2] Md. Tanvir Arafat Khan, S.M. Shahrear Tanzil, Rifat Rahman, S M Shafiul Alam, "Design and Construction of an Automatic Solar Tracking System", International Conference on Electrical and Computer Engineering, ICECE 2010.

[3] Syafii Ghazali, Refdinal Nazir, Muhammad Hadi Putra, and Kamsory, "Sensorless Solar Tracker Based on Sun Position for Maximum Energy Conversion". The International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2015), Palembang, Indonesia.

[4] Arslan A. Rizvi, Khaled Addoweesh, Abdelrehman El-Leathy, Hany Al-Ansary, "Sun position algorithm for sun tracking applications", IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society, Nov. 2014.

[5] Ceyda Aksoy, Cenk Yavuz, "Comparison of Solar Trackers and Application of a Sensorless Dual Axis Solar Tracker", Journal of Power and Energy Engineering, June 2015.

[6] Francisco Javier Gómez-Gil, Miguel De Simón-Martín, Jesús Peláez-Vara, Justo Ruiz-Calvo, "A review of solar tracker patents in Spain", 3rd International Conference on Renewable Energy Sources, At Santa Cruz de Tenerife (Spain), vol. 2. pp.: 292-297, 2009.