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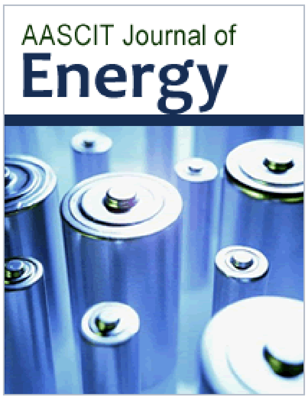

Performance Test of Two-Axis Solar Tracker System with Distinct Tracking Strategies

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Abstract
Unstable electricity generation in Iraq motivates the researchers to employ the eco-friendly energy as one of the most reliable and effective solutions to meet the increased electricity demand. On the other hand, the decreasing in fossil fuel resources and its environmental effect on the earth is another crucial reason. Solar energy gained more attention in the current decade due to endless power production that depends on the sun. This paper presents a two-axis solar tracking system to ensure maximum extraction of energy from the sun. An automatic two-axis solar tracking system developed using Arduino UNO controller based on sun-earth geometrical relationships and DC motors with gearbox arrangement on a mechanical structure. Set of four LDR (Light Dependent Resistor) used to grip maximum sunlight and to trim the azimuth and altitude angles as well. The results show that the automatic two-axis solar tracking system is more efficient than a fixed angle system.

1. Introduction

There is a necessity to obtain high levels of solar energy to increase the reliance on renewable energy seriously to reduce the dependence on energy generated from the burning of fossil fuels. To extract maximum power from the sunlight, the solar tracker system is used to follow the path of the sun, which leads to maintain the PV panel perpendicular to the sunlight during daylight time.

Many of sun tracking studies carried out to test the performance of the solar tracking system with several types of tracking strategies including open and closed loop method. For open loop system, the motion of the sun is tracked via geometric formulas that relate the position of the sun with respect to earth; or via forecasting of the sun paths. However, this automated tracking system stays running without any feedback signal from the light of sun; which means the accuracy of the sun position depends on the algorithm that the system based on. Otherwise, for closed loop method, the tracking system senses directly the radiation of sun by a certain light sensor. Photosensor or light sensor are as a feedback signal to the system; the feedback signal from the sun's light sensor ensures that the PV panel is always at the right angle to sun's rays. The closed-loop tracking mechanism has lower tracking accuracy error than open loop mechanism. Nevertheless, a closed-loop tracking mechanism is not reliable under dusty or cloudy climates [1]-[5].

In this work, an intelligent automatic closed loop dual-axis solar tracking system prototype with a sun-location tracker mechanism and wireless supervisory PC program is achieved. The tracking system consists of Arduino UNO as a controller, LDR modules as a light sensor, gearbox arrangement, PV panel as a solar collector and plastic box covered with tin foil to protect the control circuit. If the weather is cloudy or dusty with no light to sense, the tracker continues track the sun path based on sun - earth geometry. This system is designed to follow the path of the sun whatever the weather condition was. The experiments show that the power generated by the proposed tracking system is increased in the overall of about 10% ~ 40% more than a fixed angle system in general.

2. System Working Essentials

A-Methodology

To track the position of the sun speedily, the Arduino UNO controller should first calculate the theoretical altitude and azimuth angles as shown in Figure 1 as a rough adjustment of the automatic tracking mechanism through following equations:

$$\text{Altitude} = \sin^{-1}(\sin\delta\ \sin\emptyset + \cos\delta\ \cos\emptyset\ \cos\omega) \qquad (1)$$

$$\text{Azimuth} = \cos^{-1}[(\sin\delta\ \cos\emptyset - \cos\delta\ \sin\emptyset\ \cos\omega)/\cos Altitude] \qquad (2)$$

Where: δ: Declination angle, $\emptyset$: Local latitude, ω : Hour angle

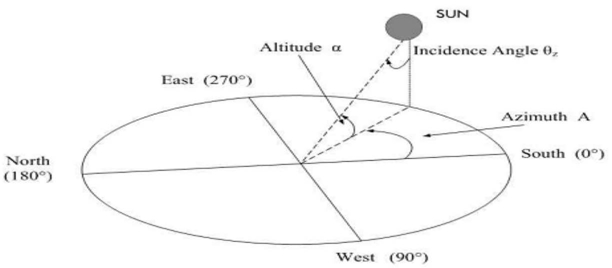

Figure 1. *Azimuth and Altitude angles. [7]*

The theoretical value of altitude and azimuth angles that come from sun-earth relationships are translated into digital commands for driving DC motors to the corresponding position. Then, the system automatically trims the altitude and azimuth angle of the PV panel according to the feedback signal of the proposed LDR sensor module. The sunlight sensor module consists of four LDR-sensors. Two angles sensors are placed on outlet shafts of altitude and azimuth angles for measuring the final value of altitude and azimuth angles and transmitting these values to the supervisory computer user interface [6],[7]. The tracking system is able to track the position of the sun regardless the intervention of LDR sensor module and it is also able to work regardless the intervention of sun-earth relationships so, it is reliable under several weather conditions.

B-Control circuit

The main control circuit components are Arduino UNO controller, H-bridge driving circuit, LDR, angle sensor, real time clock (RTC), HC-05 Bluetooth module and two geared DC motors as shown in Figure 2.

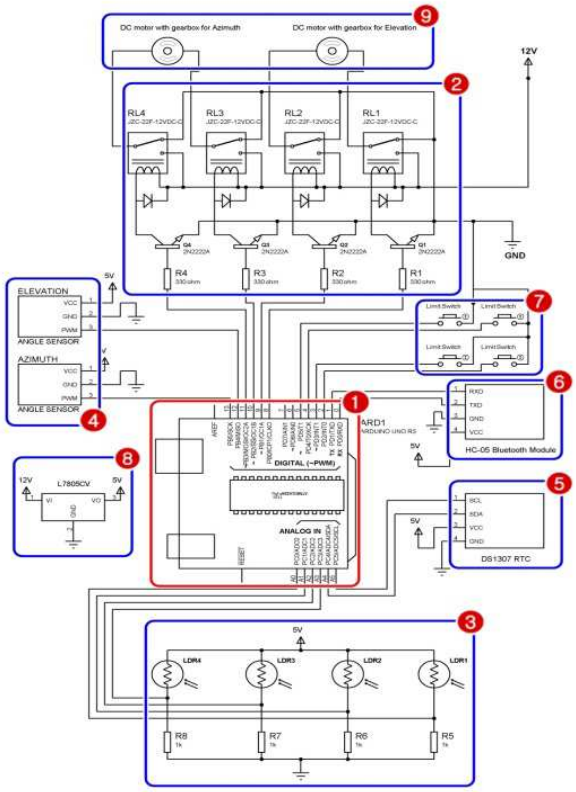

Figure 2. *The circuit diagram with borders.*

1- Arduino Uno Platform, 2-The H-Bridge circuit,3- The sunlight sensing circuit, 4- The Angle Sensor (Rotary Encoder), 5-Timing Circuit (Tiny Real Time Clock), 6- HC-05 Bluetooth to Serial Port Module ,7-Limit Switches,8-Voltage Regulator, 9- DC motor with gearbox

C- Software

The software parts comprises of a programming language that formulated using C programming. Arduino UNO controller uploaded with codes after compiling them. The execution steps of the software shown in flowchart, Figure 3 [8].

3. Tracking System Realization and Testing

Two-axis sun position tracker means that the tracker is able to move in two directions simultaneously; up-down direction or altitude angle and left-right direction or azimuth angle. The mechanism as shown in Figure 4 is composed of an aluminum frame that hold the PV panel, LDR sensor module and two DC motors with its gearbox to attain the desired angles. Two limits switches place on the azimuth and altitude output shafts to restrict the rotation of output shafts at pre-calculated values. These switches used as an input signals to the microcontroller to identify the home position of the tracker.

The actual daily behavior of azimuth and altitude angles is shown in Figure 5, where the sunrise is at 0^o altitude and 94.68^o azimuth, so the sunrise starts from the earth's northern half, and the sun stays at that part almost for an hour and a half in the morning and the same in the evening.

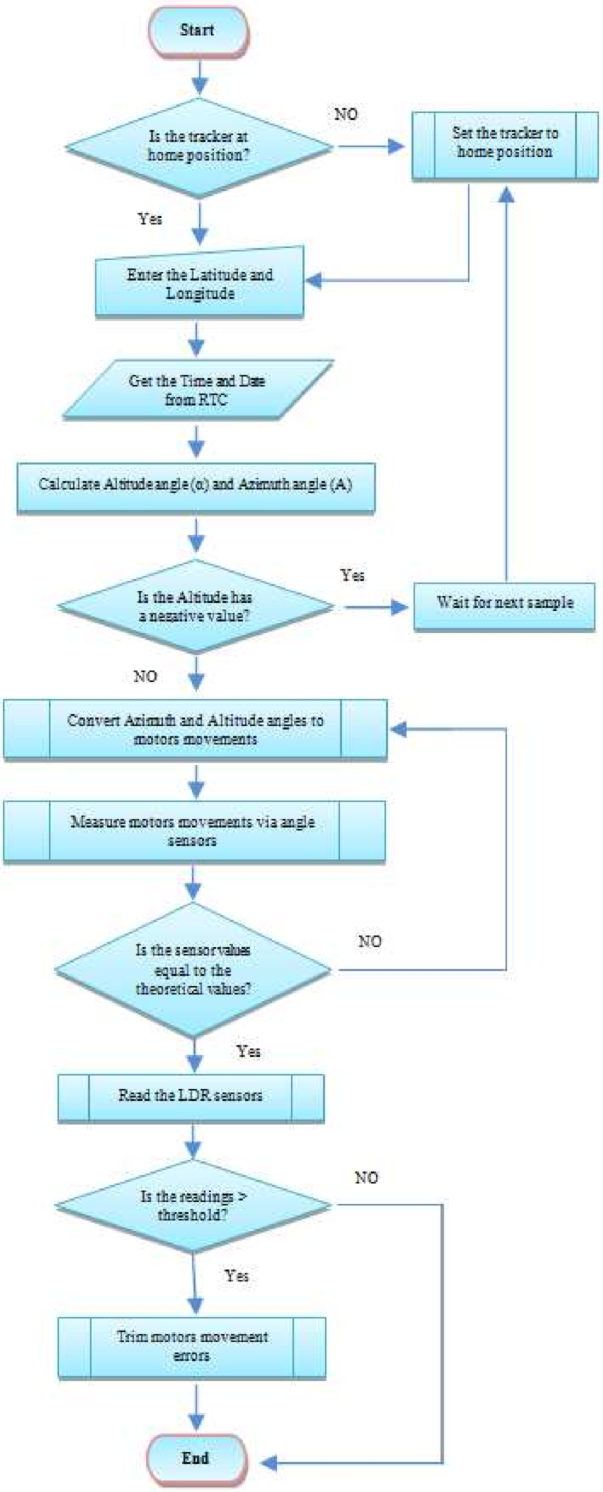

Figure 3. *Flowchart of sun tracking algorithm.*

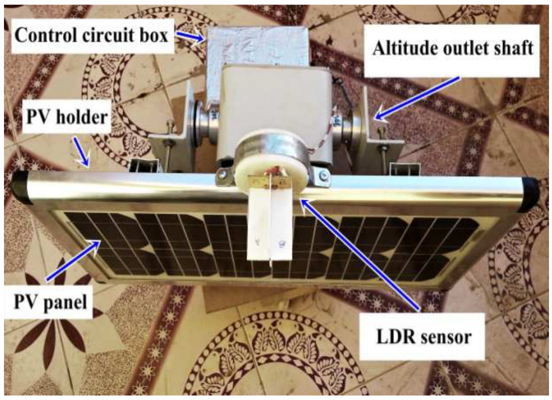

Figure 4. *Tracking system mechanism.*

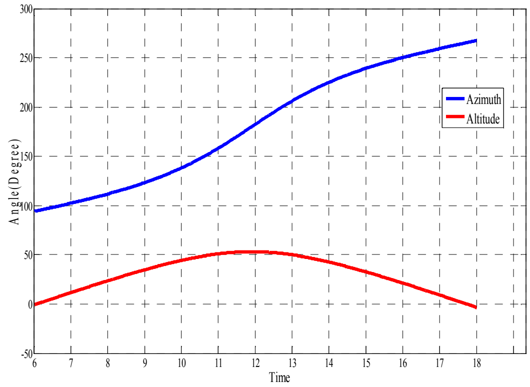

Figure 5. *Azimuth-altitude relationship with daylight time (hour) for the tracking system.*

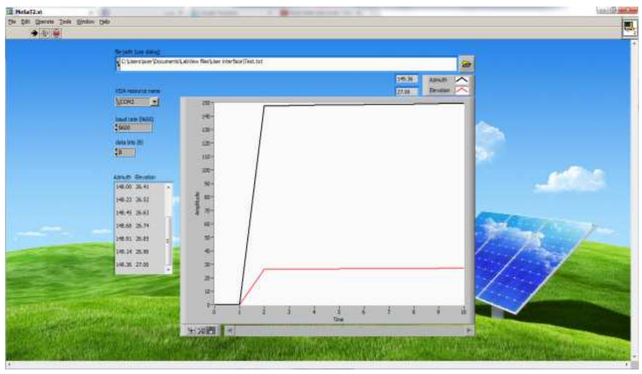

Figure 6. *Measured data of azimuth and altitude angles.*

The two curves continue to rise till noon; then the azimuth angle increases quickly, shortly before midday, while the altitude angle slows at that range. The altitude curve is symmetric about noon time while the azimuth curve is negative symmetric about noon time. After noon point, the altitude angle values start to decrease gradually with the same rate in which it reaches the noontime. During that time, the azimuth angle keeps on increasing as time is going on.

Two angles sensors or rotary encoders are attached to the tracker to ensure that the system is at a right position. The angle sensor readings are fed into Arduino Uno controller to check whether the specified position is reached. Sun-Earth algorithm results in two theoretical angles (azimuth and altitude) every minute, Arduino Uno controller converts these theoretical angles into digital commands to drive the motors to the particular position. Table 1 clarifies the readings of angles sensor at sample of time versus theoretical angles that come from sun-earth geometry.

***Table 1.** Angles sensor readings versus theoretical angles.*

Azimuth	Altitude	Azimuth Angle Sensor	Altitude Angle Sensor
182.85	53.15	182.90	53.20
183.26	53.14	183.30	53.19
183.68	53.12	183.70	53.20
184.09	53.11	184.10	53.18
184.51	53.09	184.62	53.11
184.92	53.08	185.03	53.10
185.34	53.06	185.36	53.08
186.16	53.02	186.20	53.04
186.58	52.99	186.61	53.00
186.99	52.97	186.11	53.00
187.40	52.94	187.53	52.98
187.81	52.91	187.96	52.96
188.22	52.88	188.35	52.91
188.63	52.85	188.70	52.87
189.04	52.82	189.11	52.85
189.45	52.79	189.55	52.8
189.86	52.75	189.94	52.78
190.27	52.72	190.15	52.74
190.67	52.68	190.73	52.70
191.08	52.64	191.27	52.67
191.48	52.6	191.66	52.62
191.89	52.55	191.97	52.58
192.29	52.51	192.46	52.53
192.69	52.46	192.75	52.50
193.10	52.42	193.53	52.46
193.50	52.37	193.71	52.41
193.90	52.32	194.00	52.38
194.30	52.27	194.70	52.33
194.69	52.22	195.10	52.29
195.09	52.16	195.85	52.04

When looking at the table above, it is obvious that there is a slight difference between sensor readings and theoretical angles. The difference is due to the interference of LDRs light sensor that trims these angles to orient the solar panel directly toward the sun. The angle sensor is used for two purposes, first it is used to lead the tracker to the position that came from sun-earth algorithm; and secondly it is used to read the final location after LDRs trims the theoretical angles.

The measured values of azimuth and altitude transmitted and stored continually into text file in PC software supervisory through Bluetooth module, furthermore the software monitors the system behavior, as shown in Figure 6 [9],[10].

4. Conclusion

Two-axis automatic solar tracking system and its PC software supervisory user interface is proposed and accomplished in this project. It is reliable, precise and efficient with respect to the fixed angle system. The tracking system designed to work within several climate conditions. Close loop strategy used in this system with employing Arduino Uno controller to locate the position of DC motors to ensure point to point intermittent motion resulting from the DC geared motors. Set of four LDR sensors are used to capture maximum light source. Altitude angles is restricted between 0° to 81° and azimuth angle is restricted between 60° to 300° in Baghdad. Standalone working and wireless communication with computer through Bluetooth module is achieved so, that makes the system observable and trustworthy. PC software user interface is used to store the major parameters of the system into database.

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