World Journal of Engineering Research and Technology
WJERT
www.wjert.org
SJIF Impact Factor: 5.924

OVERVIEW OF SOLAR TRACKING DEVICE AND DEVELOPMENT OF LIGHT POSITIONING DETECTOR

[1]*Ejiko S. O., [2]Ogunlowo M. and [3]Ukachi P. A.

[1,3]Department of Mechanical Engineering, [2]Department of Electrical and Elctroniengineering, Federal Polytechnic, Ado-Ekiti.

Article Received on 26/02/2020 **Article Revised on 16/03/2020** **Article Accepted on 06/04/2020**

***Corresponding Author**
Ejiko S. O.
Department of Mechanical Engineering, Federal Polytechnic, Ado-Ekiti.

ABSTRACT

Solar tracking devices have been in existence for many years but its affordability is limited to medium income earners. The ability to develop component parts locally will go a long way to reduce the cost, hence the development of light positioning detector. Overview of the contributions of some authors in solar tracking technology is presented to highlight some disadvantages that are expected to be tackled. In the development of the light positioning detector, a four quadrants sensor (light dependent resistors) was used as the detector, which serves as a medium for sensing positional change of the sun and in turn influences the repositioning of the solar panel. Signal from the (Solar Tracking Sensor) STS is fed through the potentiometer (10k variable resistors) and the IN4001 diodes, (having all their cathodes connected to the terminal 6(VIN) of ADC0804LNC (Comparator) - Slave micro-controller. This compares the input signal with the reference voltage and the error signal (the difference) is sent through the parallel port to AT89352 - Master micro- controller that then executes pre-defined task in its software. The micro-controller in line with the pre-defined programme written on its software scans through the LEDs and gives a stable signal (voltage) to those LEDs corresponding to the ‘exposed’ STS quadrant. The prototype light positioning detector was implemented to save cost using local content and affordable microcontroller.

KEYWORDS: Overview, Development, Light, Positioning, Solar, Tracking. Detector.

INTRODUCTION

Exploitation of renewable energy resources has been in the forefront of campaign throughout the world for the supply of significant proportion of the world energy needs (Ikuponisi, 2004). Solar radiation is the largest renewable resource on earth (Muller Steinhagen, 2003) and Nigeria has vast solar energy potential that is yet to be fully harnessed (Ogunlowo *et al.*, 2009). The Photovoltaic panels are made up of solar cell that convert sunlight directly into electricity through the photons striking a semiconductor materials, such as silicon, they dislodge electrons which produce potential difference between the specially treated front surface of the solar cells and the inner surface (De Meo and Steitz, 1990; Kaushika, 1999 and Zekai, 2008). In order to increase the voltage, individual cells are combined in a panel form. These panels are position based on the peak value of the solar radiation in a location (Adeyemo, 2008). However the problem with solar power is that it is directly dependent on light intensity. To produce the maximum amount of energy, the solar panel must be perpendicular to the light source (Goetzberger *et al*., 2002). The sun moves throughout the day as well as throughout the year, a solar panel must be able to follow the sun's movement to produce the maximum possible power (Goswami *et al.*, 2000). The solution is to use a tracking system that maintains the panel's orthogonal position with the light source. The application of electro-optical control unit enables tracking of the sun by a solar detecting device that is sensitive to solar radiation. Simple equipment such as photodiodes, phototransistors and Light Dependent Resistor (LDR) are employed in the device (Koyuncu and Balasubramanian, 1991; Kalogirou, 1996).

A photo resistor also known as light-dependent resistor (LDR) or photocell is a light-controlled variable resistor, which is a one type of resistor whose resistance varies depending on the amount of light falling on its surface. The resistance of a photo resistor decrease with increasing incident light intensity; in other words, it exhibits photoconductivity. A photo resistor can be applied in light-sensitive detector circuits, and light-activated and dark-activated switching circuits. (WaiMar, *et al.*, 2018).

Solar electric technology is vast developing; its worldwide use is increasing rapidly as prices of other electric energy sources rise. It is believed that solar tracking will contribute significantly in increasing the efficiency of energy collection from the PV panels. Novel Dual-Axis solar systems allow for precise control of the elevation and azimuth angle of the panel relative to the sun. Tracking is reported to potentially double the energy output of a fixed PV Solar system.

The Automatic Solar Tracking System (ASTS) was made as a prototype to solve the problem, mentioned above. It is completely automatic and keeps the panel in front of sun until that is visible. The unique feature of this system is that instead of take the earth as its reference, it takes the sun as a guiding source. Its active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximum. (Nikesh and Rakesh, 2013).

BACKGROUND

There is a great and growing need for renewable energy, in particular green energy. In years to come the desire for a source of energy that will leave future generations with a sustainable energy source will be highly demanded. A few good reasons to improve our green energy market are because not only do we want to have renewable energy for future generations, but we also want to have a sustainable energy market in future. Green energy has shown sustainable growth in past years, where oil has obviously not. In order to power our homes, businesses, and most aspects of our daily lives we require electricity, which requires massive power plants and spending billions of dollars to run them. But it is better to replace them with green energy that could provide power directly to the consumers; like businesses, the military or even private homes (Dante, 2013).

TYPE OF SOLAR TRACKERS

The effectiveness of a solar tracker and PV technology in general, is directly correlated to the amount of sunlight that it is being exposed to; its power output is dependent on the amount of light that reaches the solar cell. PV technology is most efficient when it has light (form a light source) incident on it at a perfectly perpendicular angle, i.e. forming a 90 degree angle. In order to accomplish this in a real-world situation, the PV panel must move with the sun to maintain this perpendicular angle (Mehleri *et al.,* 2010; Ejiko, 2015).

This is where the necessity for solar tracking comes in. Solar tracking is not a new concept, though it is a considerably new concept compared to PV cells. Patents began to be filed in regards to solar tracking, and even before that regarding simple light sensing technology, soon after the commercial availability of efficient PV panels hit the market about 50 years ago. Like most technology today, a large collection of solar tracking systems exist, ranging in price, effectiveness, reliability, etc. The design options for a solar tracking system must be taken into careful consideration to ensure that the system is maximizing its output from tracking the sun. If key aspects of the application needs were to be neglected, the solar tracker could actually perform below a well-positioned stationary PV panel.

Even though solar tracking will inherently give a greater power output than a stationary PV panel, the option is not always ideal. Due to the increased cost for solar tracking technology versus stationary PV panels, solar tracking is not always the best option for a given application. If a stationary PV panel is utilized, it is strategically placed facing the sun. The considerations to be taken regarding PV panel placement is that the panel must be placed in a spot where it will always have a clear line of sight (LOS) to the sun, and the panel must be positioned at an optimal angle facing the equator, depending on its latitude on earth. Due to the fact that the earth is rotating on a tilted axis and takes an elliptical path around the sun, a stationary PV panel's output will drastically vary throughout the year and even throughout the course of a day.

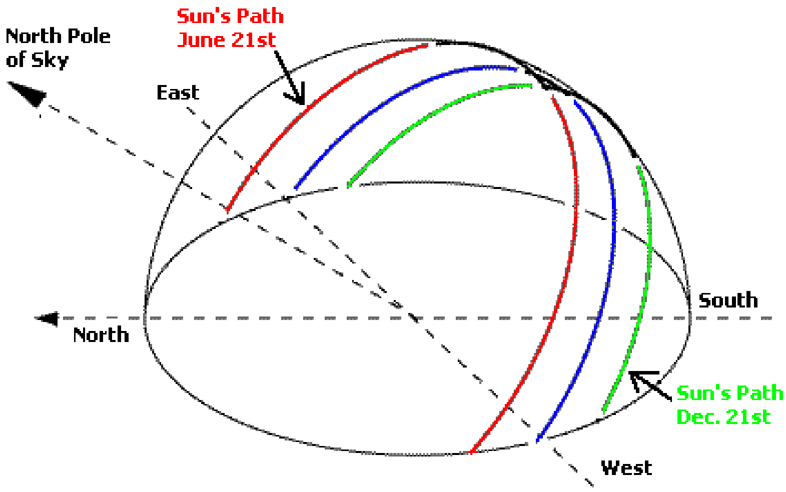


Figure 1: Earth's axis tilt/orbital path affecting Solar angle.

Source: Mousazadeh (2009): *A review of principle and suntracking methods for maximizing solar systems output*.

Solar tracking obviously addresses these issues by actively following the sun in the sky. A standard PV panel will observe about 20-35% efficiency under ideal conditions, while solar tracking has been known to potentially double that with 50-60% efficiency under ideal conditions (Mousazadeh, 2009; Ejiko *et. al.*, 2019). In general there are two main groups that can categorize solar trackers: single or dual axis trackers. Single axis trackers singularly follow the Sun's East-West (or even North-South) movement, while the two-axis trackers follow the Sun's exact movement, no mater what direction. Typically tracking is done, considering a single axis at a time, by using two photoresistors or PV cells used as sensors. These sensors are strategically placed next to one another and have a divider/tilted mount of some sort to create a voltage difference. This voltage difference is then used to determine which way the panel needs to turn to face the sun perpendicularly.

The first type of active solar collecting is single axis tracking. This will result in a greater power output than stationary PV panels, but is also more costly to design and implement. Single axis solar trackers can either have a horizontal or a vertical axis. The horizontal typeis used in regions near the equator where the sun gets very high at noon, thus not having to adjust to vertical changes so much as horizontal changes.

Overview of Existing Works

Overviews of the contributions of some authors in solar tracking technology are provided in Table 2.1 highlighting some disadvantages that are expected to be tackled.

Table 2.1: Contributions of some Authors in Solar Tracking Technology.

S/N	Title of Paper	Area of Contribution	Author(s) Year
1.	The sun's position	Developed sun's position vector relative to the earth-centre frame	Stine and Harrigan, (1985)
2.	Non-imaging, focusing heliostat.	Introduced an open-loop sensors that do not require any solar image as feedback	Chen *et al*., (2001)
3.	Computing the solar vector	Developed sun's position vector for altitude angles	Blanco-Muriel *et al.*, (2001)
4.	Two axes sun tracking system with PLC control	Designed a tracking system operated by an open-loop control mode	Abdallah and Nijmeh, (2004).
5.	An artificial vision-based control system for automatic heliostat positioning offset correction in a central receiver solar power plant.	Applied Video system to controll heliostat position	Berenguel *et al.*, (2004)
6.	A PI based hybrid sun tracking algorithm for photovoltaic concentration.	Designed a tracking system that is operated in open-loop mode	Luque-Heredia *et al.*, (2004)
7.	The tracking of the sun for solar paraboloidal dish concentrators.	Utilized parabola dish to obtained increased solar radiation for heating.	Shanmugam and Christraj, (2005).
8.	Sensor-controlled heliostat with an equatorial mount.	Developed a heliostat with an equatorial mount and a	Aiuchi et al., (2006)

		closed-loop photo-sensor control system	
9.	Design and Construction Of a Sun	Utilize 2 sensors to determined maximum panel radiation section	Akinkuade and Fasae, (2006)
10.	General sun tracking formula for heliostats with arbitrarily oriented axes.	Derive a general sun-tracking formula for heliostats with arbitrarily oriented axes	Chen et al., (2006).
11.	Digital sun sensor based on the optical vernier measuring principle.	Design digital sun sensor with optical vernier measuring principle.	Chen *et al.*, (2006)
12.	Analogue sun sensor based on the optical nonlinear compensation measuring principle	Proposed an analogue sun sensors that have accuracy of 0.2^o	Chen and Feng, (2007)
13.	An algorithm for the computation of the solar position	Obtained special formula /algorithm for calculating collectors angle	Grena, (2008)
14.	A computer tracking system of solar dish with two-axis degree freedoms based on picture processing of bar shadow	Computer program were developed for maximum tracking of radiation with solar dish	Arbab et al., (2009)
15.	General formula for on-axis sun-tracking system and its application in improving tracking accuracy of solar collector	Proposed an on-axis general sun-tracking formula to track the sun for accurate orientation	Chong and Wong, (2009)
16.	Integration of an on-axis general sun-tracking formula in the algorithm of an open-loop sun-tracking system	Obtained analytical solutions for the three orientation angles based on the daily sun-tracking	Chong *et al.*, (2009)
17.	Design and construction of non-imaging planar concentrator for concentrator photovoltaic system	Applied the concept of non-imaging optics to achieve good uniformity of the solar irradiation	Chong *et al.*, (2009)
18.	Optical characterization of non imaging planar concentrator for the application in concentrator photovoltaic system	Developed sun tracker to maintain its good performance when highly concentrated sunlight is involved	Chong *et al.*, (2010)
19.	Solar Tracking System	Utilize LDRs to sense the intensity of light and sent the data to the microcontroller.	Tudorache and Kreindler, (2010)
20.	Construction of a Solar Tracking System	Developed tracker rotate about an axis	Shotomiwa (2015)

Theoretical Background

The three basic angles in sun to earth geometry are latitude l, hour angle h and sun's declination angle d. There are several other angles that are related to solar radiation calculation. These angles are zenith angle ψ, altitude angle α and azimuth angle γ. These additional angles are related to the three basic angles. Their relationships have been established by Threlkeld *et. al.*, (2005) and are presented as follow in this section. Fig 3.1 schematically shows the apparent solar path that defines the sun's zenith, altitude and azimuth angles. Point P represents the position of the observer, Point O is the center of the earth, and I_N is a vector representing the sun's rays. The zenith angle ψ is the angle between the sun's ray and a line perpendicular to the horizontal plane at P (extension of $\overline{OP}$). The altitude angle α is the angle in a vertical plane between the sun rays and the projection of sun's rays on the horizontal plane. This follows that $\alpha + \psi = \pi/2$. The azimuth angle γ is the angle in the horizontal plane measured from the north to the horizontal projection of the sun's rays.

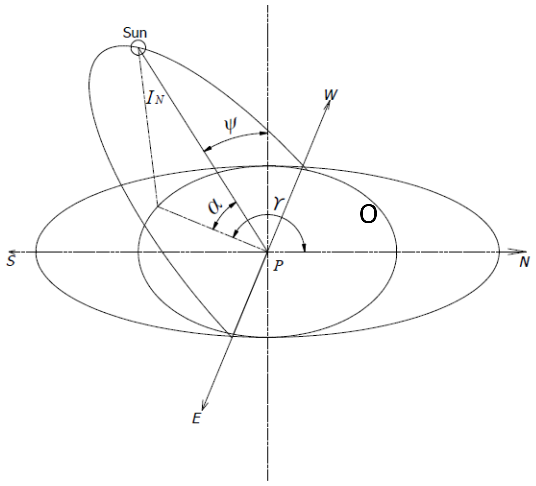


Fig. 2: Schematic View of Sun's Zenith, Alt. and Az. Angles (Threlkeld *et. al.*, 2005).

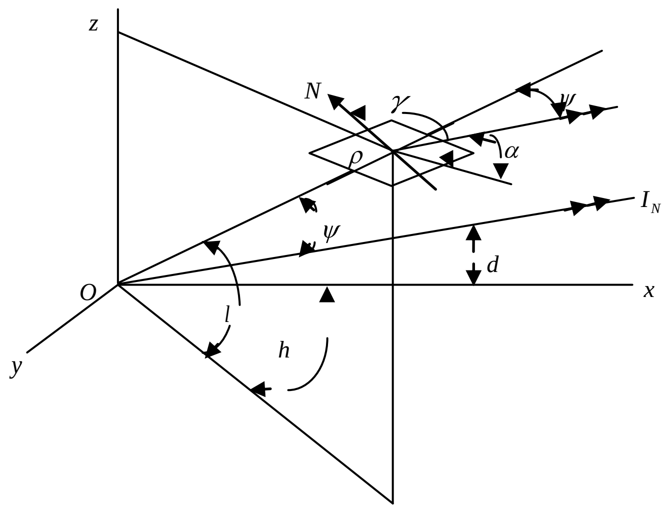


Fig. 3: Relation of a Point on the Earth's Surface to Sun's Rays (Threlkeld *et. al.*, 2005).

Fig 2 shows a coordinate system with the z axis coincident with the earth's axis. The xy plane coincides with the earth's equilateral plane. The vector I_N representing the sun's rays lies in the xz plane (coinciding with a line drawn from the center of the sun to the center of the earth). The line $\overline{PN}$ pointing north from point P is perpendicular to $\overline{OP}$ and lies in the plane containing $\overline{OP}$ and the z axis.

Making a_1, b_1 and c_1 be the direction cosines of $\overline{OP}$ with respect to the x, y and z axes. Also let a_2, b_2 and c_2 be the corresponding direction cosines of I_N.

This implies that

$a_1 = \cos l \cos h,$

$b_1 = \cos l \sin h,$

$c_1 = \sin l,$

$a_2 = \cos d,$

$b_2 = 0,$

$c_2 = \sin d,$

$c_2 = \sin d,$

The sun's zenith ψ is the angle between $\overline{OP}$ and I_N. By a common equation from analytic geometry cos ψ is given as shown in equation 1;

$$\cos\psi = a_1 a_2 + b_1 b_2 + c_1 c_2 \quad (1)$$

$$\cos\psi = \cos l \cos h \cos d + \sin l \sin d \quad (2)$$

Since $\alpha = \pi/2 - \psi$

$$\sin\alpha = \cos l \cos h \cos d + \sin l \sin d \quad (3)$$

By application of similar methods, this implies that the sun's azimuth γ in Fig. 2 is given by the relation in equation 4.

$$\cos\gamma = \sec\alpha(\cos l \sin d - \cos d \sin l \cos h) \quad (4)$$

The application of equations 3 and 4 with appropriate trigonometric identities will result to equation 5.

$$\sin\gamma = \sec\alpha \cos d \sin h$$

Fig. 4 shows the lines of Fig. 3 for the case of solar noon. At solar noon, h = 0, and $\gamma = \pi$

If $l > d$, and $\gamma = 0$ if $l < d$. For the case of $l = d$, γ is undefined for h = 0. From Fig 4 it can be deduce that

$$\alpha_{noon} = \frac{\pi}{2} - |(l - d)| \qquad (5)$$

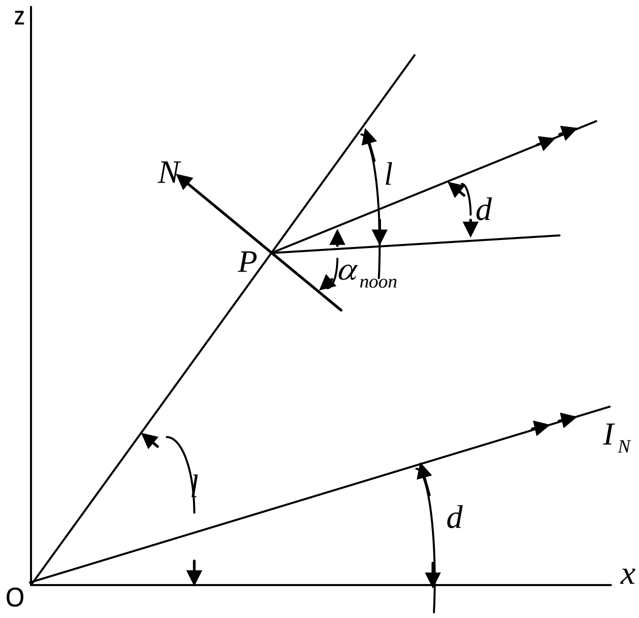


Fig. 4: Point Relation on Earth's Surface to Noon Sun's Rays (Threlkeld *et. al.,* 2005).

where $|(l-d)|$ is the absolute value of $(l-d)$. Equation 6 allows rapid determination of the daily maximum altitude of the sun for a given location. Equations 2 – 4 allow calculation of the sun's zenith, altitude and azimuth angles if the declination, hour angle and latitude are known. In applying these equations attention must be given to correct signs for the latitude and declination angles. If north latitudes are considered positive and south latitudes negative, the sun's declination will be positive for the summer period between the vernal equinox and autumnal equinox (March 22 to September 22 approximately) and negative at other times. The hour angle is measured on either side of solar noon. Thus h is limited to values between zero and π. If $h < \pi/2$, cos h is positive and if $h > \pi/2$, cos h is negative.

In calculations involving other than horizontal surfaces, it may be convenient to express the sun's position relative to the surface in terms of incidence angle θ. The vertical surface will involve the use of the wall-solar azimuth γ as shown in Fig. 4.

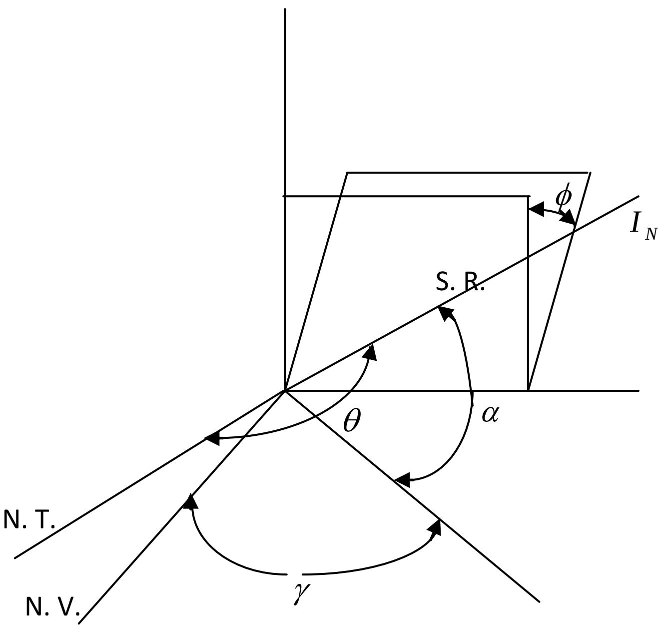


Fig. 5: Relationship between Sun's Rays and a Tilted Surface (Threlkeld *et. al.*, 2005).

where, N.T.S is the Normal Tilted Surface, N.V.S. is Normal Vertical Surface as related to S.R. which is the Sun's Rays. Fig.5 shows a surface tilted by an angle ϕ from the vertical position. The sun's angle of incidence θ is the angle between the sun's ray and the normal to the tilted surface. It is associated with a definite surface position. The wall-solar azimuth γ is the angle measured in the horizontal plane between the normal to the vertical surface and the horizontal projection of the sun's rays. Thus, α is associated with a definite wall position and may be found from the sun's azimuth γ. Also, the incidence ray of direct solar radiation on a collector is given in equation 7 by Duffie and Beckman, (1980) as

$I_{DN} = I_N \text{Cos } \theta$

where I_N is the radiation reaching the collector surface in that locality

θ is the incidence angle.

The sun's angle of incidence θ is the angle between the sun's rays and the normal to the tilted surface and is given in equation 8.

$\cos\theta = \cos\gamma\cos\alpha\cos\phi + \sin\gamma\sin\phi$ (6)

For vertical surface where $(\phi = 0)$, then (7)

$\cos\theta = \cos\gamma\cos\alpha$ (8)

For horizontal surface where $(\phi = \pi/2)$, then

$\cos\theta = \sin\gamma = \cos\psi$ (9)

This implies for a horizontal surface, that is the incident angle is equal to the zenith angle. Equations 8 and 9 shows that the incidence angle is a function of both azimuth and altitude angle. Since it is much easier to obtain the azimuth and altitude angle in respect of solar panel operation, the two angles are therefore utilize for solar panel positioning in this study.

Microcontrollers.

Microcontrollers can perform very similar tasks as PLCs, but the size of the device is much smaller. A processor, memory, and the input/output peripherals are all embedded into a single integrated circuit (IC) about the size of a fingernail. They are very cheap, costing around $3 for a single IC. But the disadvantage of microcontrollers is that they are made to control small appliances. Communication terminals such as LAN are not common in microcontroller boards, unlike the PLCs. So using microcontrollers for solar tracking in a power plant is not very feasible in terms of status monitoring and controlling them for maintenance. But it would be the best option for a home use tracker or for a prototype (Dante, 2013).

Sensors

Any device that is sensitive to the intensity of light can be used as solar tracking sensors. Two or more of those similar devices can be placed at an angle as shown in the 'four quadrants' plate 1 below. When the sun is on any of the quadrants, the sensors on that quadrant receive more light than those one on the others. If the sensors produce voltage with light intensity, the sensors receiving light would produce more voltage than those that are not. From the result, the sun ray on a particular quadrant can be detected. When sensors on all the quadrants are outputting the same value it implies the sun ray is perpendicular to the sensor unit.

Prototype Description.

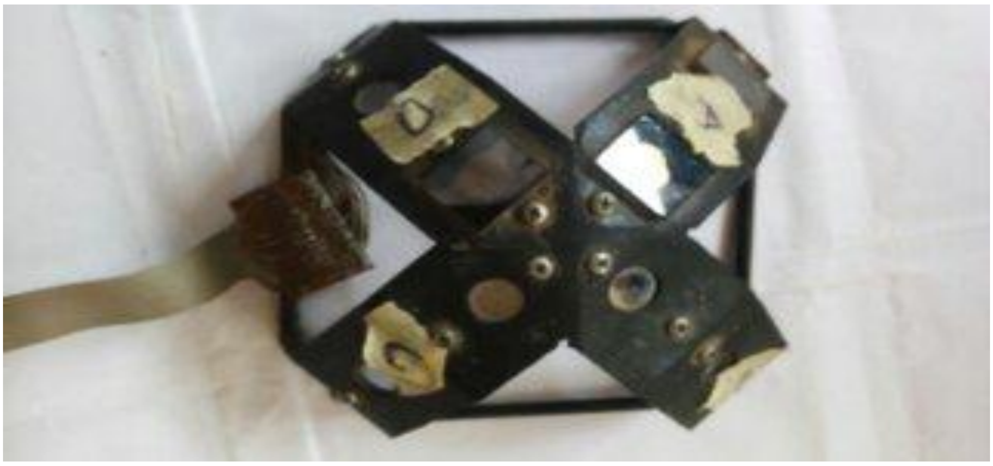


Plate 1: The Four Quadrant Sensor (light dependent resistors)

Photovoltaic cells.

Photovoltaic cells, though when combined made up a solar panel, can be used to detect light intensity. It produces the maximum voltage when the sun is perpendicular to the cells. As the angle between the cell and the sun ray decreases, the voltage also drops. When the cells are parallel with the sunlight, it will produce a minimum voltage.

Light Dependent Resistor (LDR)

A photo resistor or light-dependent resistor (LDR) or photocell is a light-controlled variable resistor, which is a one type of resistor whose resistance varies depending on the amount of light falling on its surface. The resistance of a photo resistor decrease with increasing incident light intensity; in other words, it exhibits photoconductivity. A photo resistor can be applied in light-sensitive detector circuits, and light-activated and dark-activated switching circuits. A photo resistor is made up of semiconductor materials having high resistance. LDRs are light dependent devices whose resistance is decreased when light falls on them and that is increased in the dark. In the dark, a photo resistor can have a resistance as high as several mega-ohms (M Ω) (WaiMar *et. al.*, 2018). Light dependent resistors or photo resistor is a type of resistor whose resistance depends on the amount of light falling on the sensor. The resistor of LDR increases with decreasing light intensity.

Light Emitting Diode (LED).

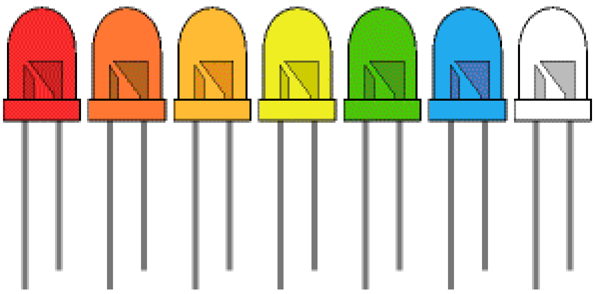


Plate 2: Different Colours Of LEDs.

Light emitting diode is a type of diode that products light when current flows through its terminal. But it also has a property of producing current when it receives light, just like a photodiode. As the light intensity increases, the current a LED produces also increases.

Controllers

The main purpose of the controller is to receive data from the sensors, process it, and give signals to drive the motors and actuators. Looking at it simply, a human can take the place of a controller. A person can see where the sun is and rotate the tracker manually to get the highest energy. But it is not a feasible option for a long term or when there is more than one tracker, like in a solar power plant; so automated controllers become a necessity. Controllers must also take into account what to do when the sun sets, when the wind is too high and in other physical conditions.

METHODOLOGY

The experimental unit set up to measure the optical sensitivity of the light dependent resistor (LDRs) – sensors. The experimental setup used in this research included a 9.0 V Direct Current (D.C.) electrical supply, Solar Energy Trainer Module which is used as a variable light source, four quadrants LDRs sensor, multi-meter and a DT-8809A professional lux meters (Max. range 100 lux, Resolution 0.1 lux, Accuracy ±%5) have been used, The experimental mechanism is shown in Plate 3. Fig. 6 shows the circuit diagram of the developed detector while Fig. 7 present the structural view of the solar tracker capturing the detector as positioned.

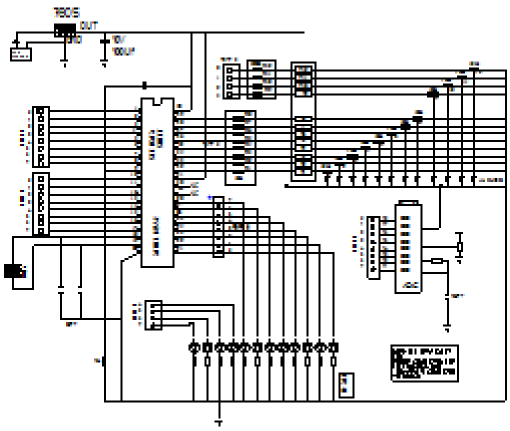
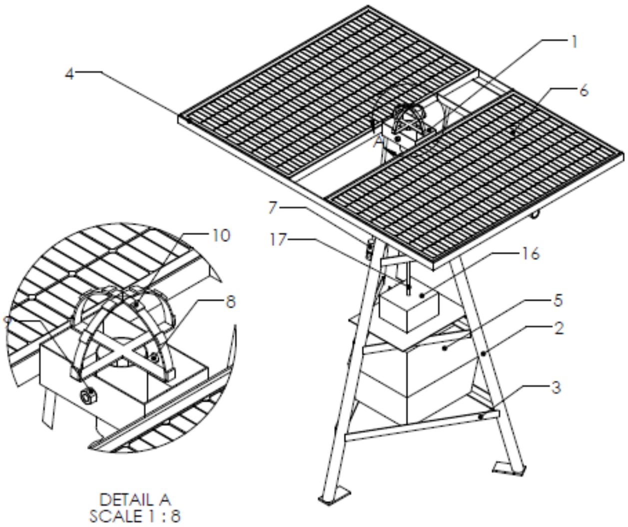


Fig. 6: The Circuit Diagram of Light Positioning Detector.

Plate 3(a): Measurement of light intensity using a LUX meter.

Plate 3(b): Measurement of LDRs' current under the influence of light from

Plate 3(c): Measurement of the voltage across LDRs. Solar Energy Trainer.



ITEM NO.	PART NUMBER	QTY.
1	pivolt	1
2	stand	3
3	cross bar	12
4	soar panel frame	1
5	electronics box	1
6	solar panel	2
7	actuator	2
8	pivot bolt	1
9	pivot nut	1
10	sensor	12
15	battery box	1
16	microcotroller box	1
17	sensor cable	1

Fig. 7: Structural Diagram of the Light Detector Solar Tracker.

Table 2: Results of Application.

Luminous Intensity (Lux)	**1st Quadrant Ldrs**	**2nd Quadrant Ldrs**	**3rd Quadrant Ldrs**	**4th Quadrant Ldrs**	**Average Current (Ma)**	**Reasistance (Ω)**
10	0.07	0.07	0.07	0.07	0.07	96,000.00
20	0.23	0.24	0.23	0.23	0.23	29,217.39
58	0.25	0.25	0.26	0.26	0.26	25,846.15
106	0.27	0.26	0.27	0.26	0.27	24,888.89
153	0.29	0.29	0.28	0.29	0.29	23,172.41
203	0.32	0.32	0.32	0.31	0.32	21,000.00

Note: While the Vcc (voltage supply to the light positioning detector) was measured to be 8.5v d.c, the measure voltage across the LDR was 6.72v dc

Table 3: LDRs Average Current/Resistance Output to Variable Light Intensity

LIGHT aINTENSITY (LUX)	**AVERAGE CURRENT (mA)**	**LDRs' RESISTANCE (KΩ)**
10	0.07	96.0
20	0.23	29.0
58	0.26	26.0
106	0.27	25.0
153	0.29	23.0
203	0.32	21.0

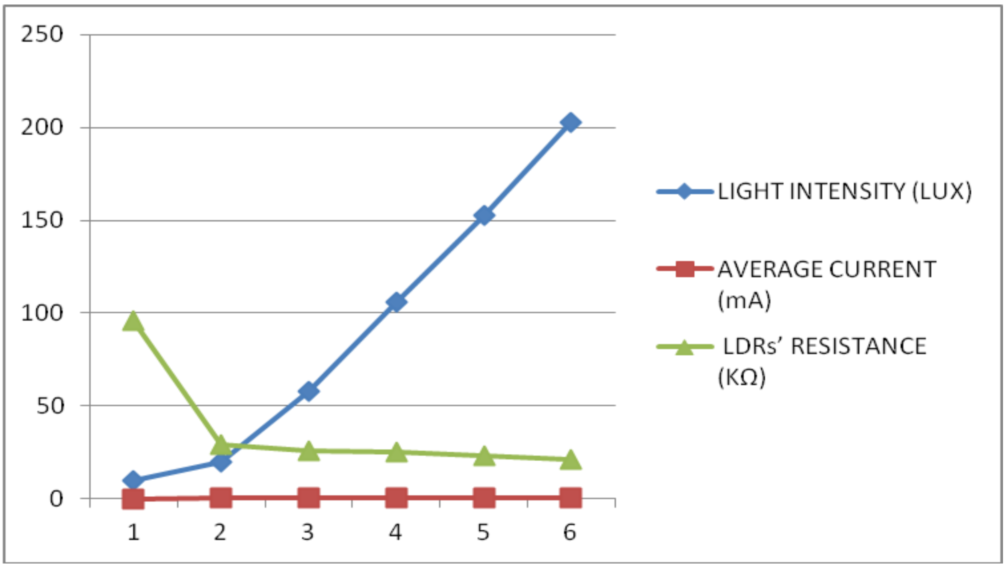


Fig. 8: LDRs Current/Resistance to Variable Light Intensity.

RESULTS AND DISCUSSIONS

Table 2 show that the average current through the LDR increases as the light intensity increases. This is so because the resistance of the LDR also decreases with the increase in the light intensity as displayed on the table. Fig. 8 is the graph of LDRs Current/Resistance to Variable Light Intensity. The graph shows a direct relationship between the light intensity and the average current through the LDR, however, it is obvious from the graph that the resistance of the LDR drops as the intensity of the light increases.

It was also affirmed that the voltage measured across the LDR under the experimental condition (6.72v dc) was the same voltage supplied to the terminal 6(VIN) of ADC0804LNC (Comparator) - Slave micro-controller.

Conclusion and Recommendation

The prototype light positioning detector was implemented to save cost using local content and affordable microcontroller. The model is simple and energy saving; it can be fitted for auto detection of sun light in solar tracker. When the sun light is available the solar panels will be positioned to track the maximum solar energy available. It can be used for households solar power is required.

REFERENCES

1. Abdallah, S. and Nijmeh, S. 2004. Two Axes Sun Tracking System with PLC Control Energy Conversion and Management, 45(12): 931-193.
2. Adeyemo S. B. 2008. Improving Power through Energy Conservation in Nigeria Paper at the 1st National Engineering Conferences, November, 14-17, University of Ado-Ekiti, Ekiti State.
3. Aiuchi, K.; Yoshida, K.; Onozaki, M.; Katayama, Y.; Nakamura, M. and Nakamura, K. 2006. Sensor-controlled Heliostat with an Equatorial Mount. Solar Energy, 80(9): 1089-1097.
4. Akinkuade, S. T. and Fasae, K. P. 2006. Design and Construction Of a Sun Tracking System" 1st International Conference and Exhibition, 221-224, School of Sciences and Computer Studies, The Federal Polytechnic Ado-Ekiti, ID STAR printer, Ikere-Ekiti.
5. Arbab, H.; Jazi, B and Rezagholizadeh, M. 2009. A Computer Tracking System of Solar Dish with Two-axis Degree Freedoms Based on Picture Processing of Bar Shadow. Renewable Energy, 34(4): 1114-1118.
6. Berenguel, M.. Rubio, F.R. Valverde, A. Lara, P.J. Arahal, M.R. Camacho, E.F. and Lopez, M. 2004. An Artificial Vision-based Control Aystem for automatic Heliostat Positioning Offset Correction in a Central Receiver Solar power Plant. Solar Energy, 76(5): 563-575.
7. Blanco-Muriel, M. Alarcon-Padilla, D.C. Lopez-Moratalla, T. and Lara-Coira, M. 2001. Computing the solar vector Solar Energy, 70(5): 431-441.
8. Chen, Y.T.; Chong, K.K.; Bligh, T.P.; Chen, L.C.; Yunus, J.; Kannan, K.S.; Lim, B.H.; Lim, C.S.; Alias, M.A.; Bidin, N.; Aliman, O.; Salehan, S.; Rezan S.A.H., S.A.; Tam, C.M. and Tan, K.K. 2001. Non-imaging, Focusing Heliostat, Solar Energy, 71(3): 155-164.
9. Chen, F. Feng, J. and Hong, Z. 2006. Digital Sun Sensor Based on the Optical Vernier Measuring Principle, Measurement Science and Technology, 17(9): 2494-2498.
10. Chen, F. and Feng, J. 2007. Analogue Sun Sensor Based on the Optical Nonlinear Compensation Measuring Principle, Measurement Science and Technology, 18(7): 2111-2115.
11. Chong K.K. and Wong, C.W. 2009. General Formula for On-axis Sun-tracking system and its Application in Improving Tracking Accuracy of Solar Collector. Solar Energy, 83(3): 298-305.

12. Chong, K.K. Siaw, F.L. Wong, C.W. and Wong G.S. 2009a. Design and Construction of Non Imaging Planar Concentrator for Concentrator Photovoltaic System, Renewable Energy, 34(5): 1364-1370.
13. Dante J. (2013) Dual-axis Solar Tracker: Functional Model Realization and Full- scale Simulations. A Major Qualifying Project Report submitted to the Faculty of Worcester Polytechnic Institute. Sponsored by, French Development Enterprises, 11.
14. De Meo E. A. and Steitz P. 1990. Advances in Solar and Wind energy, Boer KW Edition. American Solar Energy Society and Plenum, New York.
15. Duffie, J. A. and Beckman, W. A.1980. Solar Engineering of Thermal Processes, John Wiley and Sons, New York.
16. Ejiko, S.O. (2015), "Development of a Dual Axis Tracker", A paper presented at the 10th Engineering Forum , School of Engineering, The Federal Polytechnic, Ado-Ekiti, on 23rd – 26th October, 2015 at The Polytechnic Conference Centre, Ado-Ekiti, Ekiti, State, 2: 173-184.
17. Ejiko, S.O., Oke P. K., Titiladunayo I. F. and Ogedengbe T. I. (2019), "Application of Mathematical Models and Sensors for Optimization of Solar Energy Collection Using a Developed Tracking Device", International Journal of Scientific Engineering and Science http://ijses.com, 3(1): 22-30, 2456-7361.
18. Grena, R. 2008. An Algorithm for the Computation of the Solar Position, Solar Energy, 82(5): 462-470.
19. Goetzberger, A. Hebling, C. and Schock, H., 2002. Photovoltaic Materials, History, Status and Outlook, Materials Science and Engineering: R: Reports.
20. Goswami, Y., Kreith, F. and Kreider, J. 2000. Principles of Solar Engineering", Taylor and Francis, Philadelphia.
21. Harmini, T.N, (2017) "Monitoring System of Stand Alone Solar Photovoltaic Data" International Conference on Electrical Engineering and Computer Science, Faculty of Technique Semarang University, 2017.
22. Ikuponisi S. F. 2004. Energetic Solution Status of Renewable Energy in Nigeria, International Conference on Making Renewable Energy a Reality Organized by One Sky Canadian Institute of Sustainable Living, Canada, November, Pp 21-27 inAbuja/Portharcourt/Calabar, Nigeria.
23. Kalogirou, S. A. 1996. Design and Construction of a One-axis Sun-tracking System, Solar Energy, 57(6): 465-469.

24. Kaushika, N. D. (1999): “Design and Development of Fault-tolerant Circuitry to Improve the Reliability of Solar PV Modules and Arrays”. Final technical report of the Department of Science and Technology, the Government of India. Research Project no. III 5(98)/95-ET.
25. Koyuncu, B. and Balasubramanian, K. A. 1991. Microprocessor Controlled Automatic Sun Tracker”. IEEE Transactions, 37(4): 913–917.
26. Luque-Heredia, I. Mananes, M. T., Moreno, J. M. and Auger, J. L. 2007. A Sun Tracking Error Monitor for Photovoltaic Concentrators, Electronics, 129-134, Robotics and Automotive Mechanics Conference.
27. Mousazadeh H, (2009) *A review of principle and suntracking methods for maximizing solar systems output*, Renewable and Sustainable Energy Reviews, 2009; 13: 1800-1818.
28. Muller-Steinhagen, H. 2003. Concentrating Solar Power A Vision for Sustainable Electricity Generation. Available on www.ecm.auckland.ac.nz/conf/Auckland-2.pdf
29. Mehleri, E.D., Zervas P.L., Sarimveis, H., Palyvos, J.A. and Markatos. N.C. (2010) "Determination of the Optimal Tilt Angle and Orientation for Solar Photovoltaic Arrays." *Renewable Energy*, 2010; 35.11: 2468-475.
30. Nikesh. D. W. and Rakesh. A. D. (2013) “Automatic Solar Tracker System” International Journal of Scientific & Engineering Research, Volume 4, Issue 6, June-2013 93 ISSN 2229-5518 IJSER © 2013 http://www.ijser.org pg -9.
31. Ogunlowo, M. Alake, T. J. and Ademiloye, I. B. 2009. Harnessing Solar Power for Sustainable Electricity in a Depressed Economy”, Proceeding of 5th Engineering Forum, Pp 213-216, 9th – 12th November, Federal Polytechnic, Ado-Ekiti.
32. Shanmugam, S. and Christraj, W. 2005. The Tracking of the Sun for Solar Paraboloidal Dish Concentrators, Journal of Solar Energy Engineering, 127(1): 156-160.
33. Shotomiwa, A. J., 2015. Construction of a Solar Tracking System, Bachelor Degree Thesis, Electrical Engineering Department, Faculty of Electrical & Electronic Engineering, Federal University of Technology Akure, Nigeria.
34. Stefan R. (2012)The Prospects for Cost-Competitive Solar PV Power,” http://www.gsb.stanford.edu/news/headlines/Reichelstein-solar-2012.html
35. Sterling B. H. (2011) Solar Power Prospects. *National Centre for Policy Analysis*; Policy Report No. 334 May (2011) http://www.ncpa.org/pdfs/st334.pdf
36. Stine, W.B. and Harrigan, R.W. 1985. The sun’s position, Solar Energy Fundamentals and Design: With Computer Applications, 1985; 38–69, John Wiley and Sons, Inc.

37. Threlkeld, J. L, Kuelin, T. H. and Ramsey, J. W. 2005. Thermal Environmental Engineering, 3rd Edition, 287-303, Prentice Hall, Inc.
38. Tudorache, T. and Kreindler, L. 2010. Design of a Solar Tracker System for PV Power Plants, Acta Polytechnic Journal Hungarica, 7(1): 23-39.
39. WaiMar M. A, Yadanar W, and Nay W. Z, (2018) Implementation of Solar Photovoltaic Data Monitoring System International Journal of Science, Engineering and Technology Research (IJSETR), August 2018; 7(8): 2278-7798 591 p.593.
40. Zekai, S. 2008. Photovoltaic (PV) Cells Solar Energy Fundamentals and Modeling Techniques, 256-259, Springer-Verlag London Limited.