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Design, Construction and Test of a Solar Tracking System Using Photo Sensor

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***Abstract*-For optimal harnessing of solar radiation, it is important to orient the solar collectors or PV modules with the changing direction of the daily solar irradiation. A solar tracking system consisting of a photo sensor was designed and tested in Kumasi, Ghana. The solar tracking system, include a quadrate array of sensor made up of four Light Dependent Resistor, Potentiometer, Servo motors and a Microcontroller. The designed system has a maximum angle of tolerance to be 2 degrees for any noticeable response of the system to the movement of the sun. An experiment was carried out on the working system to demonstrate the design functionality. Problems and possible improvements were also presented.**

Keywords-Solar tracker; sensor; Servo motor; microcontroller

I. INTRODUCTION

Solar energy is one of the most sought-after renewable resources. This comes as a result of its cheap source and its reliability to sustain. There are two different types of technologies involved in harvesting solar energy; these include photovoltaic panel and the solar-thermal panel. Photovoltaic panel is mainly used for power generation and solar-thermal is used for heating water or for drying. The solar thermal panel can also be used for power generation. The sun rises from the east and sets in the west, travelling along the latitude during the day and along the longitude during the seasons. The relative position of the sun is a major factor in the performance of the solar energy system. Sunlight has two components, the “direct beam” that carries about 90% of the solar energy and the “diffuse sunlight” that carries the remainder. As majority of the sun energy is in the direct beam, this gives a considerable reason to track the sun rays using a solar tracker [1].

A Solar tracker is a system or device that orients various photovoltaic and solar thermal panels toward the sun. It ensures that the direct beam from the sun is incident normal to the surface of the panels at all times. Installing a solar tracker to a solar system proves to be more efficient than a stationary solar system in terms of power generation.

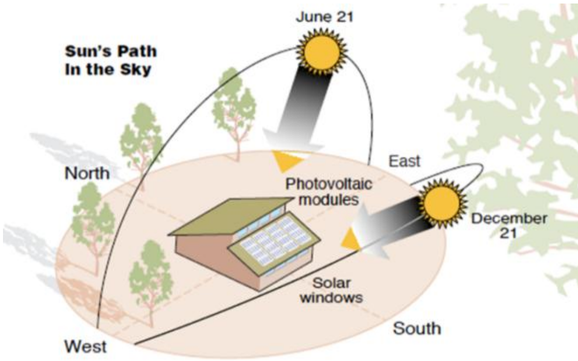

Fig. 1. The movement of the sun from the south to northern hemisphere and along the latitude form east to west [7]

Movement of the Sun

The sun appears to rise in the eastward horizon and sets in the westward horizon. The planet earth rotates around the sun but however as the earth spins and rotate around the sun it appears to the inhabitants on the earth that the sun is moving across the sky. This is known as the movement of the sun.

As depicted in Figure (1), the position of the sun with respect to that of the earth changes in a cyclic manner during the course of a calendar year. Tracking the position of the sun in order to expose a solar panel to maximum radiation at any given time is the main purpose of the solar tracking system. Every day as the sun rise and set from the east to the west respectively it crosses the meridian at local noon, and it takes the sun on an average 24 hours to go from noon position to noon position the next day. The ‘noon position’ is when the sun is on the meridian on a given day, our clocks are based on this solar day [2]. During winter the sun is relatively close to the equator, travelling the shortest and lowest arc across the sky. At this period the impact of the sun rays that strike the various locations on the earth is high due to relative low position of the sun across the sky [3].

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The winter solstice falls in December 21ist of the year in the southern hemisphere. “During summer the sun is relatively further from the equator, travelling the longest and highest arc across the sky. At this period the impact of the sun rays striking the various location on the earth is low due to its relatively high position across the sky” [3]. The summer solstice falls in June 21 in the northern hemisphere. In summary the sun travels along the latitude of the earth during the day and travels along the longitude during the seasons (from the southern hemisphere to the northern hemisphere).

The purpose of a solar tracker is to accurately determine the position of the sun. This enables a solar panel that has a solar tracker installed to obtain maximum solar energy from the sun at all times when the sun is out. While solar panels are an effective means of collecting energy, their efficiency at doing so is directly related to their angle with the sun. This is because PV cells get most energy from facing the sun; a stationary solar panel collects less sunlight than the one that follows the sun across the sky. The problem that this study addresses is the inefficiency associated with fixed solar panels (panels that do not track the sun across the sky). Two axes, as well as single axis solar panels allow for a better output from the PV cells, but they can be very expensive and require a lot of maintenance [4].To collect effective solar energy, a solar panel must be within about 20° from normal or perpendicular to the sun [5]. A precise knowledge of the movement of the sun is important to accurately model and use mathematical relations to predict the movement of the sun, hence the need to design a solar tracker. It has been estimated that ‘solar systems which utilize a tracking unit can generate 20% (with a single axis tracker) to 30% (with a dual axis tracker) more power than a fixed or stationary unit [6]. The main aim of this work is to design an automatic solar tracker to keep the panels perpendicular to the solar rays at all times. The specific objectives of this study are:

- To design an effective sensor array that is able to provide directional information and guide a major drive system to track the movement of the sun across the sky.
- To write a program capable of analyzing the signals from the sensor array and give instruction in form of a signal from a micro-controller to a drive system to change the direction of the solar panel toward the sun
- To design a drive system that would create a directional change of the solar panel.

II. MATERIALS AND METHOD

Tracking Process

Tracking is achieved starting from the sensors, as a first input of signal to the micro-controller. Depending on the number of sensors used, the micro-controller receives several input from each sensor used, and then provides two signals to be sent to servo-motors for a two degree of freedom adjustment. The micro-controller processes the sensor’s input and provides an appropriate signal which is sent to the servo-motors for their movements. This in turn causes one or more shafts that serve as a torque transmitter to rotate the solar panel about an instructed axis as commanded by the micro-controller hence changing its position. The shaft also serves as a support to the solar panel. The rotation of the solar panel about any axis is brought to a halt when the micro-controller detects that all sensors are receiving the same amount of sunlight. The tracking system is powered by the electrical energy generated from the solar panel.

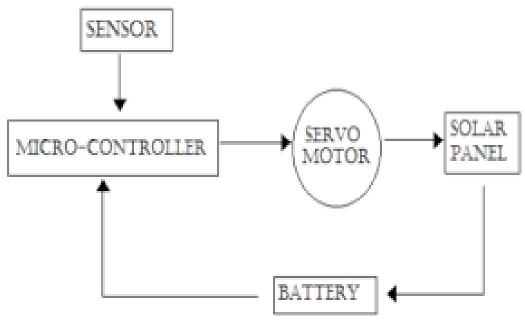

Fig. 2. Solar Tracking System Illustrated In The Block Diagram

Detail Design, Calculations & Analysis

Circuit Diagram

For the tracking system to be able to detect and respond quickly to the movement of the sun away from the Light Dependent Resistor (LDR) a sensible value for the fixed resistor in the voltage divider circuit must be chosen. This is done by connecting the fixed resistor to the variable resister (LDR) in a standard voltage divider circuit construction and then reading the voltage value across the fixed resistor using a multi-meter. There are just two ways of constructing the voltage divider, with the (LDR) at the top, or with the (LDR) at the bottom figure 3

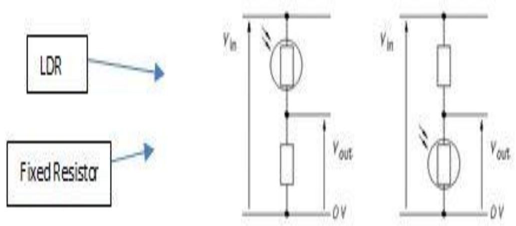

Fig. 3. Voltage divider

$$V_{out} = \frac{R_{bottom}}{R_{bottom}+R_{top}} \times V_{in} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

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Table 1. Resistance value of Light Dependent Resistor

Resistance value when exposed to Light (kilo ohms)				Resistance value when totally covered (kilo ohms)			
Measured Value R1	Measured Value R2	Measure Value R3	Average R_{Light}	Measured Value R1	Measured Value R2	Measured Value R3	Average $R_{covered}$
16	16.23	15.74	15.99	62	62.5	62.3	62.27

Experiment to Investigate Value for Fixed Resistor to Obtain a Desired System Sensitivity

Apparatus

1. Multi-meter
2. Resistors
3. Light dependent resistor(sensor)
4. Jump wires
5. Battery (9V)

Resistor value of light dependent resistor (LDR) when exposed to room light totally and when totally covered.

To determine the optimum value of the fixed resistor, the difference in voltage of the LDR when expose to light and shaded are read with a multi- meter from the circuit shown in Fig 24 and 25 respectively. Hence the largest voltage difference gives a more sensitive sensor to change in illumination [8].Voltages are read across the fixed resistor.

Table. 2. Voltage difference for values of fixed resistor

Fixed Resistor Value (ohms)	V_s when shaded from light (volt)	V_L when exposed to light (volt)	Voltage difference $V = V_L - V_S$ (volt)
960	0.085	0.465	0.38
1k	0.13	0.525	0.395
1.2k	0.16	0.63	0.47
3.9k	0.295	1.465	1.17
10k	0.925	2.74	1.815
56k	3.67	5.895	2.225
100k	4.37	6.595	2.225

III. RESULTS AND ANALYSIS

Conclusion Derived from Experiment

The experiment conducted showed that about 10k ohms the voltage difference (V) when variable resistor is exposed to light and when it is total cover is larger and remains constant for any further increase of fixed resistor value. The sensitivity of the Light Dependent Resistor to illumination is directly proportional to the voltage difference. For this project a 10k ohms will be used in the circuit design.

Sensor Array Design and Determination of Maximum (B) Angle of Tolerance

Also improving upon the sensitivity of the system, the maximum angle at which the sun moves away from the system is an important design factor. For a more sensitive system the maximum angle of tolerance should be very small to be able to cause a change in the light intensity on the sensors (i.e cast a shadow).

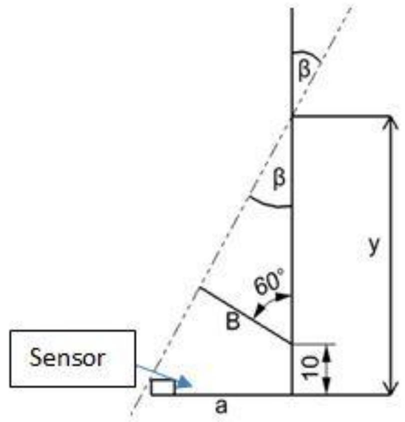

Fig. 4. Side view of sensor array dimensions in millimeter

From Fig 4

$$\tan\beta = \frac{a}{y} \qquad \therefore \qquad y = \frac{a}{\tan\beta} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{B}{\sin\beta} = \frac{(y-1)}{\sin(180-(\beta+60))} \qquad \therefore \qquad B = \frac{(y-1)\sin\beta}{\sin(180-(\beta+60))} \ldots\ldots\ldots\ldots\ldots\ldots\ldots .(2)$$

For an angle of tolerance $\beta = 2^{\circ}$ and an horizontal distance of (a = 12.2 mm)

$$y = \frac{10}{\tan 2} \quad = \quad 286.4mm$$

Therefore

$$B = \frac{(286.4-10)\sin 2}{\sin(180-(2+60))} \quad = \quad 10.93mm$$

Hence for a tolerance angle of 2° the length of tilt plane B = 10.93mm

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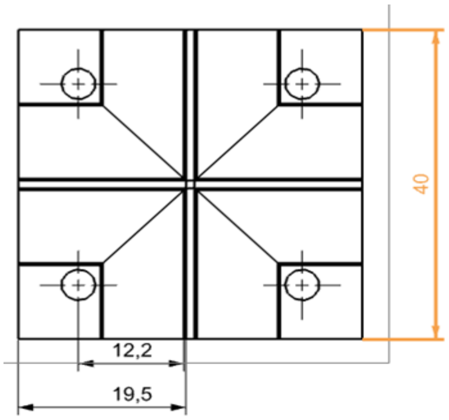

Fig. 5. Plan Of The Sensor Array (All Dimensions In Mm)

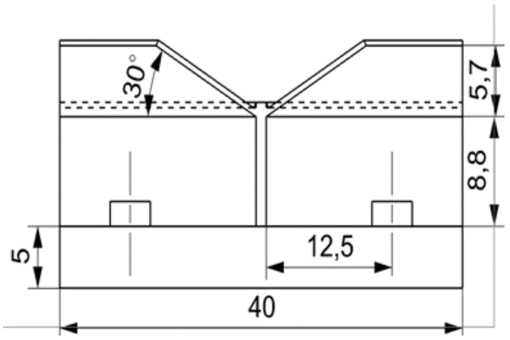

Fig. 6. Side View Of The Sensor Array (All Dimensions In Mm)

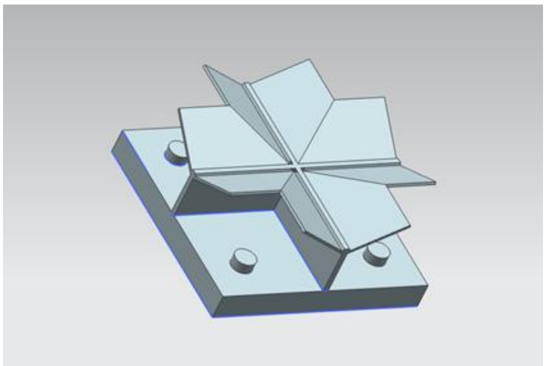

Fig. 7. 3d Model Of Sensor Array

Circuit Connection
Component

1. *4 Light dependent resistors:*
They are also known as variable resistor which service as sensing element for the tracking system. It senses the intensity of light that falls on it by varying it electric resistance. The resistance decreases with increasing light intensity and increases with decrease in light intensity.

2. *4 Fixed Resistors of 10k:*
The value of the fixed resistor determines the voltage difference when exposed to light and total cover. Hence the sensitivity of the variable resistor in the circuit to illumination depends on the value of the fixed resistor

3. *2 Potentiometer of value 10k :*
This component in the circuit helps regulate between the maximum and minimum respond time or delay time and sensitivity. A system operation or user may desire some certain value of response time and sensitivity this is easily achieved by adjusting the potentiometer.

4. *Jump wires:*
They are used to connect the components together in the electrical circuit.
5. *2 Servo motors:*
They are responsible for the angular positioning of the photovoltaic panels supported of the frames.
6. *Arduino Uno Microcontroller:*
Its use to read signal from the photo sensor which is translated to movement signal for the servo-motor

Specification:

Micro-controller: ATmega328

Operating Voltage: 5V

Digital 1/0 Pins: 14 (of which 6 provide PWM output)

Analogue Input Pins: 6

Clock Speed (Bytes): 16MHz

Table. 3. Components and Rated Value

Component No	Component Name	Component Rated Value
1	Potentiometer	10k ohms
2	Light Dependent Resistor	Variable
3	Fixed Resistor	10k ohms
4	Vertical Servo Motor	9.8kgcm
5	Horizontal Servo Motor	9.8kgcm
6	Micro Controller	ATMEGA328P-PU

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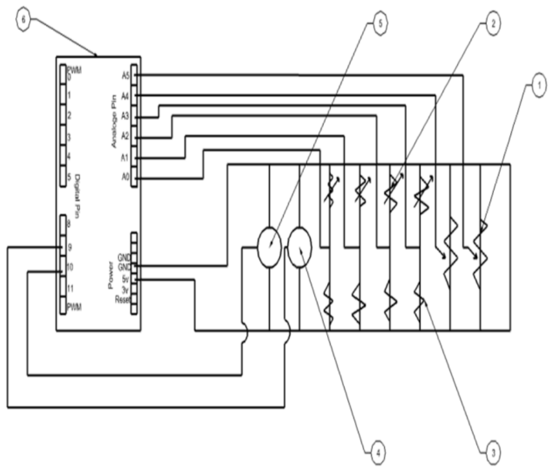

Fig. 8. Circuit Diagram

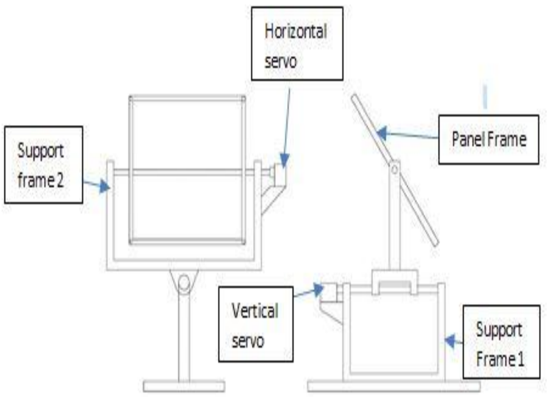

Fig. 9. Front And Side View Of Model

Calculation of Torque required for rotation
In order to select a motor that will be able to rotate the solar panels together with the support frames calculation on the torque required to cause this rotation have to be done. This section of the chapter provide all design specification and dimensions of materials use for construction and their weight

Horizontal Motor Selection

Mass of frame 1 = 1.0g

Mass of shaft = 0.57g

Length of shaft = 12cm

Moment of inertia of a rectangular body I = $\frac{m(a^2+b^2)}{12}$

Where$\propto$ = angular acceleration

a = 10.4cm b = 9.5cm where a is the length of the rectangle and b is its width

$I_{rectangle} = 1.653\times 10^{-6}$kgm^2

Where $\propto$ = angular acceleration and ω is angular speed I = moment of inertia

$\propto = {}^{\nabla\omega}/_{t}$ where $\nabla\omega = \omega_1 - \omega_0$ and

ω_0 = Initial angular velocity
ω_1 = Final angular velocity

For a design speed of 500rpm (52.35rads^{-1})

Time (t) = 10sec from potentiometer value 10k ohms (i.e 1000 is 1 sec)

Therefore Angular acceleration $\propto$ = 5.235rads^{-1}

T = I$\times\propto$ = 8.653×10^{-6}Nm or 0.0882g-cm

For shaft I = $\frac{mL^2}{12}$ where L is the length of the shaft and M is it mass

$I_{shaft\ 1} = 6.84\times 10^{-7}$kgm^2

Torque = I$\times\propto$= $3.581\times 10^{-6}Nm$ or 0.0365g-cm for shaft 1

Hence total torque = 0.0191 +0.046 =0.0651g-cm

Vertical Motor
Mass of frame 1 plus frame 2 = 2.2g or 0.0022kg

Mass of shaft 2 = 0.57g or 0.00057kg

Mass of Horizontal Motor = 55g

Radius of shaft (r) = 0.1cm

Torque (T) = I $\times\propto$ I = $\frac{mL^2}{12}$ of a shaft

Taking a total mass of frame plus shaft 1 to be the mass of shaft to be rotated $m_s = 2.77\times 10^{-3}$kg

$I_{shaft} = 3.324\times 10^{-6}$kgm^2

Torque T = $3.324\times 10^{-6} \times \left[\frac{2\pi\times 500}{60}\right]^2 \times \left[\frac{0.1}{100}\right]$ = $1.740\times 10^{-5}Nm$ or 0.177g-cm

Torque to rotate the horizontal servo motor on frame 2 = mass $\times$ torque arm

Torque arm = 9cm

T = 55$\times$ 9 = 495 g-cm

Total torque required to rotate both horizontal motor plus frame and shaft = 0.177 + 495 = 495.18g-cm

Motor Specification for both Vertical and Horizontal Motor

Dimensions: Length (40.6mm), Width (19.8mm), Height (42.9mm)

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Torque: 4.8Volts (9.40kg-cm), 6.0Volts (11.00kg-cm)

Speed: 4.8Volts (0.17sec/60 degrees), 6.0Volts (0.14sec/60degree)

VI. CONCLUSION AND RECOMMENDATION

The embodied final solution is a three part support structure consisting of a two shaft, three support frames and two servo motor with a sensor array. A design model was constructed to depict the improved concept capability and design feasibility. The tested design model was able to achieve a complete tracking of the sunlight making sure the panel is positioned perpendicular to the sunlight reaching it. The final solution thus fulfilled the set objectives of being simple and be able to do an automatic tracking. For further design, we recommend

1. The micro controller unit should be removed and use to design a stand-alone circuit this will reduce the complexity of the circuit and increase the design life of the circuit.

2. Sensor array should be protected using a transparent glass dome

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APPENDICES

Program codes

```
#include<Servo.h> // include Servo library
Servo horizontal; // horizontal servo
Int servoh = 90; // stand horizontal servo
Servo vertical;       // vertical servo
Int servov = 90; // stand vertical servo
//LDR pin connections
// name  = analogpin;
int ldrlt = 0;        //LDR top left
int ldrrt = 1;        //LDR top right
int ldrld = 2;        //LDR down left
int ldrrd = 3;        //LDR down right
void setup()
{
Serial.begin(9600);          // Servo connections
  //name. attach(pin)
horizontal.attach(9);
vertical.attach(10);
}
void loop()
{
int lt = analogRead(ldrlt);  //top left
int rt = analogRead(ldrrt);  //top right
int ld = analogRead(ldrld); //down left
int rd = analogRead(ldrrd);            //down right
int dtime = analogRead(4)/20;        //read potentiometers
int tol = analogRead(5)/4;// tolerance value

int avt = (lt + rt)/2;                              //average
value top
int avd = (ld + rd)/2;                              //average
value down
int avl = (lt + ld)/2;                              //average
value left
int avr = (rt + rd)/2;                              //average
value right
int dvert = avt - avd;//check the difference of up and down
int dhoriz = avl -avr;        //check the difference of left and
right

  if(-1*tol>dvert || dvert>tol)          //check if the difference
is in the tolerance else change vertical angle
  {
    if(avt>avd)
    {
servov= --servov;
    if(servov> 180)
   {
servov=180;
   }
  }
  else if(avd>avt)
{
servov = ++servov;
   if(servov< 0)
  {
servov = 0;
  }
  }
vertical.write(servov);
}
if(-1*tol>dhoriz || dhoriz>tol)        // check if the
difference is in tolerance else change horizontal angle
{
  if(avl>avr)
 {
```

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```
servoh = ++servoh;
  if(servoh< 0)
  {
servoh = 0;
  }
 }
else if(avl<avr)
 {
servoh = --servoh;
  if(servoh> 180)
  {
servoh = 180;
  }
 }
 else if(avl == avr)
 {
  // nothing
 }
horizontal.write(servoh);
}
delay(dtime);
}
```