CONSTRUCTION AND SIMULATION OF DUAL AXES AUTOMATIC SOLAR TRACKING SYSTEM

[1] YUSUF S. J. AND [2] ROMANUS I.O.
[1]Department of Pure and Applied Physics Adamawa State University Mubi, Adamawa State. [2]Department of Science Laboratory Technology Federal Polytechnic Mubi, Adamawa State.

ABSTRACT
This research work presents construction and simulation of dual axes automatic solar tracking system. With the rising cost of conventional energy and the effect it has on global warming, there is a need to develop an alternative way of generating energy. The solar tracking system was designed to align the solar absorbing surface (photovoltaic panel) perpendicular to the direction of sun for maximum absorption of solar radiation. Proteus circuit design software was used to design and simulate the circuit. PIC16F1939 microcontroller programmed in C programming language was used as the control unit; to receive signals from the sensors (light dependent resistors) and to drive the appropriate servo motors. Result of the simulation shows that a pulse modulated waves was obtained at the control terminal of the servo motors. The hardware of the circuit was then constructed and tested. Results of the experiment performed observed an efficiency of 44.08% compared to a fixed photovoltaic system. With such efficiency, the system can be recommended for generating maximum energy from the sun.

Keywords: *Microcontroller, photovoltaic panel, solar tracking, light dependent resistors and servo motors.*

Introduction
A solar tracker is a device or system which orients a photovoltaic panel, parabolic solar concentrator, solar reflector or lens toward the direction of sun for maximum absorption of solar energy. Solar tracker is used to drive a photovoltaic panel perpendicular to the direction of the incident solar radiation (Bazyari, 2014). There are two types of solar tracking systems which are classified based on their mode of motion; single axis and dual axes solar tracker

(Ray, 2012). From the tracking point of view, when a tracker moves the photovoltaic panel from east to west the motion is referred to as horizontal motion. On the other hand, if the tracker moves the panels from north to south the motion is referred to as vertical motion. Solar tracking system can be designed to undergo motion along one of the axis or along both axes. If the tracking system can move the photovoltaic panel along only one axis either east to west or north to south, the tracking system is referred to as single axis tracking system. Alternatively, if the tracking system can move the photovoltaic panel along both axes simultaneously, the tracking system is referred to as dual axes solar tracking system.

There are three categories of solar tracking system depending on their mode of operation; open loop, closed loop and hybrid solar tracking systems (Lee *et al*, 2009). In open loop tracking a microcontroller is programmed to calculate the position of the sun using solar hour angle, solar azimuth, zenith or solar elevation angle which depends on time and location. The tracker then automatically moves the solar panel toward the direction of solar radiation. The close loop solar tracking system uses light sensitive devices such light dependent resistors to sense the direction of solar radiation. A shadow on the light dependent resistor is send to the microcontroller as an error signal and the controller automatically sends an equivalent pulse modulated signal to drive the motor through an angle according to the width of the signal. The hybrid tracker combines both the open loop and the closed loop to track the sun for higher accuracy.

Many studies had been conducted to get the photovoltaic panel aligned perpendicular to the direction of sun, using different techniques (McFee 1975; Zogbi and Laplaze 1984; Nuwahid *et al.* 2001; Roth *et al.*, 2004).The first solar tracking system was designed by McFee in 1975. He designed an algorithm to compute the total received power and flux density distribution in a central receiver power system. Since then, many researchers contributed immensely to the development of solar tracking system. The tracking system proposed will provide a better way of generating energy from the sun.

This research work is intended to design a system that will track solar radiation automatically. To achieve this, microcontroller is programmed to senses the direction of solar radiation from optical sensors and to drive servo motors which turns the photovoltaic panel toward the direction of sun. The system works automatically.

The research has as its thrust to construct a system that orient a photovoltaic panel toward the direction of solar radiation for maximum output of the photovoltaic panel. To achieve this, the following challenges where addressed: To construct an electronic circuit that will sense the direction of solar radiation, to design a DC servo motor control interfaced circuit that will rotate photovoltaic panel (solar panel), to simulate the circuit and to construct an electromechanical system that will automatically tracks maximum solar radiation.

MATERIALS AND METHOD

Materials

The materials used for the tracking system are;

(a) PIC16F1939 microcontroller,
(b)Light dependent resistors (sensors),
(c) Servo motor,
(d) Photovoltaic panel,
(e) Power supply and
(f) Connecting wires.

Two softwares were employed; proteus circuit design software and MPLABX308 programming software. The tracking circuit was con structed and simulated using the proteus software while MPLABX308 programming software was used to instruct the microcontroller.

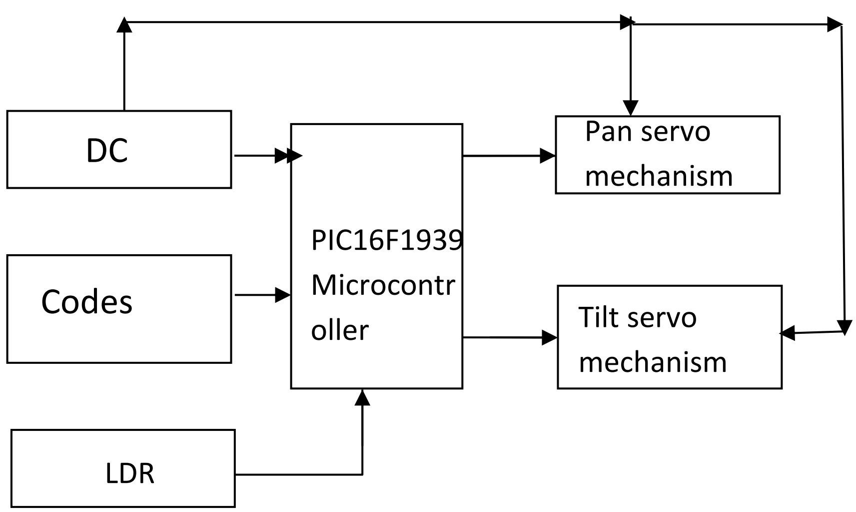

Figure 1;The block diagram of the solar tracking system.

The power supply design

To power the system, two power sources were used. A 9V battery regulated down to 5V using LM 7805 voltage regulator IC and a 5V, 230mA lithium polymer battery to power the two servo motors.

LDRs and pan/tilt servo mechanism

To sense the intensity of the solar radiation, light dependent resistors were used. This is achieved by systematic arraying of four LDRs into a mechanism with four groves called the nose as shown in Figure 2 and Figure 3. The groves was made by crossing two plane wood each having a size of 10.0cm×5.0cm.

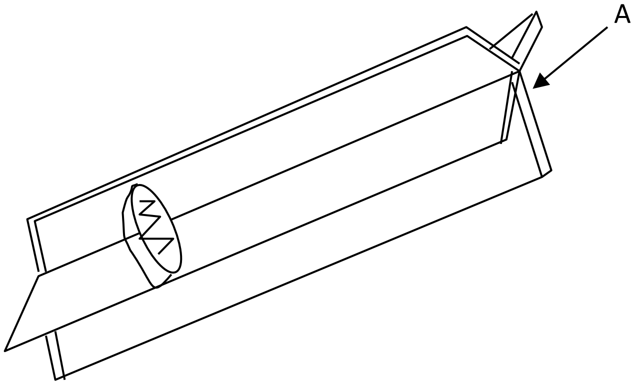

Figure 2. Nose of pan and tilt Mechanism

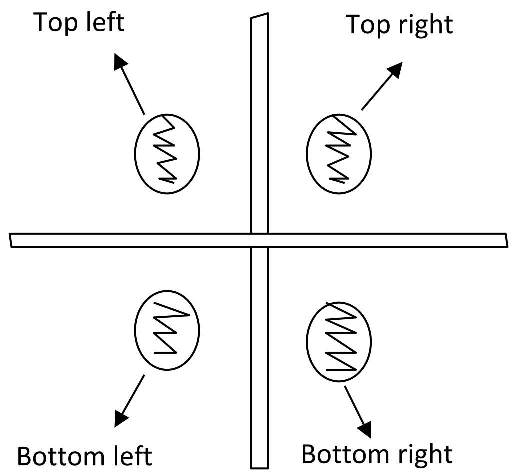

Figure 3. Nose of pan and tilt Mechanism with LDRs installed.

The Voltage Divider

Figure 4 is the voltage divider circuit used in this project.

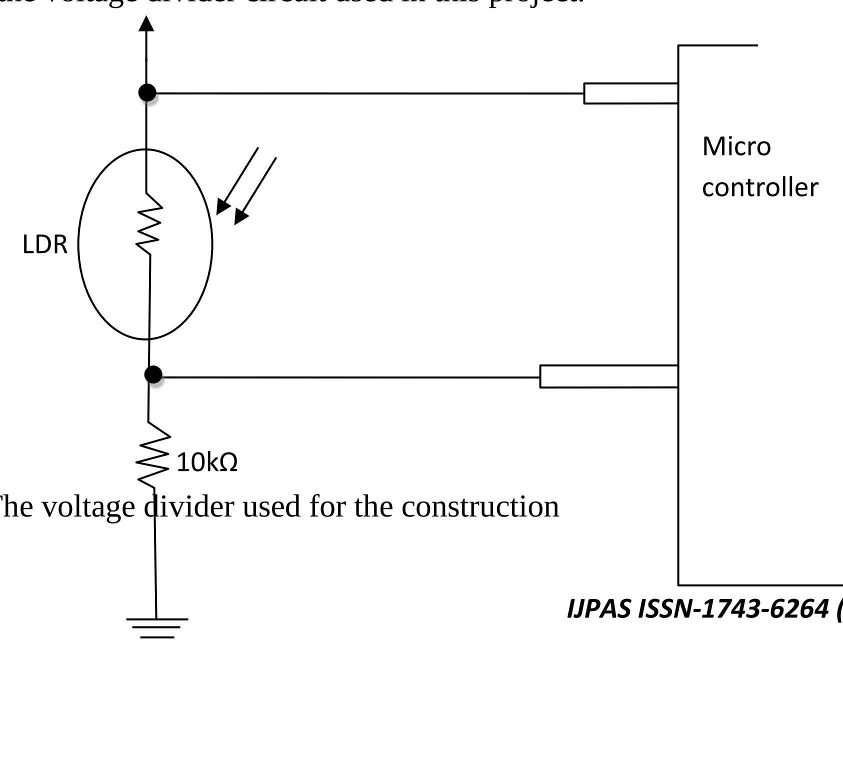

Figure 4. The voltage divider used for the construction

Figure 4. The voltage divider used for the construction

Let V be the input voltage of the microcontroller, as the intensity of the incident solar radiation falling on the LDRs varies its resistance also changes. This causes the input voltage of the controller to vary as the intensity of the solar radiation falling on the LDRs changes. Thus, the input voltage to the controller is giving by the Equation (1)

$$V = \frac{R_2}{R_{1+R_2}} \quad (1)$$

Where R_1 is the resistance of the LDRs and R_2 = 10000Ω standard resistor.

$$V = \frac{10000}{LDR+10000} \quad (2)$$

This is how the microcontroller read changes in resistance as a change in voltage in the voltage divider circuit. In this project, four of such circuits were designed for each LDR. The positions of the LDRs are labeled according to Figure 3.3b. As light falls on the LDRs, the microcontroller read the voltage across each of their voltage divider and regroup these four LDRs thus;

Average top = (top-right LDR + top-left LDR)/2
Average bottom = (bottom-right LDR + bottom-left LDR)/2
Average right = (top-right LDR + bottom-right LDR)/2
Average left = (top-left LDR + bottom-left LDR)/2

The microcontroller then uses an algorithm in the flow chart of Figure 5 to know exactly the direction of the incident light.

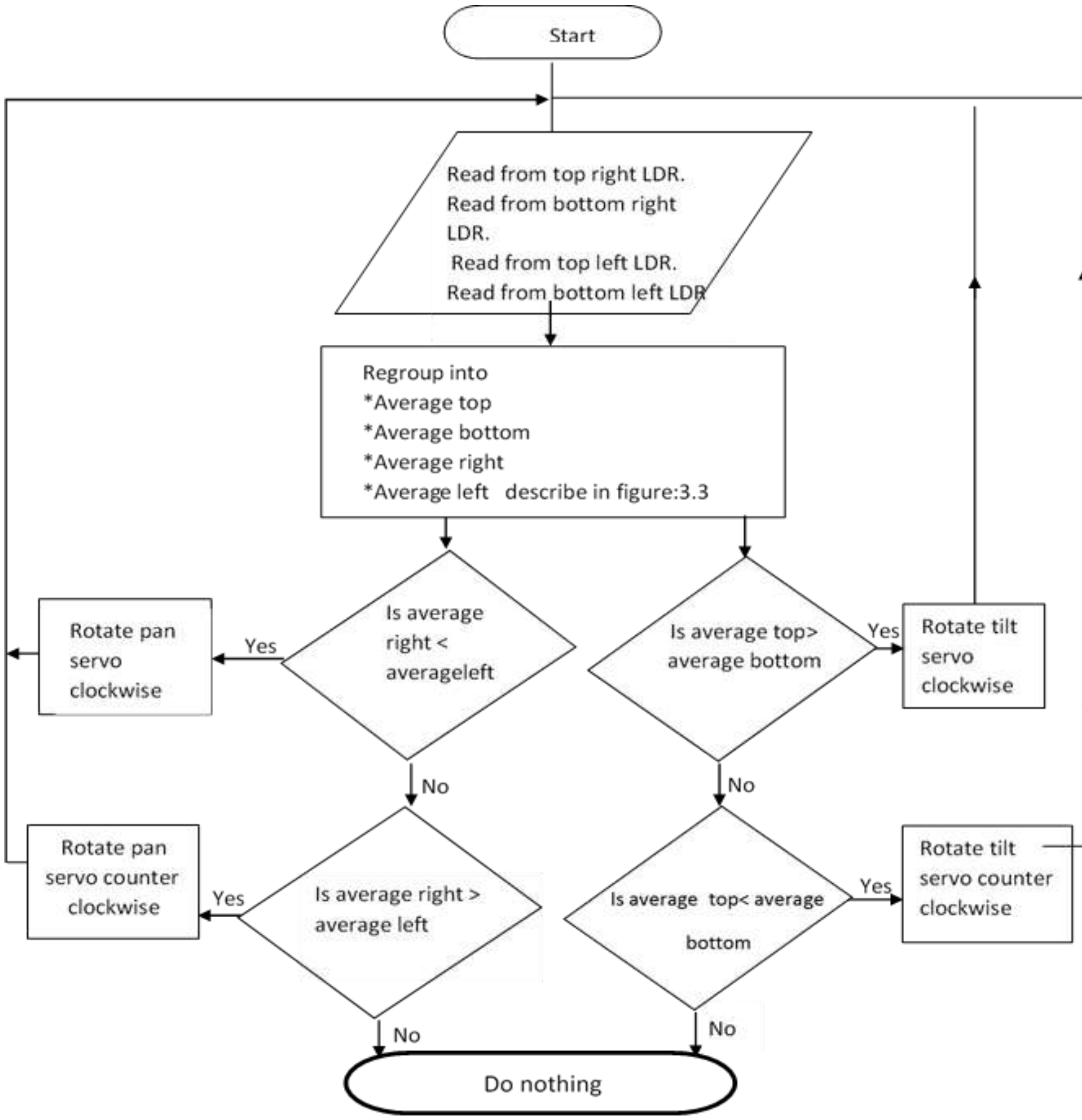

Figure 5. Flow chart showing the algorithm used for the solar tracker

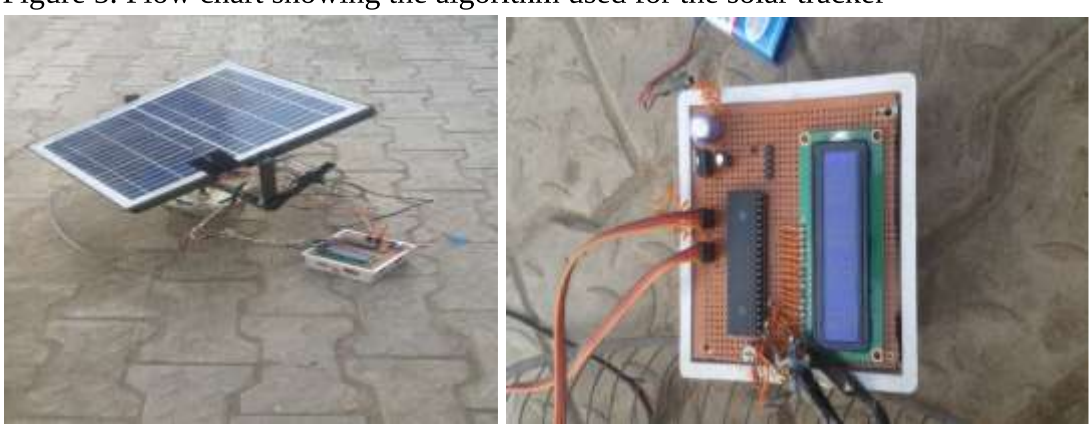

Plate 1. Complete view of the solar tracking system

PIC16f1939 Microcontroller

The microcontroller is the brain of the tracker, and it controls the tracking system. Basically, it receives input from sensors, specifying position of the sun and in response it sends pulse to move the panel to the direction of the sun in which optimum solar rays could be received. The microcontroller is made of software and hardware components. The software component is basically the computer program that decodes the input signals and set out appropriate signals in response to the input to control the tracking system.

Table 1 Output of the tracking system\

Time (hour)	Voltage (V)	Current (A)	Power (W)
9.00	15.73	0.90	14.16
10.00	16.05	0.98	15.73
11.00	16.15	1.08	17.44
12.00	16.78	1.14	19.13
13.00	17.98	1.18	21.21
14.00	17.30	1.12	19.34
15.00	16.78	1.10	18.23
16.00	15.66	0.95	16.91
Total power			142.15

To design the codes of the microcontroller, an MPLABX308 programming software was obtained and installed into a computer system. The codes were written in C programming language according to the algorithm of Figure 5 i.e. to sense the direction of light from the four light dependent resistors and produce appropriate signal to drive the servo motors.

To convert the program written in C programming language into a machine language understandable by the microcontroller an XC8 compiler was used. The compiler generate hex files which contains all the instructions written in C programming language and convert them into machine language readable by the controller.

The Driver Circuit

Two MGR996R metal gear servo motors were used to drive the photovoltaic panel in this research. A servo motor is an electric motor that rotates its shaft with great precision base on the instruction it receives through the control terminal. It provides angular precision, which means, unlike other electrical motors that keep on rotating when power is applied to them and stop only when power is switched off, the servo motor rotates only to a certain degree depending on the width of the pulse width modulated signal it receives from the controller.

Figure 6 MGR996R metal gear servo motor (MGR996R Datasheet)

Two of such motors were used, One to serve as a pan servo to rotate the photovoltaic panel horizontally about East-West axis and the other as a tilt servo to rotate the panel vertically about North- South axis. The two servo motors were coupled mechanically on an aluminum metal frame. The control signal applied to the control terminal of the two servos is a pulse modulated signal generated from the microcontroller whose width depends on the intensity of the solar radiation received by the light dependent resistors (sensors). To connect the servo motors to the microcontroller, programs are written using C programming language and then linked to the microcontroller using PICkit3 to command the microcontroller to generate pulse modulated signals that rotates the servo motors appropriately.

Method of Simulation

After the circuit has been designed using the proteus circuit design software and the codes were designed using MPLABX308 programing software, the circuit was then simulated.

Mechanical Coupling

After the electrical design the overall structural design of the solar tracker is coupled mechanically. The electrical components were connected using soldering iron and lead on a printed circuit board. The photovoltaic panel is mounted on an iron metal frame of suitable size. The two servo motors were fixed on the metal frame to hold the photovoltaic panel such that one rotates the photovoltaic panel vertically (upward or downward) and the other rotate it horizontally (rightward or leftward). The tracker is design to have a dual movement. The fixture to hold the sensors is then assembled. Plane wood was cut into two equal size and fixed to cross each other to form four grooves. The light dependent resistors were fixed on each groove to sense the direction of incoming solar radiation. The plane wood acts as an opaque object to the incoming solar radiation.

The Circuit Diagram of the Solar Tracking System

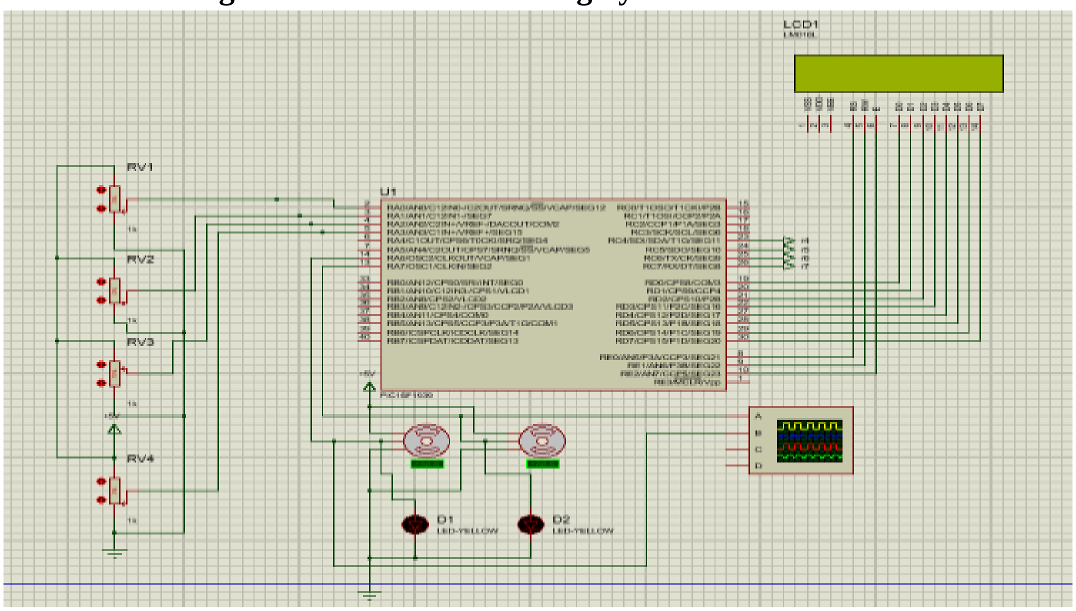

Figure 7 Circuit diagram of the tracking system

Principle of Operation

When powered, the whole system turn ON, the microcontroller begins to read the voltages from the four LDRs and follows the algorithm describes in the flow chart. If the average voltage readings from the voltage divider circuit of top-left and top-right LDRs is greater than the average voltage readings of bottom-left and bottom-right LDRs, then the microcontroller sends signals to the tilt servo to move the servo upward otherwise it sends signal to the tilt servo to move the servo downward. Also, if the average voltage readings from the voltage divider circuit of the top-left and bottom left LDRs is greater than the average voltage readings from the voltage divider circuit of top-right and bottom-right LDRs, the microcontroller sends a signal to the pan servo motor to move toward the left otherwise it sends the signal to the pan the servo motor to move toward right.

Efficiency of the tracking system

The efficiency of the tracking system is calculated with the aid of Equation (3).

$$Efficiency = \frac{power\ of\ trcking\ system - power\ of\ fixed\ photovoltaic\ system}{power\ of\ fixed\ photovoltaic\ system} \times 100\%$$

(3)

RESULTS AND DISCUSSION

Results

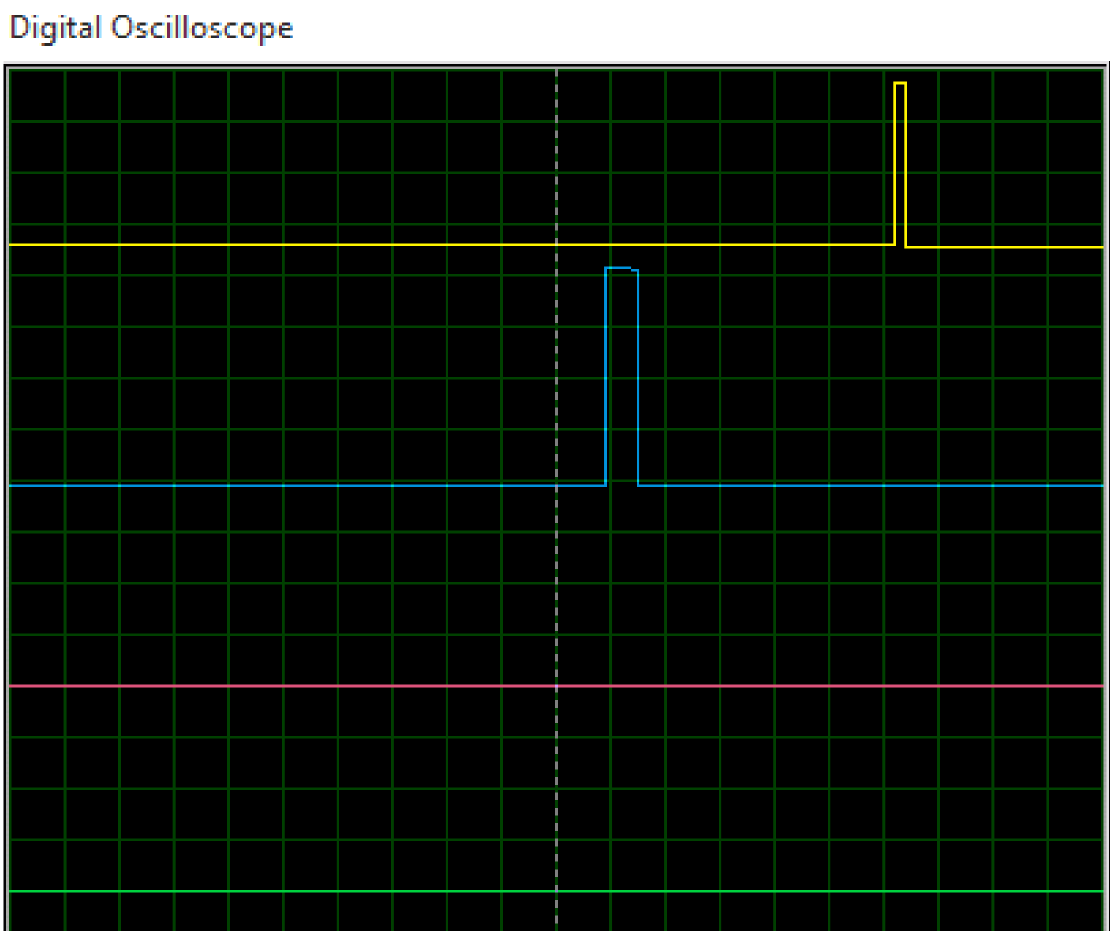

Figure 8. Result of the simulation from an oscilloscope showing the pulse of square waves that\drives the servo motors.

Table1 showing current, voltage and power from the tracking system, the power was obtained using

$$P = VI \quad (4)$$

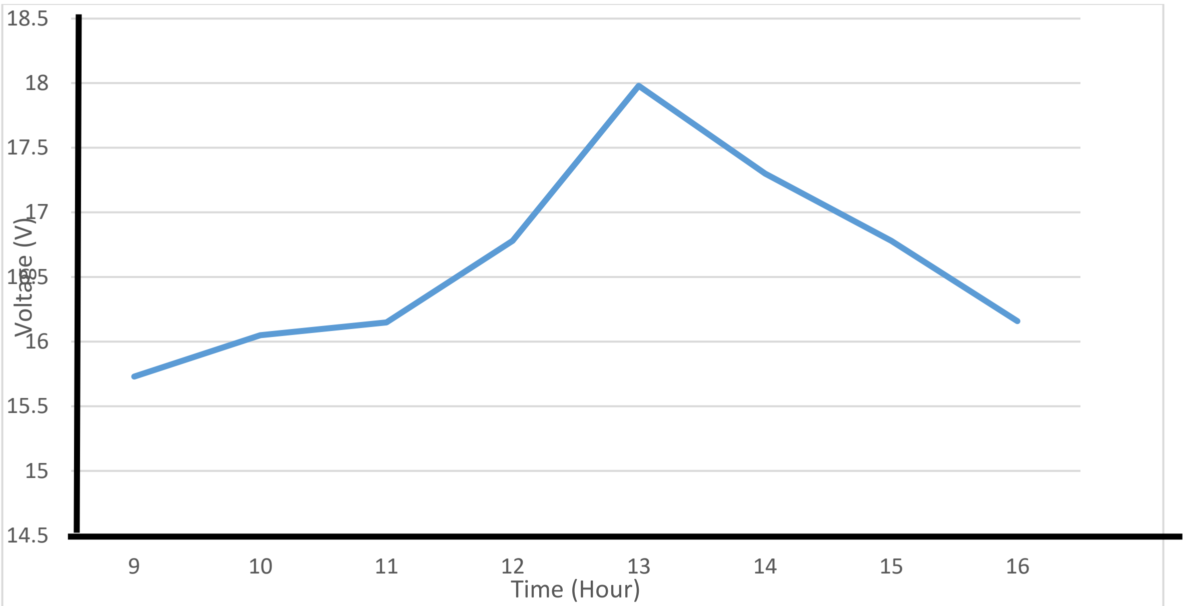

Figure 9. The graph of voltage against time for the tracking system

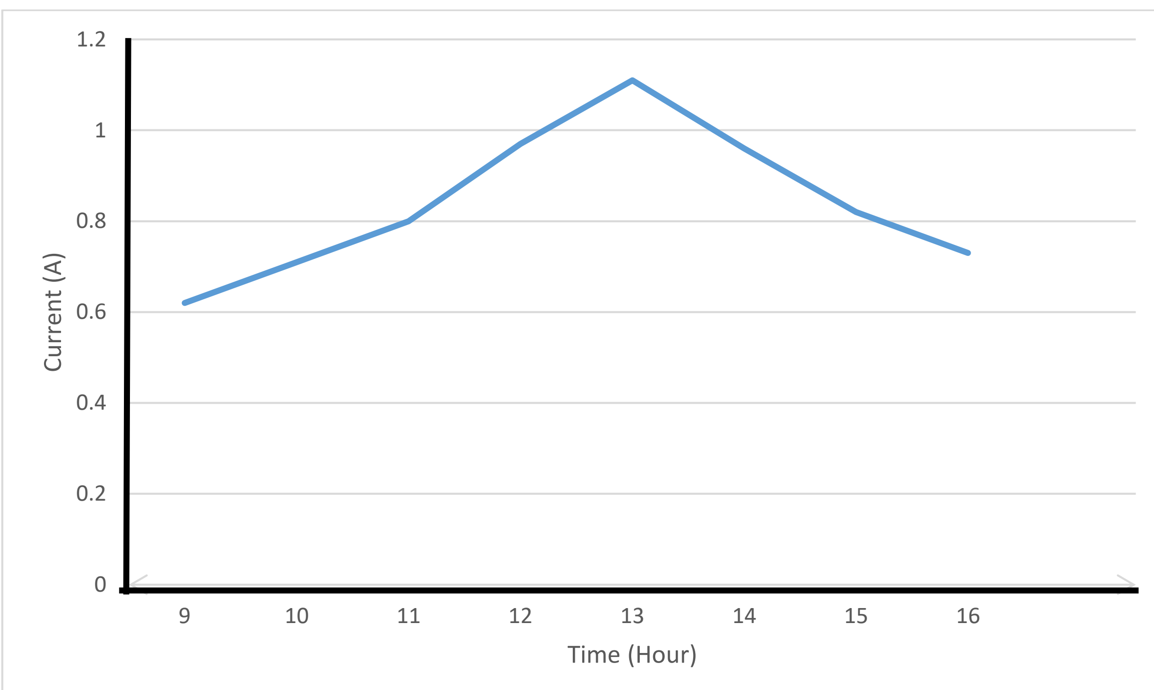

Figure 10 the graph of current against time for a tracking system.

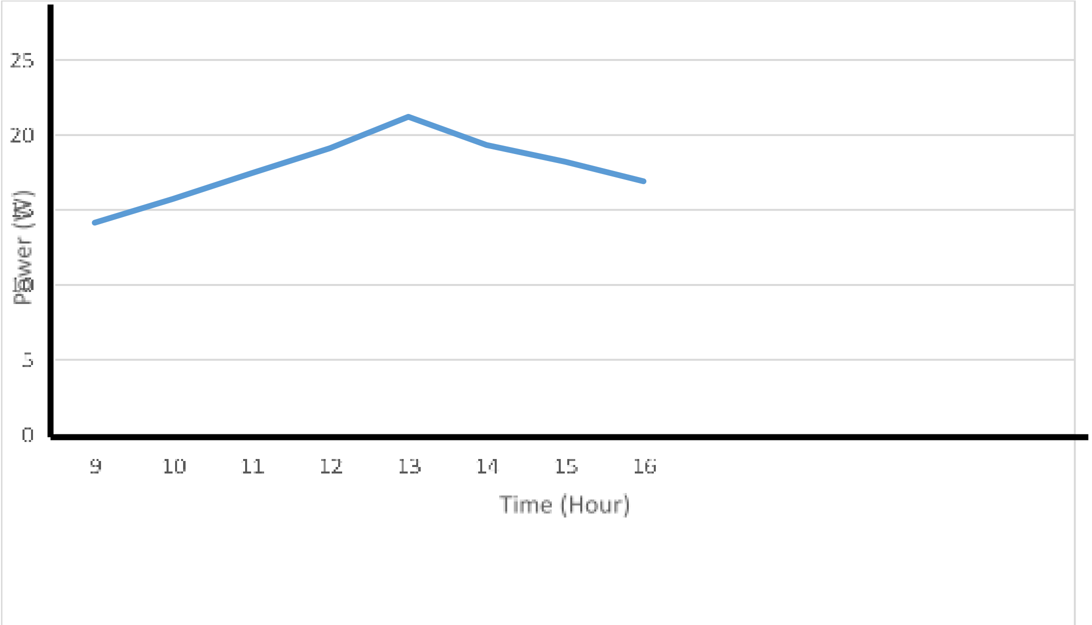

Figure 11. The graph of power against time for a tracking system.

Discussion

Figure 8 shows the results of simulation of the solar tracking system obtained from an oscilloscope. During simulation, it was observed that when the play button was pressed, current begins to flow through each of the components that made up the circuit. The two servo motors adjust themselves to their neutral position while the crystal display LCD1 lights up and begin to display the variation of the potentiometer as a results of the variation of the resistance of the light dependent resistors (LDRs).

It was observed that when the voltage of each of the potentiometer circuit is varied as seen on the crystal display LCD1, the appropriate servo rotate to a certain angle. For instance, it was observed that when the voltage of the LDR1, is increased up to 140mV, servo motor1 rotates clockwise. At times as the voltage of the sensors are kept varying, both servos are observed to rotate in either the same direction or in a direction opposite to each other. This shows that the sensors (light dependent resistors) might have sense the direction in which the light intensity is high and then send it as an error signal to the microcontroller. The microcontroller then convert the analogue signal into digital (pulse modulated signal) using its analogue to digital converter (ADC) that drives the motors in a direction according to the width of the signals. Thus, since the variation in the voltages as a result of the variation of resistance causes the microcontroller to generate signal that drive the appropriate servo motor, objective one and two of this study is achieved.

From the data obtained in Table.1 an efficiency of 44.08% was observed. This supported the works of Zogbi and Laplaze 1984, Nuwahid *et a*l. 2001, Rubio *et al*. 2004, Abdallah and Nijma 2014, Kiyak and Goi 2016 i.e. the output of the tracking system increases compared to a fixed photovoltaic system.

Conclusion

In this research, sun tracking system was designed and constructed based on microcontroller as the control unit. The microcontroller based circuit with few components was used to drive servo motors which provides accurate tracking of the sun.

All the objectives were achieved, after the design and simulation, the hardware components of the circuit was then obtained and build on a printed circuit board. The whole system was then coupled mechanically on a frame. Result of testing in a laboratory shows that when the direction of light from high intensity touch light is varied, the system automatically moves the photovoltaic panel toward the direction of the light. The fourth objective of the research work which was to construct an electromechanical system that automatically track the direction of solar radiation was achieved.

The constructed device was then taken to an open environment to observe its output power. Digital multimeter was used to measure the output voltage and current of the tracking photovoltaic systems after each hour starting form 9:00AM in the morning. Results obtained shows that an efficiency of 44.08% was obtained compared to a fixed photovoltaic pane tilted at an angle of 45^0 south-west. With such an efficiency, the device can be used for generating electricity from the sun.

Recommendation

The automatic solar tracking system is recommended for generating energy from the sun because of its reliability and cost effective as compared to the usage of conventional energy. Analysis made realized an efficiency of 44.08% compared to a fixed photovoltaic system. Therefore, the device can be used as an alternative means of generating energy and reduced the risk posed on animals by global warming.

REFERENCES

Abdallah S. and Nijmeh S. (2004). Two axes sun tracking system with PLC control. *Journal of energy conversion and manage*. 45:1931–1939.

Bazyari S., Reza K., Shahrokh F., Amir G. and Khashayar B. (2014). A Study on the Effects of Solar Tracking Systems on the Performance of Photovoltaic Power Plants. *Journal of Power and Energy Engineering*, 2:718-728.

Kiyak E. and Gol G. (2016) .A comparison of fuzzy logic and PID controller for single Axis solar tracking system. *Journal of renewable energy*. 2(1) 98-94

McFee R.H. (1975). Power collection reduction by mirror surface non flatness and
Tracking error for a central receiver power system. *Appl. Opt*. 14: 1493-1520

Nuwahid R.Y., Mrad F. and Abu-said M. (2001). The realization of simple tracking Concentrator for the university research application. *Renewable energy*, 24: 207-222.

Ray S. (2012). Calculation of sun's position and tracking the path of sun for a particular geographical location. *International journal of emerging technology and advanced engineering.*

Roth P., Georgieg A., and Boudinov H. (2004). Design and construction of a system for sun-tracking. *Journal of Renewable Energy*, 29: 393-402

Rubio F.R., Berenguel M., Valverde A., Lara P.J., Arahal M.R., Camacho E.F. and Lopez M. (2004). An artificial vision-based control system for Heliostat Position offset correction in central receiver solar power plant. *Solar Energy*, 76: 563-575

Zogbi R. and Laplaze D. (1984). Design and construction of solar tracker. *Solar Energy magazine,* 33: 369-372