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Design and Implementation of a Dual Axis Solar Tracker Using Arduino Microcontroller

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Abstract: Energy is pivotal to the human and capital development of any nation; hence, the ever growing quest to discover reliable and sustainable energy sources. Researches on renewable energy sources ranging from wind, tidal, hydro power and solar energy is on-going; all geared towards providing better electrical energy source. Solar energy, however, holds a very promising future as far as sustainable energy solution is concerned. It is silent, green, with zero negative impact to the globe and no pollution. Unlike the conventional energy sources from fossil fuel, it reduces greatly the impact of global warming and remains endless. The developed solar tracker has two automatic tracking axis for both the zenith daily and the azimuth annually as well as displaying in real-time solar irradiation and tilt angles on the mounted LCD. The self-controlled tracking is achieved by using a MEGA2560 microcontroller board, programmed to read analog values from an array of LDRs, convert them to digital values, compare them and drive the stepper motors in the desired direction until equal light is sensed by alternate LDRs. At this point, the panel is aligned perpendicular to the sun rays to capture the maximum possible energy. A working prototype is successfully designed and constructed. The testing revealed very precise tracking made possible by using micro-stepping modes of the stepper motors. This also gave a very high tracking accuracy of about $\pm 0.056^0$.

Keywords: Dual Axis Tracker, Solar Irradiation, Solar Panel, Stepper Motors, Tilt Angle.

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1. INTRODUCTION

The world population is increasing by the day, so also is the energy demand. In Nigeria for instance, it has been observed by [1], that the current energy demand in the country far exceeds the supply which results to a situation often termed “epileptic power supply”. According to [1], the recent crash in the prices of crude oil and the instability experienced in most of the regions where this resource is produced is evident to the fact that these energy sources are not reliable. Besides, it is common knowledge that these resources are exhaustible and hence, un-sustainable. Ironically, most countries of the world still depend on this unsustainable energy sources to meet their energy needs.

In the quest to find solutions which will be sustainable, affordable and reliable substitute for crude oil, researches have been on-going on ways to perfect the use of renewable and green energy sources. Green energy can be recycled, much like solar energy, microhydro power, wind power, biomass energy, terrestrial heat, temperature difference of sea water, sea waves, morning and evening tides. Solar technology is one of the highly promising sources of future energy supplies because it’s environmental friendly and remarkably universally abundant nature. Without doubt, solar electricity has continued to prove successful in addressing the predicted future energy need. Different researches estimate that covering 0.16% of the land on earth with 10% efficient solar conversion systems would provide 20 TW of power, nearly twice the world’s consumption rate of fossil energy [2]. This proves the potential of solar energy which in turn points out the necessity of maximizing the captured solar irradiation by the provision of solar tracking mechanism. It is in this regard that the Arduino based optimum tilt angle dual axis solar tracker is proposed.

Since the emergence of solar electricity, various methodologies have been employed in the system design and installation; with the view of harnessing to a greater extent the sun’s irradiations. Various researchers in this field have designed, simulated, implemented, and discussed their different ideas; all aimed at improving the efficiency of already existing systems.

A study on people in underprivileged cities of developing countries and how they could benefit from the use of a solar distributed generation system done by [3] assessed possible means to provide an efficient solar distributed generation system using a scaled down dual-axis solar tracker. The tracker aligned with the light source by 1.5 degrees with calculated energy gain of 48.982% compared to an immobile solar panel. Compared to a single axis tracker, its energy gain was 36.504%. This study presents a good analysis because it considered the affordability of solar electricity but without detailed technicalities in the design which could be improved upon.

[2] in his work designed and implemented a dual axis solar tracker using arduino as the main controller. The methodology employed motor driver L298N which is a dual bridge motor driver, Light Dependent Resistors as the

sensor. Results from the work were compared in a table that shows the current and voltage values received from both the static and tracking panel for different times and it led to the following deductions: in a day, it is seen that at 8:00 am there is much improvement in current by tracking panel compared to the static panel. But as time goes on this difference in current between this two technology decreases up to around 1:00 pm. After that when the sun rotates more towards west this difference increases again. The highest current of static panel and tracking panel is 0.28amps and 0.34amps respectively at 12:00 pm. The results were only analytical without giving technical analysis or proffer lasting solution in the implementation.

Investigation of potential system benefits of simple tracking solar system using a PIC16F877, stepper motor and light sensors reading series of values was carried out by [4]. A design of bi-directional solar tracking system was presented by [5]. The study reveals that LPC 2148 microcontroller was used with an internal ARM processor. The signals from the light dependent resistors were used to drive a geared motor to get maximum intensity of light. A 900V inverter and 12volts, 100AH battery was also integrated to power the system. While this work employs good processor to handle the signals thereby ensuring accuracy in the tracking mechanism, it did not show how feasible the system integration to power grid is, thereby leaving a gap in that aspect.

A study carried out by [6], discusses a similar tracking system where the control circuit is based on an ATMega328P microcontroller which is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. This design proved to be efficient. However, it had one degree freedom – one rotating axis and this means it would not account for seasonal changes in sun's position.

A paper published by [7] discussed A Microcontroller Based Solar Tracking System and its Implementation. The block diagram showed a microcontroller interfaced with a stepper motor using a voltage/current driver, three LDRs read analog values which were converted to digital by ADC. This work achieved a single axis tracker but its efficiency is still limited as the sun's annual path is not considered. The paper also recorded that there was no voltage control to take care of the fluctuations due to varying sun intensity.

This work proposes a dual axis tracking mechanism that adjusts automatically to track the solar movement and display in real-time tilt angle values and its corresponding solar irradiance values which could be used for teaching and further research.

2. DESIGN AND ANALYSIS

The entire project is achieved through the design and implementation the various units: input, control and processing and output systems which simultaneously work to achieve the sun tracking. The design of this solar tracker is composed of four main functional units; namely:

1. The tracking and Sensor unit
2. The control unit
3. Irradiance and display unit
4. Power supply Unit.

The other part is a set of instructions for the input processing, decision making and command output, written in C programming language: software Design. The interconnection of these units as well as electronic interactions between these various units is captured in Figure 1.

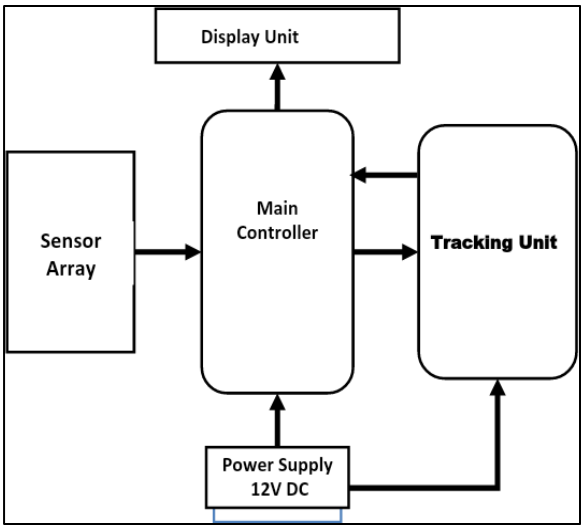

Figure 1. Block diagram of the dual axis automatic solar tracker

2.1 The Tracking and Sensor Unit

This unit is the mechanical framework that carries the payload which will be oriented at optimum position against the sun. The payloads could be photovoltaic panels, reflectors, Collectors, lenses or other optical devices. This will be achieved via comparing the inputs from the light sensors. The solar panel is attached to a stepper motor shaft; the motor rotation results in the tilting of the angle at which the solar panel is inclined.

The specifications of the solar panel used are summarized in Table 1.

Table 1. Solar Panel Specifications

Features	**Description**
Dimension (mm)	255 by 190
Maximum power (pmax) (W)	5
Output tolerance	±5%
Current at pmax (A)	0.29
Voltage at pmax (V)	17.5
Short circuit current (A)	0.32
Open circuit voltage (V)	22.05

2.2 Stepper Motor

The DC motor selected for this work is a bipolar stepper motor, NEMA 17 variant. It is chosen because it provides just sufficient torque to support the mechanics of the design efficiently. Table 2 shows some of the technical specification of the stepper motor.

Table 2. NEMA 17 (17HS8401) Technical Specifications

Step angle accuracy	±5% (Full step, no load)
Resistance accuracy	±10%

Inductance accuracy	±20%
Temperature rise	80deg max(Rated current 2phase on)
Ambient temperature	200deg ±50deg
Insulation resistance	100MΩ Min, 500VDC
Insulation strength	500VAC for One minute
Step angle (deg)	1.8
Motor length (mm)	48
Rated current (A)	1.8
Phase Resistance	1.8 Ω
Phase inductance (mH)	3.2
Holding Torque (N.cm)	52
No. Of wires	4
Motor weight (g)	400

Two steppers are used in this design. This is to actualize a two degree of freedom (2DoF) axis that will take into account the Zenithal and Azimuthal movements of the sun as illustrated in the Figure 2.

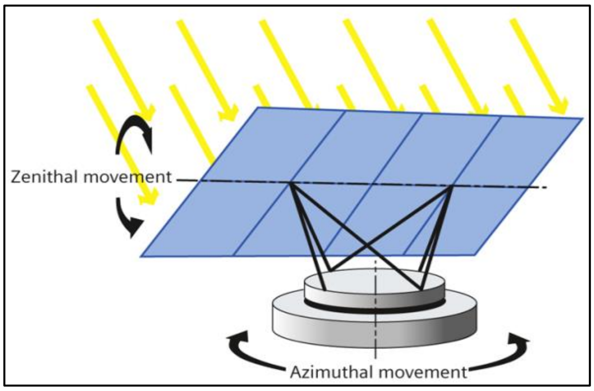

Figure 2. Illustration of the dual axis motion of the tracker.

2.3 Motor Driver

The TB6600 is used in this design. Since the motor requires higher voltage and current than the controller, it is needful to supply the motor independently. The TB6600 driver used for this model is designed around TB6600HG IC which is a Pulse-width Modulated (PWM) chopper type single chip bipolar sinusoidal micro-step stepping driver. Maximum load is rated at 4.5A, supply voltage rages from 10V to 42VDC. It is compatible with Arduino (the choice microcontroller in this design) and other microcontrollers that can output a 5V digital pulse signal. It supports speed, direction and eight different current controls (0.5A, 1A, 1.5A, 2A, 2.5A, 2.8A, 3.0A, 3.5A. A 4-way DIP switch is used to set the micro step modes (1/1, ½, ¼, 1/8, 1/16 [8].

2.4 The Sensor

There are three main sensors used in this design. They are as follows:

1. Light Sensors
2. Accelerometer
3. Solar Cell

2.4.1 Light Sensors

A sensor receives signals and converts it into electrical form which can be further used for electronic devices. The light dependent resistors (LDRs) are used in the circuit to sense the change in the sun's position. To utilize the photocell, it is placed in series with a resistor. A voltage divider is thus formed and the output at the junction is determined by the two resistances [7]. The value is then fed to the analogue input pin of the microcontroller. Figure 3 illustrates the photocell circuit.

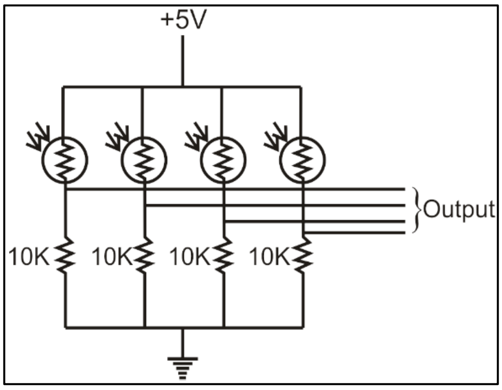

Figure 3. The photocell circuit

2.4.2 Accelerometer

An accelerometer is integrated in the design; this is basically to measure and provide the angle of inclination or tilt of the solar panel in real time. The accelerometer used is the ADXL335. The ADXL335 is a complete 3-axis acceleration measurement system. The ADXL335 has a measurement range of ±3g. The accelerometer can measure the static acceleration of gravity in tilt-sensing applications as well as dynamic acceleration resulting from motion, shock, or vibration [9].

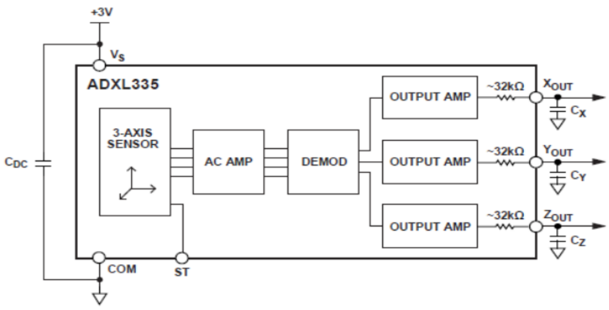

Figure 4. Functional Block diagram of the ADXL355 Accelerometer (ADXL335 Datasheet)

2.4.3 Solar Cell

The solar cell used in this design is to sense the solar irradiation. The circuit is designed using the same principle of voltage divider similar to that employed in the LDR circuit. The solar cell is a photodiode but more sensitive to light than the LDR. The BPW 34 is the package used. It is a very tiny (miniaturized) PiN photodiode. The cell's sensitivity spans across a wide range of light wavelengths (430 – 1100nm). Its rated open circuit voltage, V_{oc} is

350mV and short circuit current, I_{sc} is 47μA [9]. With adequate computer programming and ADC integration, it is calibrated to measure solar irradiance and display the output in Watts per meter square (w/m^2).

2.5 The Control Unit

The processing unit performs the overall control and decision-making function. This decision is based on set of instructions stored in the memory. It takes in series of inputs from the various sensors: light sensors, solar cell and accelerometer and gives output commands to the motor driver which enables the motor to move to align the solar panel perpendicular to the sun. The microprocessor used in this design is the Arduino MEGA 2560 microcontroller board. The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter [16].The power pins are as follows:

Vin: The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). Voltage can be supplied through this pin, or, if supplying voltage via the power jack, access it through this pin.

5V: The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.

3V3: A 3.3 volt supply generated by the on-board regulator. Maximum current drawn is 50 mA.

GND: Ground pins.

Some pins have specialized functions:

Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and14 (TX). Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.

External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2). These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attach Interrupt () function for details.

PWM: 0 to 13. Provide 8-bit PWM output with the analogWrite() function. SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS). These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language. The SPI pins are also broken out on the ICSP header.

LED: 13. This is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

I2C: 20 (SDA) and 21 (SCL). Support I2C (TWI) communication using the Wire library (documentation on the Wiring website).

The Mega2560 has 16 analog inputs, each of which provides 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though it is possible to change the upper end of their range using the AREF pin and analog Reference () function.

Other pins on the board are:

AREF: Reference voltage for the analog inputs. Used with analog Reference ().

Reset: Bring this line LOW to reset the microcontroller, typically used to add a reset button to shields which block the one on the board.

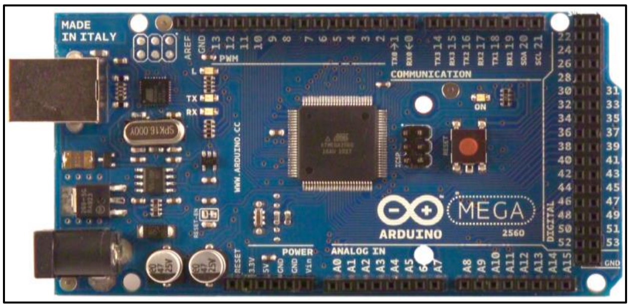

Figure 5. The Arduino MEGA 2560 Board.

Arduino is an open-source physical computing platform based on a simple I/O board and a development environment that implements the Processing/Wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software on a computer (e.g. Flash, Processing, MaxMSP). The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 Universal Asynchronous Receiver/Transmission (UARTs) (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [16].

Table 3. Technical Specifications of the MEGA 2560 Board.

Microcontroller	ATmega2560
Operating Voltage	5 V
Input Voltage (recommended)	7-12 V
Input Voltage (limits)	6-20 V
Digital I/O Pins	54 (14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB (8 KB used by bootloader)
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Source: Arduino MEGA 2560 datasheet

2.6 The Display Unit

The display unit outputs two main values: The solar irradiance value and the tilt angle of the solar panel. The 16x2 LCD is the choice display used. It is a very basic module commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on. The display unit used is the 1602 LCD board interfaced with the I2C board. I2C or IIC is a serial protocol for two-wire interface to connect low-speed devices like microcontrollers, EEPROMs, A/D and D/A converters, I/O interfaces and other similar peripherals in embedded systems. I2C uses only two wires: SCL (serial clock) and SDA (serial data). Both need to be pulled up with a resistor to +Vdd. [22]. The main essence of interfacing the I2C with the LCD is to greatly reduce number of pins which would have been used by LCD to just two: Serial Clock (SCL) and Serial Data (SDA).

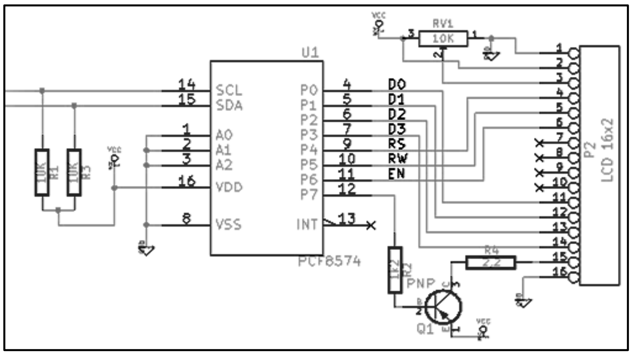

Figure 6. I2C and LCD 1602 Schematics [22]

2.7 The Power Supply Unit

The power supply unit used in this design is a simple 12VDC power adapter delivering 2A current. However, the energy from the system could be used to power the motor driver and the control unit.

3. IMPLEMENTATION

3.1 Software Implementation

The program for the design is written with the Arduino IDE in C programming language and uploaded to the microcontroller via a USB serial port.

3.2 Tracking Algorothm

Figure 7 illustrates how the LDR arrangement works in sensing the solar position. During sunrise, the East LDR will see more light than the West LDR. This is possible because of the opaque sheet separating the LDRs. The microcontroller compares the difference between these values with a set threshold value above which the motor will be enabled to step till the two opposite LDRs see just about equal light then it stops. The same principle is employed in tracking the azimuth when the sun sweeps some 45 degrees North and south. When the sun sets and light falls less than the second threshold value which is less than the first, it returns to a rest position. It continues in this 'sleep' mode till there is enough light on the LDR to 'wake'.

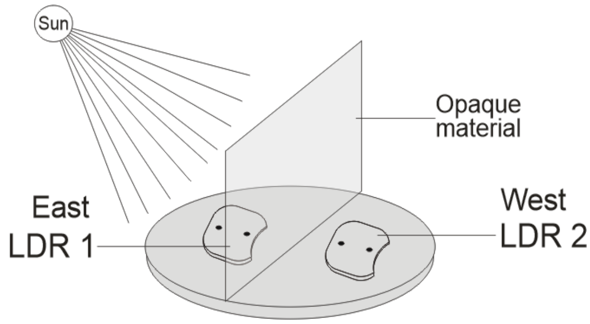

Figure 7. Solar sensing

3.3 Mode of Operation and Flow Chart

When the controller is powered, variables are declared, I/O ports are initialized and then analogue voltages are read. The motion of the system occurs when the TB6600 stepper driver is enabled. The stepper driver has about six pins: Pulse (PUL) +ve and –ve, Direction (DIR) +ve and –ve, Enable (ENA)+ve and –ve. When the enable pin receives HIGH or LOW command from the microcontroller, the motor is energized or turned off respectively. The pulse pin controls the step timing and delay (which brings about speed variations) and the Direction pin when HIGH or LOW causes the motor to step in clockwise direction or anti-clockwise direction respectively. However, to reduce the lines of program, the ENA+,PUL+ and DIR+ are fixed to +5 i.e. permanently HIGH unless the program says otherwise. This is done to reduce wires used in connections and simplify program flow.

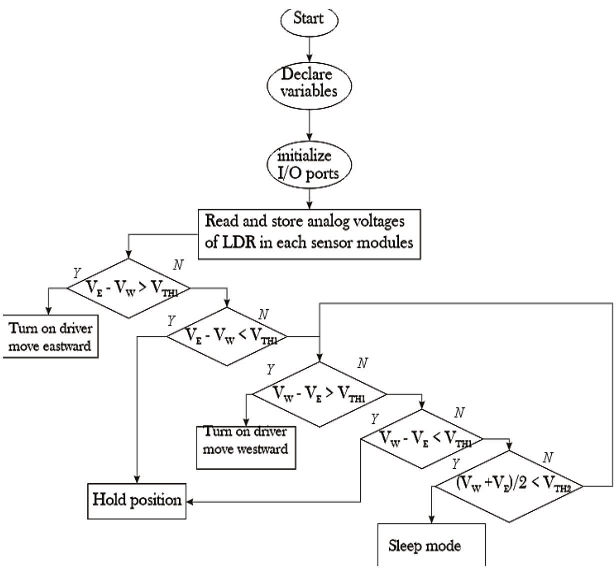

Figure 8. Flowchart of tracking algorithm

In the program flow, a threshold value is set to V_{TH1}, this is the threshold value above which the system will continually track. The difference in the value of the East LDR and that of the West LDR, V_E and V_W respectively is compared with this threshold value V_{TH1}. If the result is true, the motor driver is powered to tilt the panel towards the East. Another threshold value, V_{TH2} is set lower than V_{TH1}. If the difference is below this threshold, the system goes to SLEEP. The same principle is followed to track along the horizontal axis (x-axis).

The operation of the designed solar tracker is achieved by using a MEGA2560 microcontroller which compares the ADC values which is proportional to light intensity illuminated onto the LDRs in each sensor module. The microcontroller has ADC pins to convert analog values to digital values. Each LDR circuit produces analog voltage which is proportional to light intensity. Comparing the values of the LDRs helps in detecting which is under shadow and then send +5V pulse to the motor driver that powers the motor to tilt the necessary axis till about equal amount of light is received.

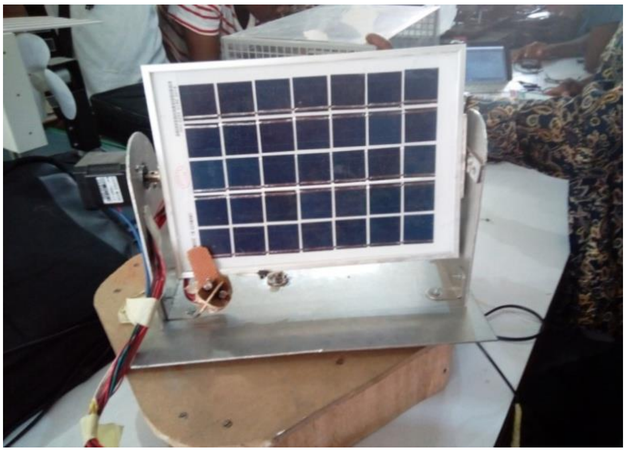

Figure 9. Pictorial view of the solar tracker

Figure 10: Voltage reading of the solar tracker system

4. RESULTS AND DISCUSSION

Table 4 shows the various voltage readings obtained using a multi-meter from the solar tracker and the fixed (horizontally placed) solar panel of the same capacity at different time intervals of the day.

Figure 12 is the plot of the various readings obtained. It can be observed from the plot that there is comparatively much energy yield in the tracking system than the fixed panel. Also, as time increases towards noon, the difference in the energy yield decreases and is approximately equal around noon and continues to increase in difference towards sunset.

Table 4. Voltages obtained from fixed and tracking solar panels.

Time	Fixed Panel Values (Volts)	Tracking panel Values (Volts)
6:00	0.00	0.00
7:00	10.50	11.40
8.00	11.00	15.40
9.00	12.00	17.00
10.00	14.00	17.40
11:00	16.40	17.52
12:00	17.60	17.60
13:00	17.60	17.52
14:00	16.80	17.32
15:00	15.60	17.26
16:00	14.00	17.20
17:00	11.60	17.00

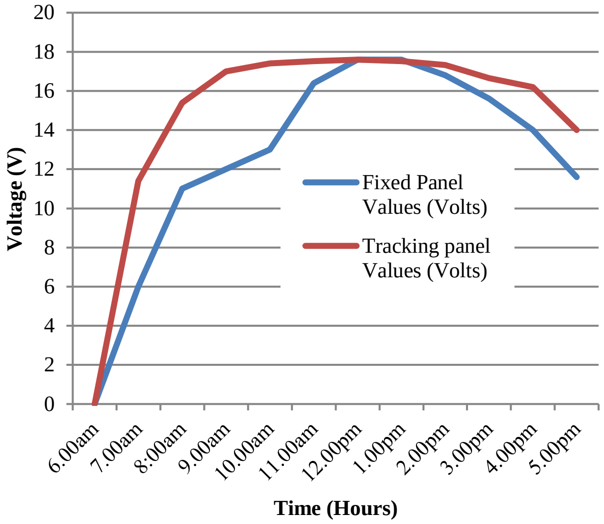

Figure 12. Plot of Output Voltage with Fixed Panel vs Dual Axis Tracker

5. CONCLUSION

In this work, a solar tracking system has been designed and implemented with the result from the tests showing reasonable increase in the energy yield. The mechanicals were done with aluminum sheets and stepper motors were used as the actuators. The sensors used are LDRs, Photo diode (BPW34) and 3-axis accelerometer. An Arduino MEGA2560 microcontroller board was used to control the movement of the solar panel. The decision-making of the microcontroller is based solely on available data collected by the sensor which makes the system intelligent and responsive to changes in the physical environment. Its high resolution tracking makes the alignment of the solar panel very precise as the motor is micro-stepped up till the 32ndth mode i.e. to achieve a rotation of 1.8^0 the motor takes 32 steps, this is the near-peak precision in positioning using steppers. The integration of various sensors helps to obtain useful data which could be used for further research purposes.

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APPENDIX 1 CIRCUIT DIAGRAM