Implementation of a Solar Tracking System with GPS Module Integration

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ABSTRACT

The sun illuminates the whole earth by rising from east and setting in the west. The sun rays irradiating directly on a panel gives the best output and hence the panel must directly face the sun throughout the day for maximum efficiency and output. Hence, a solar tracking system was designed to focus a solar panel directly towards the sun as it moves through the sky every day. It was designed using a single axis tracking controller system, which tracks the sun based on astronomical equations which uses time, date and location to locate the sun's position. The proposed system employs the use of an Arduino Atmega 328P as its major component, saddled with the task of finding the instant sun's position based on a Solar Position Algorithm (SPA) and with the aid of a real-time clock (RTC) and the global positioning system (GPS) module. The system also periodically measures the panel's location using an accelerometer to adjust any error between the measured and the calculated angles. After construction, the system was tested by running it for 10 hours from which favorable results were achieved.

Keyword: - *Solar tracking system, Atmega328p, Solar Position Algorithm (SPA), global positioning system (GPS), and solar panel.*

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1. INTRODUCTION

Over the past three decades, solar energy systems have emerged as a useful source of renewable energy, and is widely applied both domestically and industrially for homes and industries respectively [1]. The high demand of energy and the cost of acquiring energy have prompted the harvesting of the ever present solar energy in the midst of constant depletion and rising cost of conventional sources of energy therefore making the use of solar energy an important alternative source [2], [3]. However, due to the relative motion of the sun with respect to the earth's geographical regions and local atmosphere it is a certainty that the entire earth surface does not experience constant solar irradiance [4]. For this reason, different researches are ongoing on how to extract maximum solar rays for maximum power by designing sun (solar) tracking systems (STSs). These STSs ensure that the solar panel is facing the sun directly for the entire day for optimum efficiency since the parallel rays of the sun irradiating directly gives the best output [2], [3], [5].

STSs are more advantaged compared to their stationary counterparts due to their increased exposure to sunrays. This increase has been estimated to be as much as 10 to 25% depending on the geographic location where the system is planted. In order to design STSs, some critical features need to be adopted such as durability, reliability, accuracy, cost effective, and easy maintenance. Based on the tracking technologies, the STSs is divided into five categories that is, active tracking, passive tracking, manual tracking, semi-passive tracking, and chronological tracking. Amongst these tracking technologies, the active tracking systems account for about 76.42% usage in applications [6]. In terms of degree of freedom (DoF), STSs are classified into two (2) axes namely, Single Axis and Dual Axis as it represents the number of directions the system can independently move [7].

With advancements in computer technology and systems, improving the performance of STSs has become an area of active research in recent times primarily due to importance of selecting optimum driver to control STSs [8]. A solar tracker was developed by Ghosh and Haldar where AT89C51 microcontroller and light dependent resistors (LDRs) were used to control the movement of the solar panel [9]. In [10], an automatic one axis three position solar tracking system was designed in which the DoF is sensed with the use of LDRs thereby minimizing complexity and decreasing cost. Also, a simple tracking system was constructed and tested based on LDRs where the angle between the two LDRs was used to determine the accuracy of the system [11]. There are many designs for these solar tracking systems, but most of them track the sun with the help of light sensors using dual LDRs that follow the sun based on the light and shadow method but this kind of trackers is facing many problems because light sensor's measurements are affected by dust, bird droppings, partially shading by cloud, or reflected light by the glass of the surrounding windows of buildings [12].

This proposed tracking system will solve such problem, by designing a solar tracking system that detect the sun's position with high precision and did not have the light sensor problem using microcontroller. The system periodically read, time and date from a real time controller, and detects location using GPS module. This work will be achieved by solving astronomical equations to locate the sun position.

2. SOLAR POSITION

Based on the sun's apparent azimuth and elevation angles, the solar position is described as a function of local hour and season in reference to an observer at a specific geographic location on the surface of the earth [13].

2.1 Sun path chart

Sun path diagrams are representation on a flat surface of the sun's path across the sky. They are used to easily and quickly determine the location of the sun at any time of the day and at any time of the year. Also, latitude has its own sun path diagram.

From fig-1, one can fully understand that the sun rises from east and set at west. The highest number of the difference between the sun rise time and hour is nearly 12 hours, which occurs during June 21. And the shortest is at December 22 which is nearly 9 hours of daytime. With the help of sun path diagram one can easily determine the position of sun at a given time and date of the year.

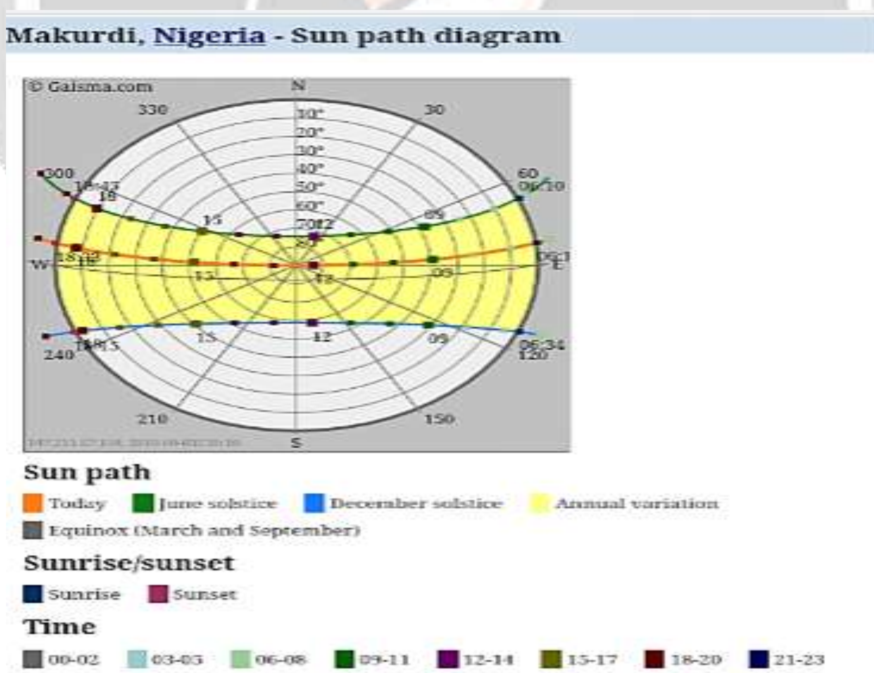


Fig-1: sun path diagram (Gaisma.com)

2.2 Solar Position Algorithm

In 2008, an algorithm was developed by Reda and Andreas for calculating the sun position by using an astronomical approach. This algorithm which is popularly known as the NREL Solar Position Algorithm (SPA) is reported to compute the position of the sun with uncertainty of $\pm 0.0003°$, at the vertex from year 2000 to year 6000 [14].
Furthermore, there are various solar angles that must be known and understood to enable us to actually have good prediction of the sun's positions. See Fig-2:

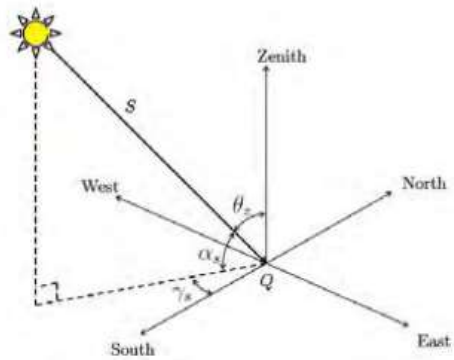


Fig-2: Observer at location Q illuminated by sun ray observed along sun vector SQ, showing solar tracking azimuth and elevation/zenith angles [13].

- Zenith Angle(θ_z) : This is the angle between the line that points to the sun and the vertical. Basically, this is just where the sun is in the sky. The angle is 90º both at sunrise and sunset.
- Elevation angle(α_s): This is the angle between the line that points to the sun and the horizontal. It is the complement of the zenith angle. The angle is 0º both at sunrise and sunset.
- Solar Azimuth Angle(γ_s): This is the angle between the line that points to the sun and south. Angles to the east are negative. Angles to the west are positive. This angle is 0º at solar noon. It is probably close to -90º at sunrise and 90º at sunset, depending on the season. This angle is only measured in the horizontal plane; in other words, it neglects the height of the sun.
- Angle of incidence and reflection(θ): This is the angle between the line that points to the sun and the angle that points straight out of a PV panel (also called the line that is normal to the surface of the panel). This is the most important angle.
- Hour angle based on the solar time(ω): This is based on the sun's angular displacement, east or west, of the local meridian (the line the local time zone is based on). The earth rotates 15º per hour so at 11am the hour angle is -15º and at 1pm it is 15º where 24 hours = 360° and solar noon is zero.
- Surface Azimuth Angle(γ): This is the angle between the line that points straight out of a PV panel and south. It is only measured in the horizontal plane. Again, east is negative and west is positive. The angle would be 0º if a panel is pointed directly south,.
- Latitude($\emptyset$): This is the angle between a line that points from the center of the earth to a location on the earth's surface and a line that points from the center of the earth to the equator.
- Declination(δ): This is the angle between the line that points to the sun from the equator and the line that points straight out from the equator (at solar noon). North is positive and south is negative. This angle varies from 23.45 to -23.45 throughout the year, which is related to why we have seasons.
- Longitude(ζ): This is the east-west position of the solar collector.

Solar position Astronomical equation is a function of time, date and position (Longitude and latitude), with the help of SPA, sun's altitude, azimuth and zenith angle can be calculated with high level of accuracy.
The SPA equations are described in [14] and are presented from (1) to (6):

$$Solartime = Standardtime + 4 \times (\zeta_{st} - \zeta_{loc}) + E \quad (1)$$

$$E = 229.2(0.000075 + 0.001868 \times \cos B - 0.04089 \times \sin 2B) \quad (2)$$

$$B = \frac{360}{365} \times (n - 1) \quad (3)$$

$$\delta = 23.45 \times \sin\left(\frac{360}{365} \times (284 + n)\right) \tag{4}$$

$$\cos\theta_z = (\cos\emptyset \times \cos\delta_s \times \cos\omega) \times (\sin\emptyset \times \sin\delta_s) \tag{5}$$

$$\gamma_s = sign(\omega) \times \left|cos^{-1}\left(\frac{\cos\theta_z \times \sin\emptyset - \sin\delta_s}{\sin\theta_z \times \cos\emptyset}\right)\right| \tag{6}$$

2.3 Development of block diagram

The solar tracker designed for this project is a single-axis solar tracker, which tracks the movement of the sun from east to west. Hence, the azimuth angle is the main output angle needed for this project. For efficient system design, the following devices was selected, which are the GPS sensor for tracking the position (latitude and longitude) of the solar panel, the real time clock (RTC) which is responsible for the time and date signals, the stepper motor is responsible for the movement of the solar panel, the stepper motor was selected because it rotates 360 degrees(because the azimuth angle is more than 180 degrees that's why servo motor are not efficient enough for this work), the accelerometer(ADXL355) sensor which serves as the feedback positional sensor of the stepper motor, and finally the atmega328P microcontroller which receives position signal of the panel from the GPS and time and date from the RTC. After receiving Time, Date and position signals from the peripheral devices connected to it. The microcontroller execute the Astronomical equations using SPA to calculate the sun's azimuth angle before activating the stepper motor to move to the desire angle corresponding to the azimuth angle.

The atmega328P was selected because it supports I2C and USART Serial communication protocol used by the RTC and GPS respectively. Fig-3 shows the block diagram for the proposed tracking system, the block diagram is made up of the following component, the microcontroller, LCD, stepper motor, GPS, accelerometer, and real time clock (RTC).

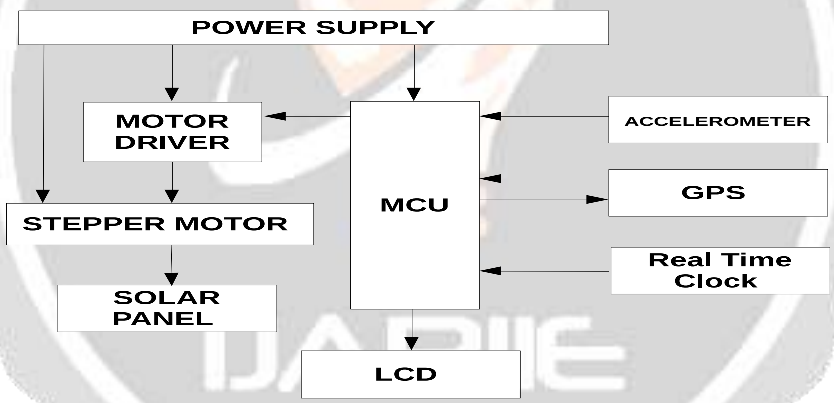


Fig-3: Block diagram

3. CIRCUIT ANALYSIS AND DESIGN

The circuit comprises of different components namely, microcontroller (ATMEGA 328P), LCD display, the GPS module, stepper motor and its driver (ULN2003A), real time clock(RTC), and accelerometer (ADXL3455).

The microcontroller is programmed in such a way that, when it receives its position (longitude and latitude) signal of the solar panel from the GPS module and receives time and date signal from the real time clock, it determines the current position of the sun using SPA. Since the equation of sun position is a function of position (longitude and latitude), time and date. After determining the sun's position the microcontroller now activate the stepper motor to move to the direction of the sun position.

The GPS module uses USART Serial communication protocol in transmitting position of the solar panel to the microcontroller; the real time clock sends time and date to the microcontroller.

3.1 Analysis of stepper motor and its driver

The stepper motor (28BYJ-48) is a DC motor that rotates 360 degrees in precise increments or STEPS. They are very useful when you need to position something very accurately. In this our case, the stepper motor is used in moving the solar panel to the direction of the sun with the help of the DXL345 accelerometer as position encoder for high angular accuracy.

28BYJ-48 stepper motor is powered with a 5V DC supply, and its current rating on full load is 100mA. The stepper motor cannot be controlled directly by the microcontroller because the maximum current (40mA) of the microcontroller pins is less than the stepper motor working current (96mA).

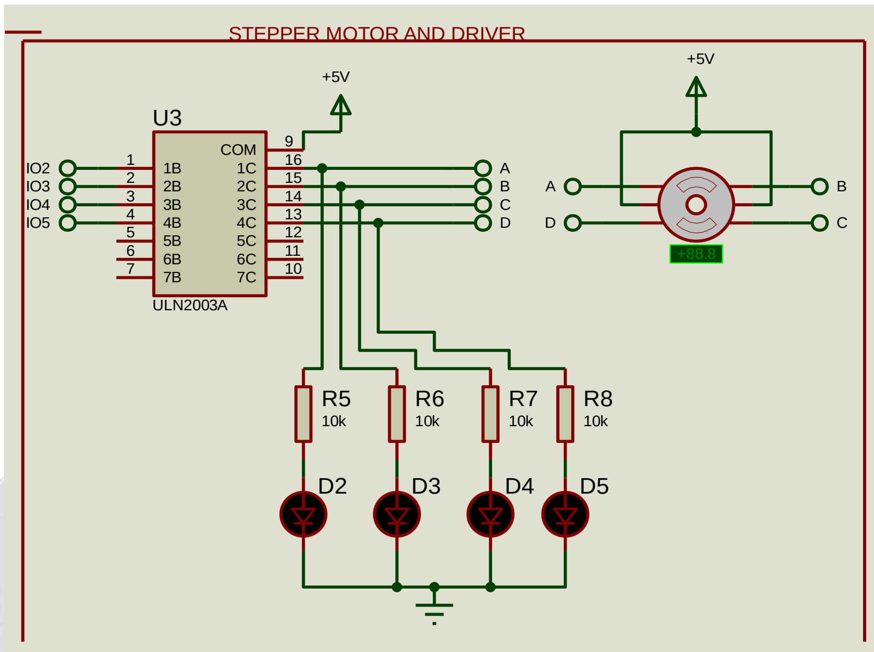


Fig -4: Stepper motor and driver

Before the stepper motor can be controlled, we connected it to the driver (ULN2003A).The stepper motor driver (ULN2003A), is a series of Darlington transistor, which can be powered with a 5V DC supply and can withstand up to 500mA load current. The input of the motor driver is connected to the microcontroller input/output pins (IO2, IO3, IO4 and IO5), and the output which is connected to the stepper motor controlled terminals (A, B, C, D).

V=5V

V_d= forward voltage drop of the LED (D2, D3, D4, D5)

I_f = forward current

$$R=(V-Vd)/If \qquad (7)$$

$R=\frac{5-2}{0.01}=300\Omega$

The equivalent resistor value=300Ω.

3.2 Programming

The programming language used, in programming the microcontroller (ATMEGA 328P) is C/C++. The system was programmed, using Arduino IDE. This IDE was chosen because of its flexibility and simplicity of the programming environment. The IDE has two main functions, the **setup** function and the **loop** function. The setup function runs (execute once) every time the system starts. The setup function is where most of the codes that need to run once in the program are declared. The LCD initialization, RTC, stepper motor, function, and the mode (OUTPUT/INPUT) microcontroller pin. The loop function runs continuously, which is where majority of the code is written. The flowchart is shown in fig-5.

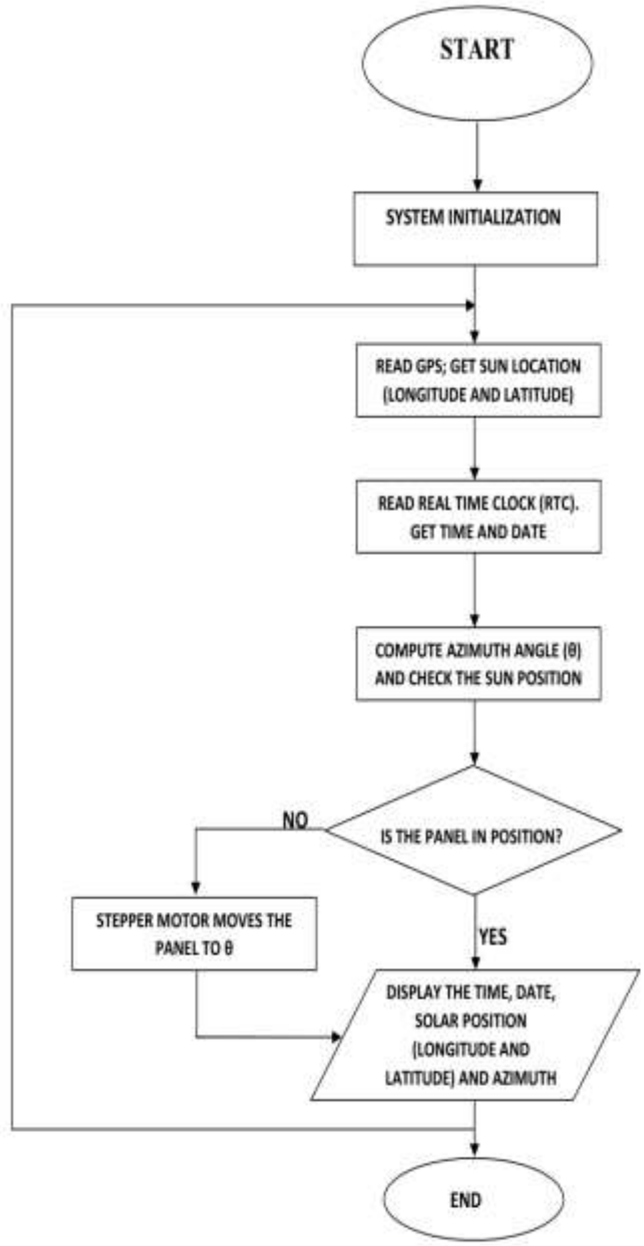


Fig-5: Flow chart of the proposed STS.

3.3 Simulation Model

The circuit was first simulated on Proteus software to test its feasibility and it was confirmed to work properly. The simulation of the solar tracker circuit showed that for every 8 minutes, the system rotates two degrees as shown in fig-6 and fig-7.

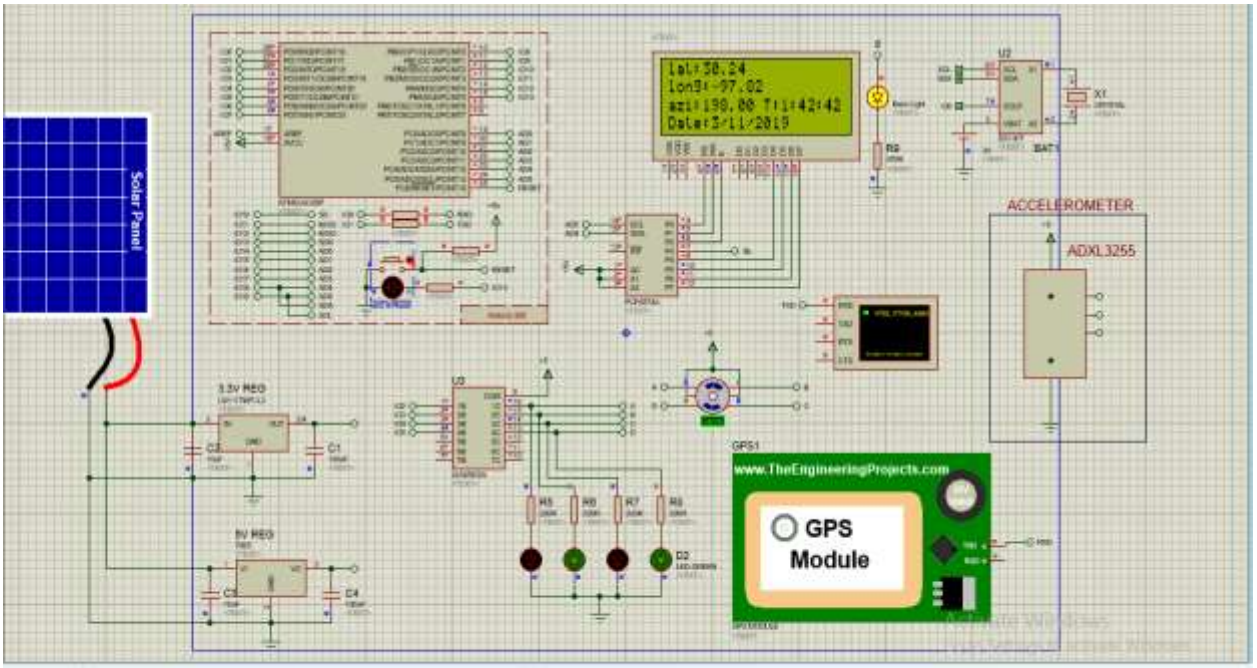
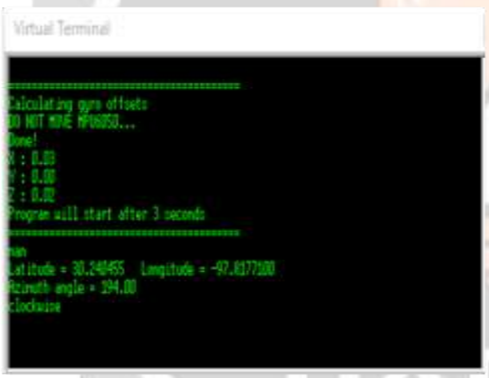
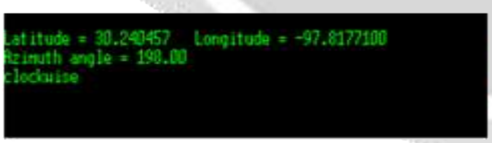


Fig-6: Simulation model



Simulation output for 1st two degree rotation Simulation output for 2nd two degree rotation



Simulation output for 3rd two degree rotation Simulation output for 4th two degree rotation

Fig-7: Simulation output

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4. RESULTS AND DISCUSSION

In the construction of the solar tracker for solar panel with GPS module, all components needed to be use for the project work were assembled and mounted in their appropriate position according to the design specification. Making use of the bread board as a prototype connecting all circuit components, it was observed how the circuit works before mounting the components on Vero-Board. Fig-8 shows the circuit implementation on both the breadboard and vero-board.

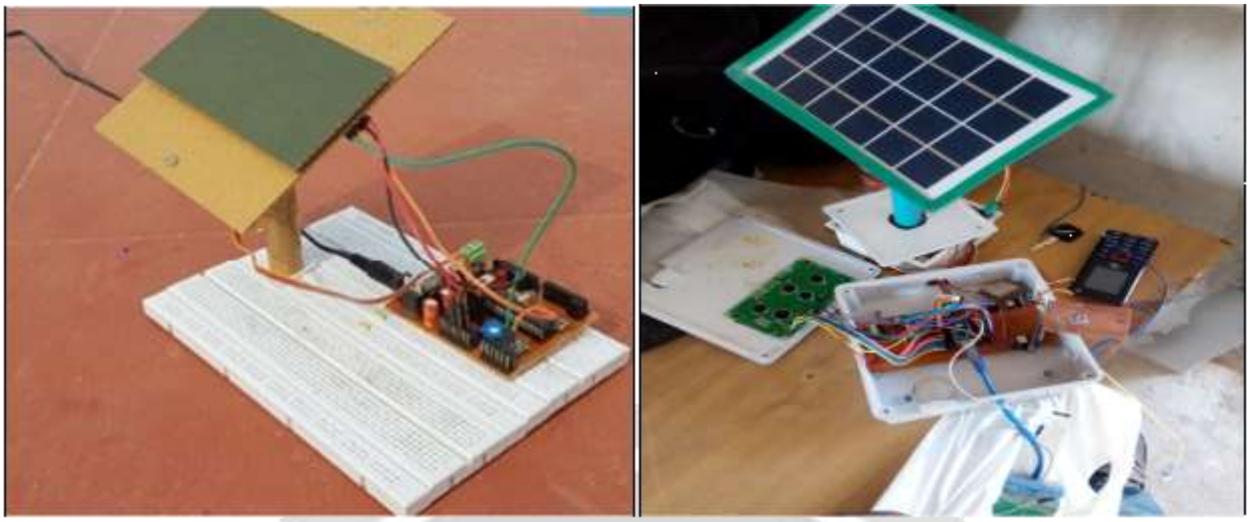

Fig-8: Circuit implementation on breadboard and vero-board.

After the construction of the various blocks that make up the system, they were tested before the final connection. The power units after the construction was tested and outputs of 5V DC and 3.2V DC volts was obtained which was used in powering the Atmega 328p and the GPS module respectively.
When all the blocks were connected to form the circuit, the system was ran for 10 hours the following result was obtained.

Table-1: Results obtained from 10 hours
(NB: Panel's working current= 0.5A, Rating = 3W, Voltage = 6V)

S/N	Time	Azimuth Angle(°)	Output Voltage	Corresponding Output power (W) (P=IV)
1	7.00AM	88.32	3.4	1.7
2	8.02AM	104.48	4.0	2.0
3	9.00AM	121.61	4.9	2.5
4	10.00AM	130.91	5.3	2.7
5	11.00AM	148.53	5.8	2.9
6	12AM	170.39	5.9	2.9
7	1.00PM	203.82	6.0	3.0
8	2.00PM	221.57	6.1	3.1
9	3.00PM	240.01	5.9	2.9
10	4.00PM	255.18	5.8	2.9
11	5.00PM	261.22	5.2	2.6

5. CONCLUSION

The proposed system was carried out in such a way that it requires minimal monitoring and control. Hence, throughout the year maximum amount of solar energy is been collected giving rise to higher efficiency compared to existing trackers. Microcontroller (Atmega328p), was used which controls all the operations of the entire system including the movement of the solar panel.
The overall objective of the project was achieved. Hence, the circuit of the solar tracker with GPS module integration was simulated using Proteus software to validate the accuracy of the system. The simulated circuit was then implemented in hardware.
Nevertheless, there is room for modification in future so as to be replicated to a larger scale.

6. REFERENCES

[1] C. Lee, P. Chou, C. Chiang, and C. Lin, 'Sun Tracking Systems: A Review', pp. 3875–3890, 2009.
[2] O. Aliman and I. Daut, 'Rotation-Elevation to Concentration', pp. 551–555, 2007.
[3] S. Armstrong and W. G. Hurley, 'Investigating the Effectiveness of Maximum Power Point Tracking for a Solar System', pp. 204–209, 2005.
[4] A. Sharma, 'Design of an Automatic Solar tracking controller Solar tracking controller', pp. 505–510, 2017.
[5] E. Science and J. Or, 'A Microcontroller Based Automatic Sun Tracker Combined with a New Solar Energy Conversion Unit', pp. 488–492, 1998.
[6] A. Z. Hafez, A. M. Yousef, and N. M. Harag, 'Solar tracking systems : Technologies and trackers drive types – A review', *Renew. Sustain. Energy Rev.*, vol. 91, no. March, pp. 754–782, 2018.
[7] A. Awasthi, A. Kumar, and M. M. S. R, 'Review on sun tracking technology in solar PV system', *Energy Reports*, vol. 6, pp. 392–405, 2020.
[8] S. Bazyari, R. Keypour, S. Farhangi, A. Ghaedi, and K. Bazyari, 'A Study on the Effects of Solar Tracking Systems on the Performance of Photovoltaic Power Plants', no. April, pp. 718–728, 2014.
[9] A. Engineering, 'Solar Tracking System using AT89C51 Microcontroller and', vol. 4, no. 12, pp. 403–407, 2014.
[10] J. Parthipan, N. R. B, and S. Senthilkumar, 'ScienceDirect Design of one axis three position solar tracking system for paraboloidal dish solar collector', *Mater. Today Proc.*, vol. 3, no. 6, pp. 2493–2500, 2016.
[11] H. Bentaher, H. Kaich, N. Ayadi, M. Ben Hmouda, A. Maalej, and U. Lemmer, 'A simple tracking system to monitor solar PV panels', *Energy Convers. Manag.*, vol. 78, pp. 872–875, 2014.
[12] A. J. Abid, 'Arduino Based Blind Solar Tracking Controller', vol. 5, no. 10, pp. 24–29, 2017.
[13] G. Prinsloo and R. Dobson, Solar Tracking: High precision solar position algorithms, programs, software and source-code for computing the solar vector, solar coordinates & sun angles in Microprocessor, PLC, Arduino, PIC and PC-based sun tracking devices or dynamic sun following hardware. Stellenbosch: SolarBooks. ISBN 978-0-620-61576-1. 2015. p1-542.
[14] I. Reda and A. Andreas, 'Solar Position Algorithm for Solar Radiation Applications', *National Renewable Energy Laboratory (NREL)*, January, 2008.