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Design and implementation of IoT-based dual-axis solar PV tracking system

***Abstract**. In the world today, power generated from solar PV plays a crucial role in the field of sustainable electrification. However, the power produced from solar system reduces significantly owing to the positioning of PV modules. In order to increase the efficiency of solar PV for an improved power generation, this paper proposes the designing and implementation of an IoT-based dual axis solar PV tracking system. The proposed solar tracker control system employs an Arduino based microcontroller unit, Global Positioning System (GPS), web-based connectivity and light-dependent resistors (LDRs). The LDRs are used for detecting the visible light spectrum, thereby enhancing tracking movement of the PV modules. The tracking controller utilizes four intensity signal radiations obtained from LDR sensors as inputs to rotate the axes based on daily sun trajectory. The results obtained from the experimental study shows an efficient performance of the proposed tracking system as compared to a fixed system.*

Streszczenie.** W dzisiejszym świecie energia wytwarzana z fotowoltaiki odgrywa kluczową rolę w dziedzinie zrównoważonej elektryfikacji. Jednak moc wytwarzana z systemu fotowoltaicznego znacznie się zmniejsza dzięki rozmieszczeniu modułów fotowoltaicznych. Aby zwiększyć wydajność fotowoltaiki słonecznej w celu poprawy wytwarzania energii, w niniejszym artykule zaproponowano zaprojektowanie i wdrożenie opartego na IoT dwuosiowego systemu śledzenia fotowoltaiki słonecznej. Proponowany system sterowania trackerem słonecznym wykorzystuje jednostkę mikrokontrolera Arduino, globalny system pozycjonowania (GPS), łączność internetową i rezystory zależne od światła (LDR). Czujniki LDR są używane do wykrywania widma światła widzialnego, co poprawia śledzenie ruchu modułów fotowoltaicznych. Kontroler śledzenia wykorzystuje cztery promieniowanie sygnału o intensywności uzyskane z czujników LDR jako dane wejściowe do obracania osi w oparciu o dzienną trajektorię słońca. Wyniki uzyskane z badań eksperymentalnych wskazują na wydajną pracę proponowanego systemu śledzącego w porównaniu z systemem stacjonarnym.* (Projekt i wdrożenie opartego na IoT dwuosiowego systemu śledzenia fotowoltaiki słonecznej***)

Keywords: Solar tracking system, Dual-axis, Photovoltaic system, Light-dependent resistor, IoT control system.
Słowa kluczowe: system fotowoltaiczny, Internet Rzeczy, .

Introduction

Presently, there is a transition of energy from conventional power system to environmentally friendly, renewable energy sources owing to the demand for clean energy and sustainable electrification [1]. The conventional power system is characterized with large quantity of harmful pollutions from fossil fuel power generation. These pollutions cause deterioration of climate change, global warming and also have adverse effects on both human and animal health [2][3][4]. Therefore, in order to solve this problem, solar photovoltaic (PV) energy, a renewable energy source is becoming more prominent owing to its accessibility irrespective of the location. The Solar PV modules help with the conversion of sun radiation into electrical energy through stimulating the electrons available in the semiconductor resources [5]. The power produced from PV depends on the several factors associated with solar radiation and the angle of orientation of the PV panels [6]-[9]. Hence, the use of Solar PV is characterized with low efficiency as a result of low conversion rate of the PV modules. In order to improve the angle of solar radiation on the PV panel, solar tracking technology can be employed so as to increase the efficiency of solar power generation.

Solar tracking is a method to trail the pathway of sunlight across the sky and keeping the solar PV at a perfect angle perpendicular to the sunlight radiation that can generate an optimal power output [10]. This tracking system can be divided into two rotational modes: single axis and dual axis modes [11]. A single axis racking system offered an adequate tracking ability and it follows the pathway of sunlight in the east-west direction, but are characterized with limited panel rotation leading to higher loss of power generated by PV modules. In contrast, dual axis tracking system have the ability to follow sun directions horizontally or vertically and with more power generation efficiency.

Numerous studies have been conducted on the mechanical design and system controller of the solar tracking system. In [12], a two axes schedule tracking system with a modified algorithm for spreading sun rays in the sky was developed. The spreading of the sun beam increases the power produced from PV panels when compared to the fixed solar tracking system. Ref. [5] presents an overview of dual axis solar tracking system on the recent development of solar tracking system configuration. Authors developed a functional model for an efficient tracking system from the reviews. Ref. [13] presents a sensor-based tracking system using UV radiation to enhance free movement of the tracking system and also the power produced from the PV. Ref. [10] proposed a programmed positioning for two axis tracking system. The tracking system controller was governed using an encoder and GPS. In [14], a fuzzy logic system control for dual axis PV tracking system was proposed. The fuzzy logic controller received the input signal from the sensors and appropriately adjust the moveable motors to place the PV panels in line of sight to the solar radiation. Ref. [15] presents a new offline non-sensor dual axis tracking system for PV and solar concentrator systems. The offline method employed solar map equations to locate maximum point with sun light for more energy capture. Ref. [16] presents both single and dual axes tracking system using adaptive neural fuzzy inference system (ANFIS) technique for predicting the accurate angles to track the exact location of the sun direction across the sky.

Further to the mechanical design of the solar tracking technology, an intelligent based control system is required for enhancing the effectiveness of the PV controller and improving the power generated. Therefore, this paper aims at designing, developing and implementing an IoT-based dual axis solar PV tracking system. Light dependent resistors (LDRs) are employed for tracking the path of the sun direction. The signals of the four LDR sensors are used as input signals to the tracking device mounted on a hydraulic actuator which is capable of following the path of the solar radiation based on the elevated angles. The tracking system employed a GPS module and internet connectivity for ensuring a proper orientation of the panel, remote monitoring and switching control of the system.

The remaining of this paper is categorized into five sections. The theoretical backgrounds of the study are outlined in Section 2. In Section 3, the proposed methods are properly described. Section 4 presents the experimental results and discussions. Finally, Section 5 summarized the conclusions.

Theoretical background

Here, the background overview of the solar PV tracking system is discussed. The global positioning system employs the pseudo-azimuthal system mechanism for the solar radiation coordination and proper location of the tracking system. In addition, the mathematical representation of the PV model is presented in order to evaluate the estimated active power from the PV system so as to ensure accurate efficiency of the tracking system.

Description of the tracking system

The solar tracking system consists of PV module that can convert the solar radiation into an electrical energy and a movable PV panel using two motors. The first DC motor permits the angular movement about its axis in clockwise and anti-clockwise direction, whilst the second DC motor allows a straight-line movement. The location of these DC motors and the direction of their movement are based on the horizontal coordinate system. This system employs a multi-dimensional sphere-shaped surface to evaluate the proper location of objects in the sky. The coordinate system uses both the azimuth angles and altitude to showcase an object position in the sky. The zenith angle is referred as the angle that is incident to the horizontal surface of the PV module. The azimuth angle is given as the horizontal angle that the object makes with respect to the local meridian. Figure 1 represents the path of the sun direction and it is determined by the horizontal coordinate system.

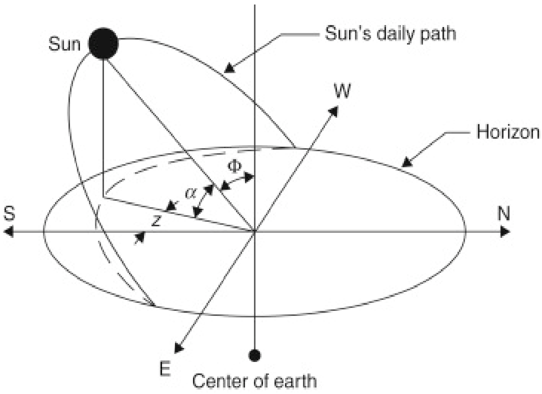

Fig.1. Horizontal coordinate system of the sun position

Mathematical representation of PV model

The solar PV panel produces DC electrical power through conversion of sun irradiation by tapping light photons to obtain electrons. The solar PV consists of several arrangement of PV modules either in series or in parallel connections to give the optimum power output [17][18]. The ambient temperature and system configuration are a determinant factor to achieve the required output power. The power produced by the PV panel can be expressed mathematically as [19]:

$$P_{pv} = I * V * n_m * FF \quad (1)$$

$$FF = \frac{V_{max} * I_{max}}{V_{OC} * I_{SC}} \quad (2)$$

$$I = s(t) * \left(I_{SC} * K * \left(T_{ct} - 25 \right) \right) \quad (3)$$

$$V = V_{OC} + K_v + T_{ct} \quad (4)$$

$$T_{ct} = T_{at} + s(t) * \left(\frac{NOCT - 25}{0.8} \right) \quad (5)$$

where Ppv stands for PV output power, output voltage is represented as V, I is given as terminal current, fill factor is given as FF, Vmax and Imax are the peak voltage and current, Isc stands for the short-circuit current, Voc is given as open circuit voltage, current temperature coefficient is given as K, Tct represents the cell temperature, Kv stands for coefficient of voltage temperature, Tat represents the ambient temperature, NOCT stands for nominal cell temperature, and s(t) represents the random irradiance

Mechanical and electrical structure

Here, the mechanical layout of the solar tracking system is discussed. The structuring of the tracking system is based on the pseudo-azimuthal mounting system approach. The movement of the solar panel as shown in Figure 2 are into two axes of rotations. The panels are made to rotate around the North to South axis and can also be coordinated to follow the path of East to West direction. By rotating both axes, it can be easy to appropriate adjustment both the altitude and azimuth angles.


Fig.2. The axes of rotation of the solar tracking system

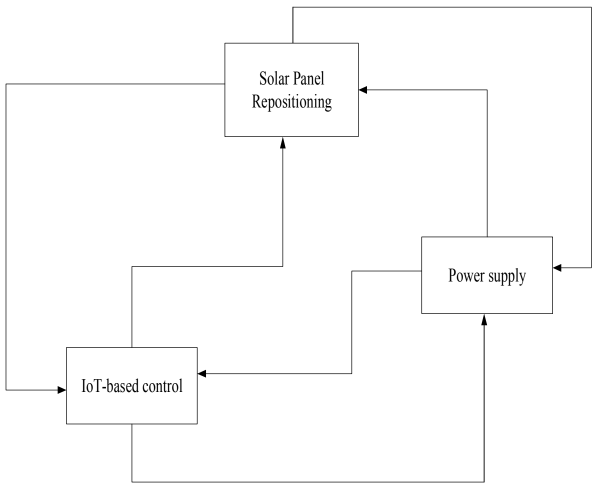

Fig.3. Block diagram of system design

Material and method

The block diagram of solar tracking system is presented in Figure 1, which consists of the solar panel repositioning system, intelligent based control system and power supply. The solar panel repositioning system comprises of the mechanical structure and altitude & azimuth actuators. The intelligent base control system consists of electronic control system, microcontrollers, GPS modules and LDR sensors. The power supply consists of the inverter. The schematic circuit of the proposed solar tracking system is shown in Figure 4.

Solar panel repositioning system

The solar panel repositioning system is shown in Figure 5. This system is responsible for adjusting the position of the solar panel to constantly keep it in the direction of the highest sunlight intensity at a particular location. The system comprises of an adjustable chassis and the actuation unit. The adjustable chassis is designed to ensure rotation of the dual axis. The actuation unit comprises of light dependent resistor (LDR), Arduino microcontroller, L298N motor driver IC, and two electro-mechanical linear actuators.

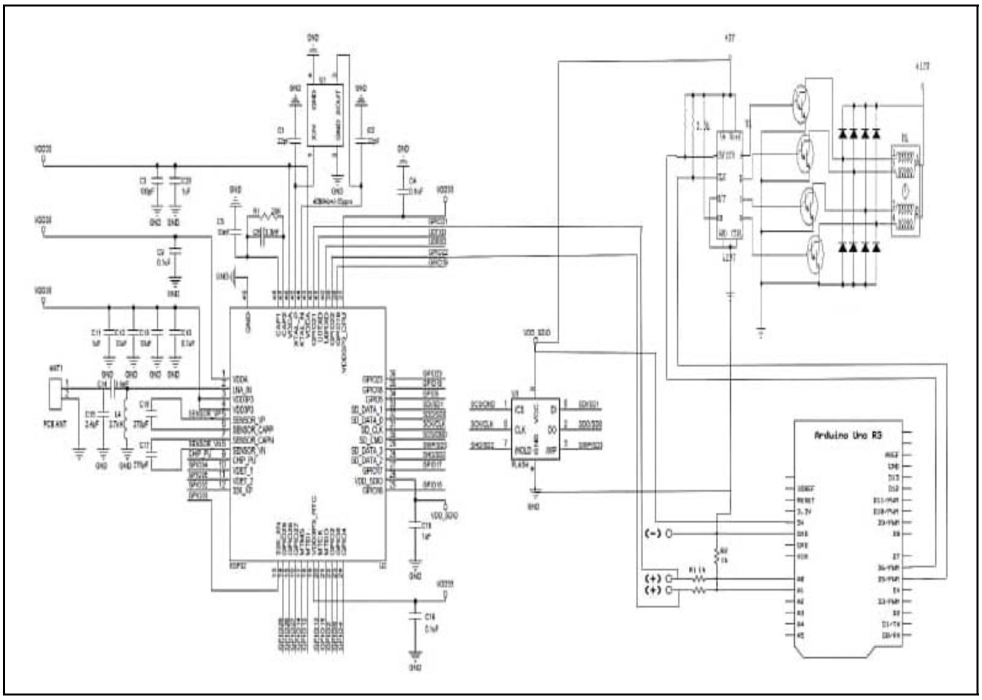

Fig.4. Schematic circuit of the solar tacking system

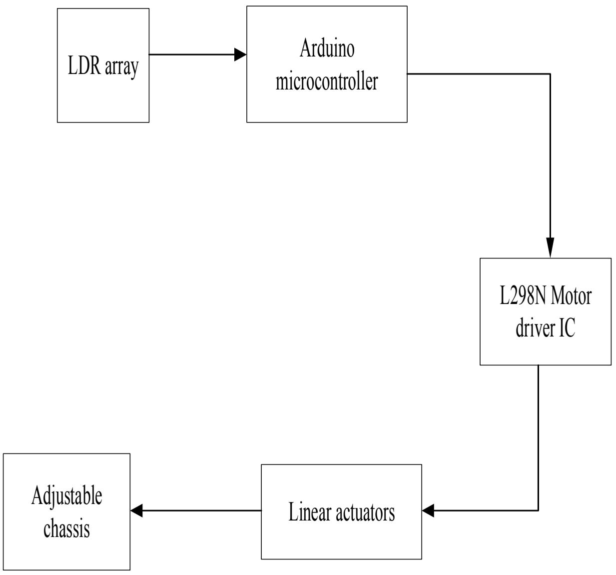

Fig.5. Block diagram of solar panel repositioning system

The LDR arrays is connected to the Arduino microcontroller unit. The Arduino Uno is responsible for reading and interpreting the data received by the LDRs [14]; then performing driving operations based on the received information. The Arduino microcontroller integrates with the Motor Driver IC in order to drive the linear actuators. The information from the microcontroller commands is received by the motor driver IC and it executes the information through the linear actuators. The adjustable chassis are moved by the linear actuators in order to orient the solar panel to the point of highest light intensity.

IoT-based control system

The orientation of the PV panel, remote monitoring and switching was controlled using an IoT based control system. The ease of control of the tracking system is made possible through the use of internet connectivity. The IoT based control system consists of IoT board, load sensors and an isolation circuit as shown in Figure 6. The IoT based control system is designed in remote network controlling of power supply to the water pump and power output of the system and this made possible to control the solar tracking system through internet connectivity. The IoT based control system consists of ESP32 IoT board, two relay drivers which serve as an isolation circuit, a PZEM004T to serve as a load sensor and the web application. The web application was designed using HTML, CSS and JavaScript programming languages. These programming languages help in the coding and this is embedded into the microcontroller board as shown in the algorithm flowchart presented in Figure 7. The web application helps the user to send a switching commands to the water pump and the inverter through the internet connectivity as shown Figure 8. ESP32 IoT board serves as the web server, which relays the switching commands the components. The isolation unit helps to connect and disconnect the power supply from the water pump and inverter.

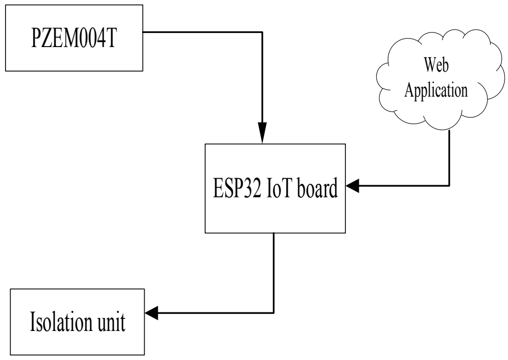

Fig.6. IoT-based control system

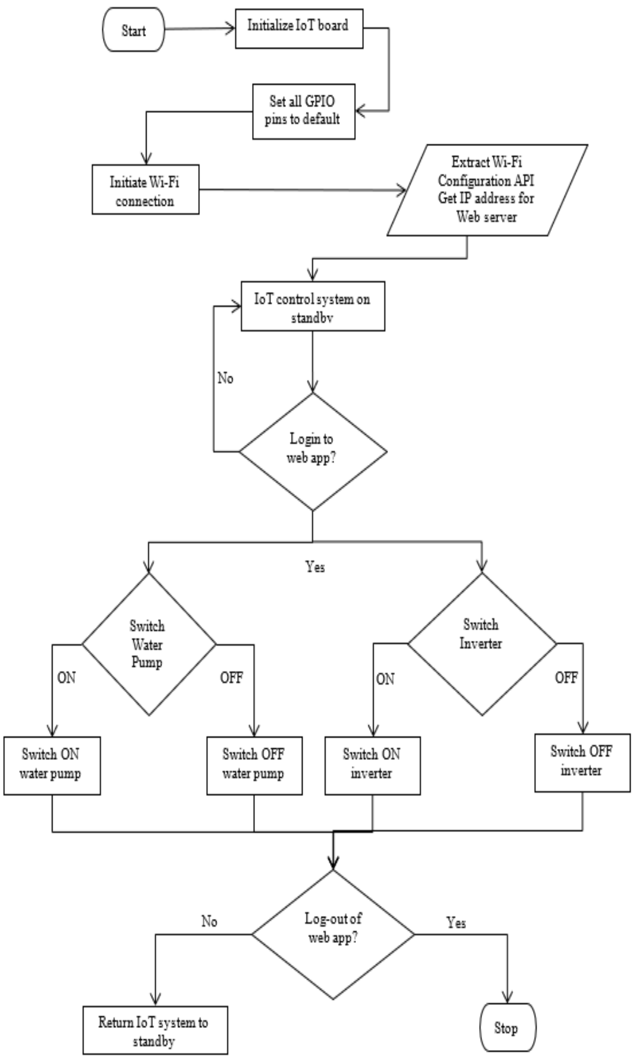

Fig.7. Algorithm flow chart of IoT-based control system

Power supply system

The power supply system supplied electrical energy to the system to power the water pump. This system is designed in such a way to ensure adequate supply of power from the solar panels to the storage cells and also to ensure smooth conversion of the stored electrical energy in battery into AC power. The power supply system consists the storage battery, charge controller, inverter and buck converters. The battery stores the power from the solar panels, whilst the charge controller ensures that the battery is optimally charged using the state of charge technique. The inverter ensures proper conversion of DC power from the battery into AC power required by the system. The buck converters are used for converting the 12 V DC power of the battery to lower voltage values. The solar panel repositioning system requires 9 V DC for motor drive and actuators, 5 V DC for Arduino board, 3.5 V DC for IoT board and 5 V DC for isolation unit.

Experimental evaluation

In this section, the experimental evaluation of the performance of the proposed solar tracking system is presented. A 50 W monocrystalline silicon PV panel was used with four LDR sensors installed at the four sides of the panel.

Figure 10 presents the graphical representation of light intensity against resistance. It is observed from the graph that the resistance offered by the LDR sensor drops as the light intensity of the sun moves from the ambient light side to the bright light of the sun. This is an indication that LDR sensors have an optimal performance in the area of light sensing.

Figures 11 and 12 show the setup and testing of motor drivers respectively. From Figure 12, a multimeter was used for measuring the four output pins of the motor drive module in order to ensure that the switching process adequately performed. The Arduino ensures proper connection between the LDR and the motor driver. Therefore, when powered as “High” by the Arduino, the measured voltage on each pin must be 9 V. This measured voltage is required to drive the mechanical actuators as shown in Table 5.

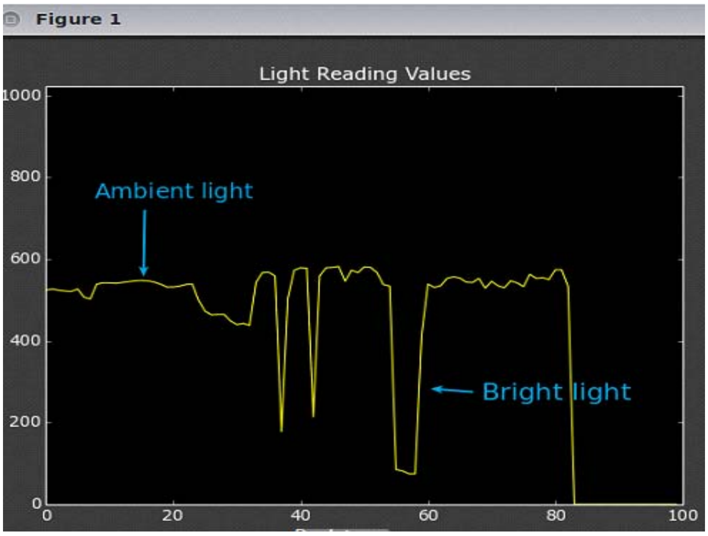

Fig.10. Performance evaluation of LDR sensors

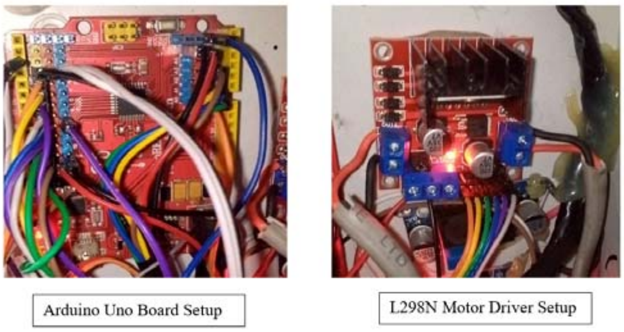

Fig.11. Setup for motor drivers

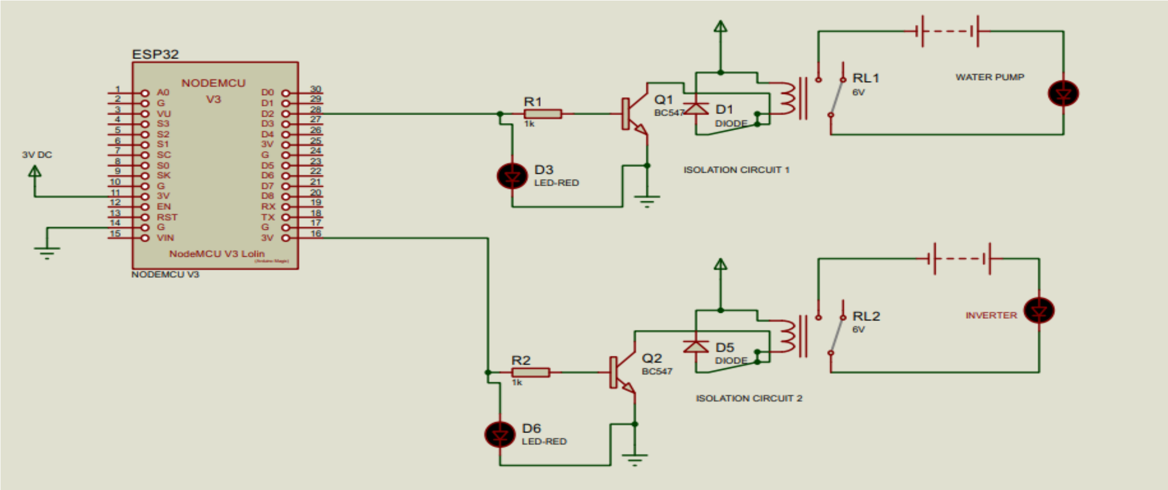

Fig.8. Schematic circuit diagram of IoT based control system

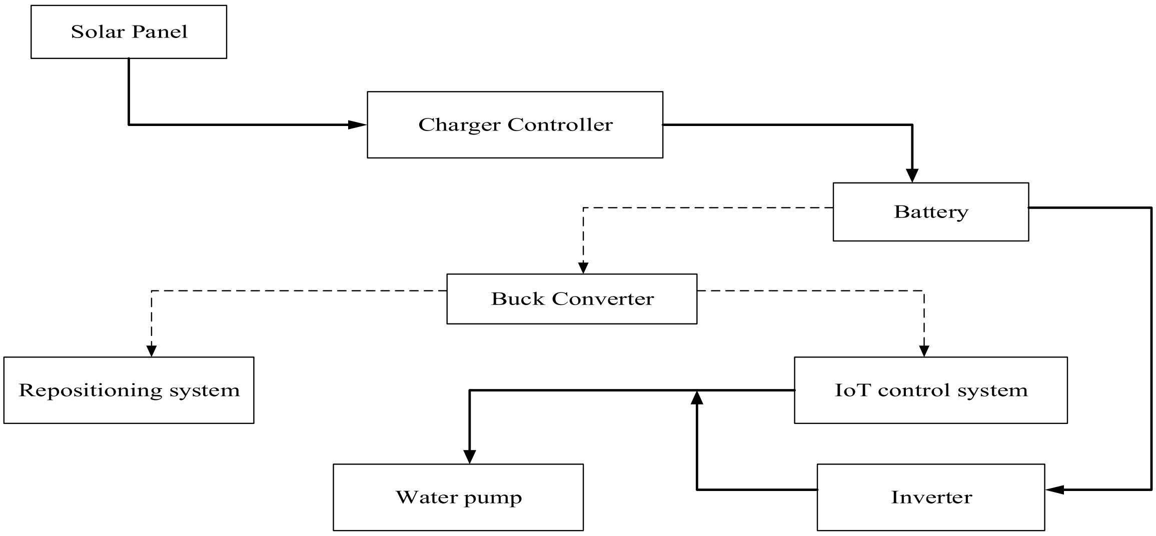

Fig.9. Schematic circuit diagram of IoT based control system

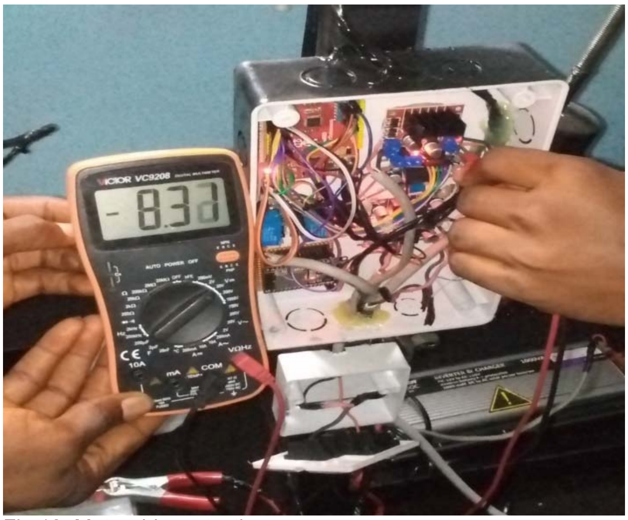
Fig.12. Motor drivers testing

The experimental results show the measured output power from the solar PV panels. Table II compares the output power from the fixed and dual axis solar tacking system based on the power charging of the battery. It is evident from Figure 12 that the dual axis tracking system has faster charging rate as compared to the fixed tracking. It is

observed that the dual axis tracking system fast track the charging period by 52.08% and thereby increasing the efficiency of the solar panel.

Table 1. Motor driver voltage output

Linear actuation operation	Actuator Configuration: Multi-meter Readings for each wheel: Voltage (V)			
	Actuator 1		Actuator 2	
	Positive terminal	Negative terminal	Positive terminal	Negative terminal
Forward motion	8.35	0	9. 05	0
Reverse motion	0	9.09	0	8.31

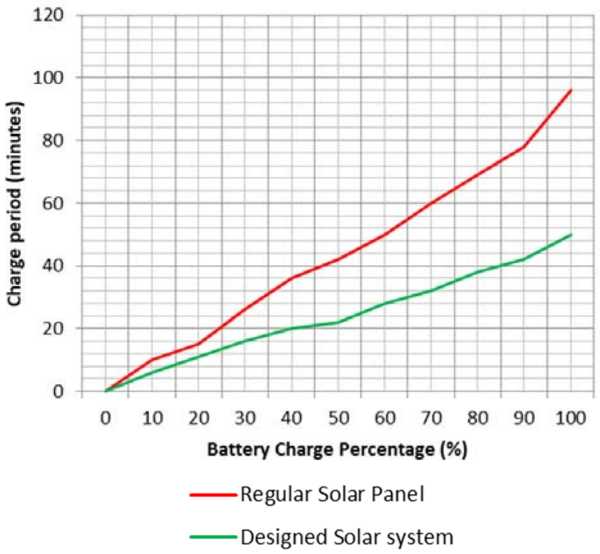

Fig.12. Charging rate of the fixed and dual-axis solar tracking system

Table 2. Power charging capacity of the fixed and dual-axis systems

Battery charging capacity (%)	Fixed solar panel: (minutes)	Dual-axis solar panel: (minutes)
0	0	0
10	10	6
20	15	11
30	26	16
40	36	20
50	42	22
60	50	28
70	60	32
80	69	38
90	78	42
100	96	50

Conclusion

This paper presents the designing, development and implementation of an IoT-based dual axis solar tracking system. The solar tracking system was designed to appropriately regulate the rotation of the PV panel to follow the sun light direction using the LDR sensors. The tracking system used a pseudo-azimuthal mounting technique to ensure a rigid mechanical structure, while four LDR sensors were employed to enhance the angle of the solar irradiance on the PV panel. The developed tracking approach is an IoT-based system that employed a GPS module and internet connectivity for ensuring a proper orientation of the panel, remote monitoring and switching control of the system. The experiment was carried out to assessed the performance of the dual axis tracking with fixed system. The experimental results show that the dual axis tracking system has a better performance when compared to fixed system. The power charging capacity of the PV system significantly increased with the charging period increased by 52.08%. In conclusion, the obtained results confirmed that the dual axis solar tracking system has better performance when compared to a fixed system and thereby increasing the efficiency of the solar panel.

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