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Development and Evaluation of Dual Axis Solar Tracking System with IoT Data Monitoring

***Abstract**. Sunlight and heat are natural sources in our earth where we can use various continually changing techniques, including solar thermal and artificial photosynthesis. Solar energy from renewable sources is a significant source of electricity. The solar trackers' function minimizes the incidence angle between incoming light and the photovoltaic panel. These mechanisms shift their orientation during the day as the sun maximizes energy absorption. Compared to the fixed angle system, solar trackers would increase solar energy. In any solar system, the shifting efficiency increases by continuously adjusting the tracking system at the best angle as the sun goes through the sky. This project presents the development of the solar tracking system using Arduino UNO, allowing the panel to move towards the high intensity of sunlight via four LDRs. The monitoring system is implemented in this tracking system in real-time data of solar energy parameters and factors affecting its deficiencies using Thing Speak platform interfacing with Wemos D1 R2. The result shows the tracking system has efficiencies of 55.38% higher than the single-axis system. The monitoring system is practical for real-time analyzing the solar panel component environmental factor.*

Streszczenie.** Światło słoneczne i ciepło są naturalnymi źródłami na naszej Ziemi, gdzie możemy korzystać z różnych ciągle zmieniających się technik, w tym z energii słonecznej i sztucznej fotosyntezy. Energia słoneczna ze źródeł odnawialnych jest znaczącym źródłem energii elektrycznej. Funkcja solar trackerów minimalizuje kąt padania pomiędzy wpadającym światłem a panelem fotowoltaicznym. Mechanizmy te zmieniają swoją orientację w ciągu dnia, gdy słońce maksymalizuje absorpcję energii. W porównaniu z systemem o stałym kącie, trackery słoneczne zwiększają energię słoneczną. W każdym układzie słonecznym wydajność przesuwania wzrasta dzięki ciągłej regulacji systemu śledzenia pod najlepszym kątem, gdy słońce przechodzi przez niebo. Ten projekt przedstawia rozwój systemu śledzenia słońca przy użyciu Arduino UNO, umożliwiającego panelowi poruszanie się w kierunku wysokiego natężenia światła słonecznego za pośrednictwem czterech LDR. System monitoringu jest zaimplementowany w tym systemie śledzenia w czasie rzeczywistym danych o parametrach energii słonecznej i czynnikach wpływających na jej niedobory za pomocą platformy Thing Speak współpracującej z Wemos D1 R2. Wynik pokazuje, że system śledzenia ma wydajność o 55,38% wyższą niż system jednoosiowy. System monitorowania jest praktyczny do analizy w czasie rzeczywistym czynnika środowiskowego komponentu panelu słonecznego.* (Rozwój i ocena dwuosiowego systemu śledzenia energii słonecznej z monitorowaniem danych I**oT*)

Keywords: Dual-axis, Solar Tracking, IOT
Słowa kluczowe: dwuosiowy system śledzenia energii słonecznej, IoT

Introduction

Solar energy is a significant source of electricity from renewable energy sources as it is easy to use, readily available, and inexpensive as been used in [1-4]. Nowadays, the world is faced with a deficit of energy besides utilizing fossil fuels or dam electricity generation. Both sources need a large area and more raw material to produce electricity. Other alternative energy sources can be highlighted as electricity sources such as solar, wind and nuclear. Energy that does not pollute the atmosphere is the most favorable renewable energy source.

Solar tracking system can track the sun and generates electrical energy. There are two fundamental tracker categories: a single axis and a dual axis. Dual axis tracking system has two axis freedom, horizontal and vertical. Dual axis solar tracker is the solar panels move according to the sun's movement and get the radiation all day.

Preethi G in [5] designed the solar tracking system that uses two LDR sensors and a servo motor to detect the sunlight, allowing solar panels to move toward sunlight. The real-time monitoring system uses the LabVIEW system related to Arduino port. Solar panel data such as voltage, current, and light intensity were measured and graphically represented in LabVIEW. The solar power system's performance is measured using the LabVIEW front panel's irradiance versus time plot, voltage against time plot, and current against time plot. It uses a cloud to transfer the data quickly. The disadvantage of this design is it uses LabVIEW where needed to connect with the serial communication port. This made the project unable to be monitored from far and has limited to short distance only. The best method is to change to a Wi-Fi module with a long-range and faster data rate. Figure 1 shows the block diagram design of the proposed system.

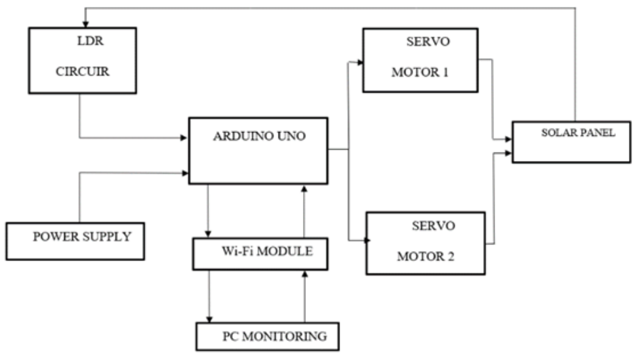


Fig. 1: Block diagram of System

A variety of experiments have been performed to determine the optimal angle of tilt and orientation (azimuth) of PV system, solar collector, or any other application in some part of the world. Since the sun's direction varies from east to west and from north to west, several types of angles are required if the ideal angle of the sun is to be calculated. The perspectives for solar geometry are described below based on the figure 2[6][7].

I. Zenith Angle, θZ - The angle from the subsolar point to the latitude of the current position.

II. Elevation Angle, α s - The inclination angle is between the lines pointing towards the sun and the horizontal plane (Sun Angle = 90° - Zenith Angle).

III. Solar Azimuth Angle, γ S - The direction of the line pointed to the north and the path heading to the south.

IV. Surface Azimuth Angle, γ - The photovoltaic panel angle to the south.

V. Declination Angle, δ - Decline Angle seasonally varies due to the Earth's tilting on the rising and rotating axes around the sun. The range of angles varies between 23.45 ° and 0 ° and between-23.45 °.

VI. The angle of Incidence, θ - Angle between the line leading to the sun and the angle pointing directly from the solar photovoltaic panel.

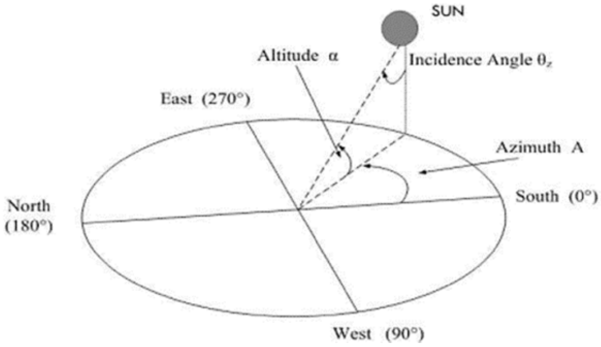


Fig. 2: Sun Angle

Manish Katyarmal in [8] designed the system to supervise solar power generation by performance, LDR) monitoring and maintenance using ATMEGA 328 and monitoring using IoT system. The Internet of Things (IoT) platform combines data from various solar panels and uses analytics to communicate the most useful information with applications tied to specific needs. These advanced IoT platforms, such as Thingspeak, Microsoft Azure, and the Google cloud platform, can pinpoint exactly which data is valid or can be safely ignored. This data can be used to identify flaws, make recommendations, and predict potential issues before they arise.

Some researchers explained the idea of an IoT system that collects data on physical parameters from different types of sensors, through different modes of communication, using a sophisticated microcontroller platform, and then uploads data to the Internet [9]. The Monitoring Center (MC) collects data from photovoltaic and other related sensor sources. The MC has a collection of tools for tracking items, detecting failures, and sending warnings across different communication channels [10].

Solar energy is emerging as a viable option for ensuring a long-term energy supply. As more rooftop solar photovoltaic systems are connected to the current grid, there is an increasing demand for real-time generation data from solar photovoltaic plants. These plants can be monitored to enhance the solar power plant's overall performance and ensure grid stability. Since the onsite monitoring is impossible for installation, remote monitoring is required for all solar power plants. At this point, using digital technologies and more advanced computing facilities to leverage the power of IoT for monitoring solar power plants appears to be promising [11]. Computer devices, mechanical and virtual equipment, things or entities with usernames, and the ability to send data across a network without human or computer interaction [12].

Methodology

To develop the good tracking system features with weather conditions in Malaysia, the solar panel is designed to bcome a dual-axis tracking system consisting of two servo motor as dual-axis. Many electronic systems are self-contained and powered by batteries. To convert solar energy into electricity, the tracking system must always align the solar panel with the direction of greatest lighting by solar cells. In this project, the prototype of dual axis solar tracker will be absorbing the energy form the sun to get the maximum power. Dual axis solar tracker consists of one Arduino uno to control the LDR light sensor and the servo motor to move the PV solar panel. Two light sensors will control the stepper motor to face the solar toward east direction and another two light sensors will control the servo motor to face the solar toward west direction. Wireless module will control the data monitoring through IoT platform. Temperature and humidity sensor also being control by the microcontroller in this project.Figure 3 shows the block diagram of the solar panel that is developed into dual-axis solar tracker.

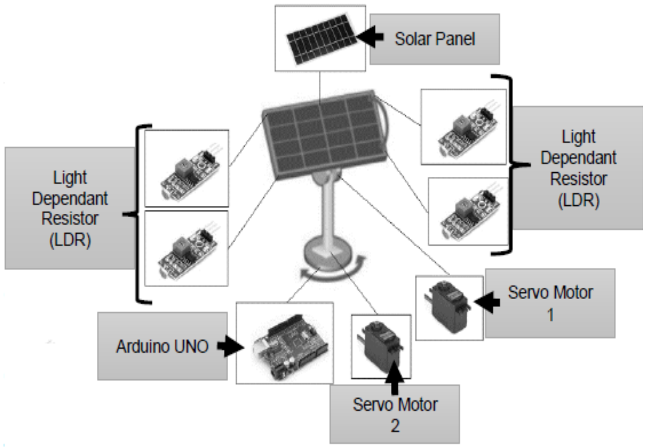


Fig. 3: Hardware design of solar tracking system

The photovoltaic solar panel used for the project is a 2W, 5V solar panel consisting of monocrystalline cell material and has a power capacity of 2W. Every solar panel has their own specification based on their performance and size of the solar. The solar chosen has a maximum peak power of 2.5W and a voltage capture of 5V. While the current in this solar panel is 500mA during the operation. Light dependent resistor sensor module is one of the sensors that come with the analog input pin together. The module of the LDR sensor is used to detect the presence of light or to determine light intensity. The sensors work when the module's output in the presence of light goes up and in the absence of light it becomes low. The LDR sensor module also comes with a potentiometer to adjust the signal detection sensitivity and the resistor operates on the photo conductivity principle. Dual axis come with servo motor thatrotate in vertical and horizontal to track the higher light intensity through the instruction by LDR sensor. Monitoring systems for solar tracker systems help improve the monitoring data while obtaining energy efficiency from the solar panel. It is also able to track the factor that reduces solar electricity and other solar power problems. The solar power system is used to monitor the maximum performances produces by the solar panel. The project used INA219 component to get the bus voltage, current and power of the solar panel, while the DHT11 function to get the surrounding temperature and humidity of the solar tracking system. The sensor uses which is INA219 and DHT11 is interfaced with WEMOS D1R2 ESP8266 Wi-Fi Module by sending the sensor data into the ThingSpeak platform.

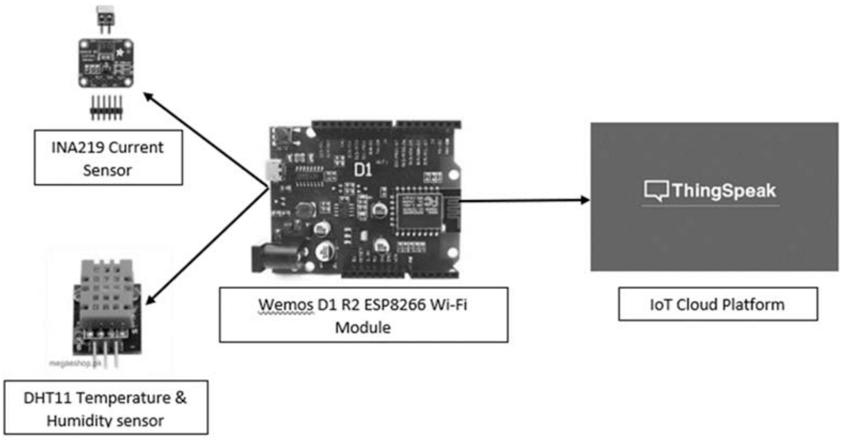


Fig. 4: Hardware design of the monitoring system

The solar tracking system reports the data that is collected by the solar panels and feeds the data to the web services such as ThingSpeak. The data recorded in the ThingSpeak cloud can be exported into an XML file that may be used to develop a solar tracking system analysis. The project analysis is shown in data analytics to record the performance of the solar tracking system in a different condition that we have in Malaysia. The dual axis solar tracking system was placed into different conditions to determine various factors responsible for affecting the performance of solar tracking. Figure 5 shows the complete prototype of the project.

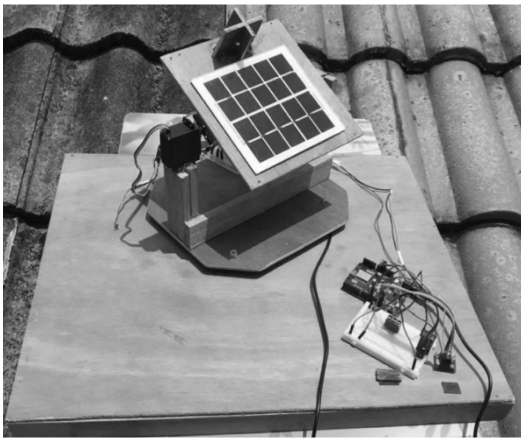


Fig. 5: Complete Arrangement of Hardware Design

Results, Analysis and Discussion

A. The Intensity of Solar Tracking System

The solar tracking system is the system that able to move the solar panel perpendicular to the sun according to the light intensity from the LDR sensor. Luminous intensity is the quantity of visible light that is emitted in unit time per unit solid angle. The outputs of the LDRs depends on how much light falls on the surface of the solar panel. The four LDR is used in the solar tracking system to distinguish the light intensity to makes the panel move to the right or left and rotate in 180 degree according to which LDR is having a higher light intensity.

The prototype is being placed under the sunlight to record the data, the values of each LDR light intensity has be read and recorded using a light meter where measure in lux. The values obtained were recorded in table 1 to show the relation of the tilt angle in the solar tracking system. The values obtained were recorded and sketch in graph as shows in figure 6.

Table 1: LDR Light Intensity Value and Angle Solar Panel

TIME	LDR 1	LDR 2	LDR 3	LDR4	ANGLE
9.00 AM	356	342	340	346	175°
10.00 AM	330	317	328	345	150°
11.00AM	800	870	884	886	140°
12.00 PM	1095	1081	800	940	88°-90°
1.00 PM	1033	1020	1090	1066	86°-90°
2.00 PM	921	1004	1280	1266	80°
3.00 PM	1098	1014	1106	1088	60°
4.00 PM	985	1010	960	975	50°
5.00 PM	1098	1014	1106	1088	30°
6.00 PM	35	31	37	38	10°

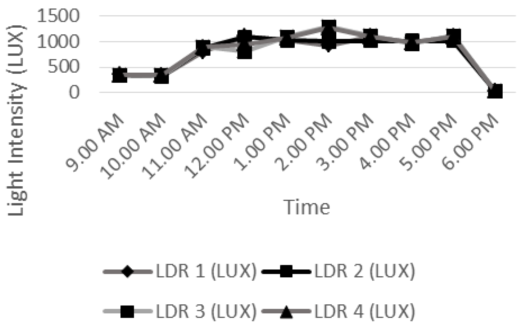
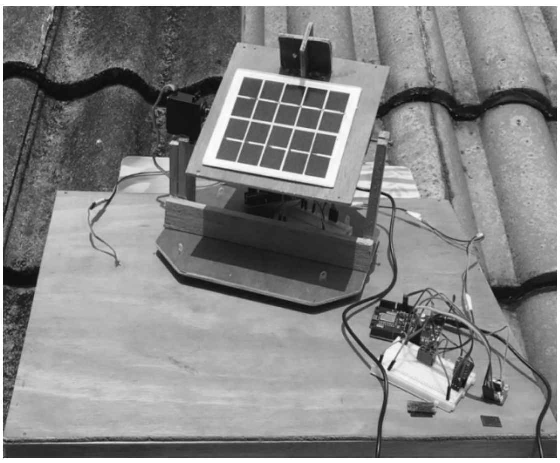
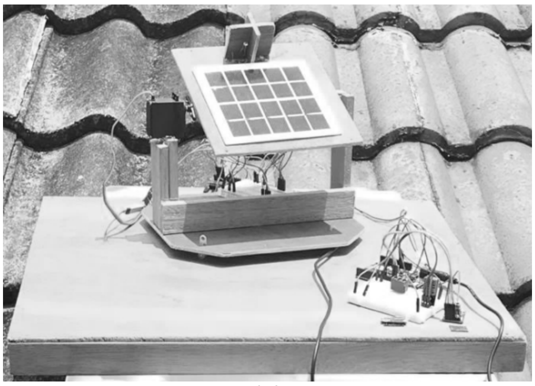


Fig. 6: Light intensity of LDR sensor module

Figure 6 shows the movement of the solar panel based on the four LDR sensors that track the sun and give instruction to the servo motor horizontal and vertical to move.



(a)



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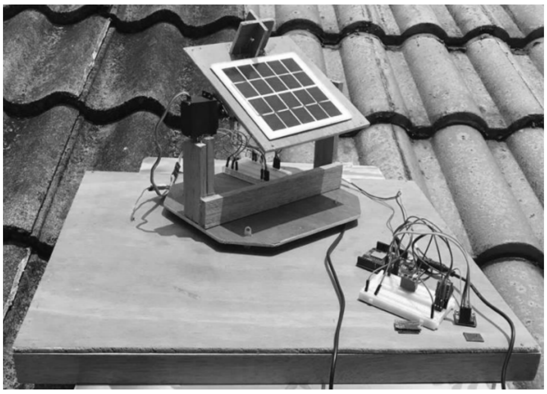

(c)

Fig. 6: Movement of solar panel using four LDR to several different angles.

A. Factors Affecting Solar Tracking System

Data measurement that is being recorded from data monitoring through ThingSpeak was taken from a wide area with no interference to prevent excessive sunlight on the sensor. The graph constructed using average output voltages with temperature and humidity. The output voltages were measured from 9 a.m. to 6 p.m.

The factor that affects the solar voltage can be related to the changes in temperature and humidity. As the temperature is high, the solar energy will produce voltage up to 5V. For moisture, when the changes in humidity are increasing, it will reduce the performance of solar voltage to absorb solar radiance. Figure 7 shows the solar energy when the weather during rainy and cloudy.

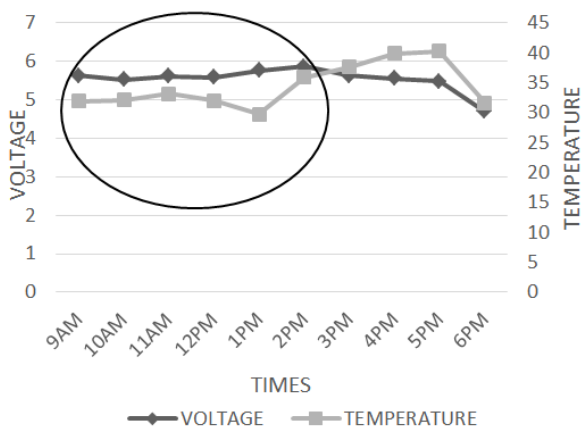

Fig.e 7: Data comparison between voltage and temperature during rainy and cloudy weather.

Figure 7 shows the drop in temperature at 1.00 PM. The cause of the temperature drop is the weather surrounding is rainy and cloudy, which reduces the voltage. As temperature increases, the energy of the PV module decreases because it is less efficient at higher temperatures. The solar panel can produce electricity at high ambient temperatures. Besides that, dual-axis solar tracking has high efficiency in tracking the sunlight even the light has been blocked by the cloud. The servo motor horizontal and vertical capable of tracking the highest light intensity.

The result shows in figure 8 that solar panel voltage is affected by humidity. These changes are due to the variable cloud formation that prevents the solar panel from reaching the sunlight, thus affecting its efficiency. The solar panel can reach peak voltage, and the cellular energy is reversed with heat if the outside air temperature is higher.

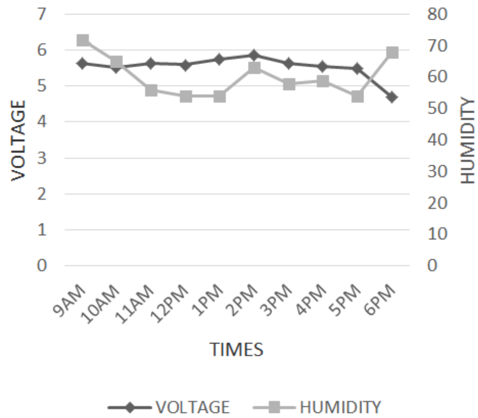

Fig. 8: Data comparison between voltage and humidity during rainy and cloudy weather.

Changes in temperature and humidity can have an impact on solar voltage. Solar energy will produce voltage up to 5V as the temperature rises. When humidity levels rise, solar voltage's ability to absorb solar light suffers when it comes to moisture.

Figure 9 shows the comparison graph of the voltage for single axis and dual-axis tracking system. The solar tracking system was placed for 10 hours from 9 AM until 6 PM, same for each solar tracking system for 14 days at different times depending on the weather.

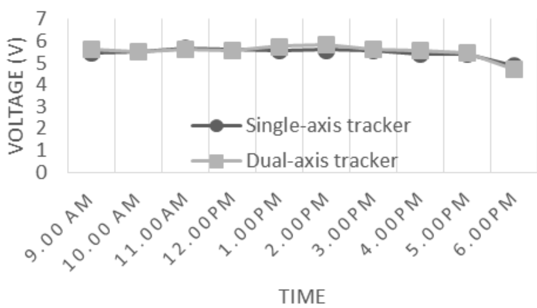

Fig.e 9: Comparison output voltage between single axis and dual axis tracking system.

Different results can be seen with a dual-axis tracking system. It can move along with the sun's progress with the help of four LDR sensors. Based on figure 9, the output voltage of each solar tracker shows a consistent result, but dual-axis solar tracking gains more voltage than the single-axis tracking system. The single-axis tracker only can move from the east to the west, following the sun movement, but the dual-axis tracking can detect more sunlight intensity to gain more power since there is a horizontal servo motor that can detect sun even if there are blocking clouds on the sun and can detect the ray of light at the high amount of light. Thus, the efficiency of the single-axis is 54.74% and the dual- axis solar tracking system is 55.38% higher than the single-axis tracking system.

Conclusion

A solar tracker with a monitoring system that uses ThingSpeak to analyze the data and performance of the solar tracker system has been constructed and tested. A dual-axis solar tracker has been developed in this project along with single-axis solar tracker data used to compare the result since each solar tracker has big different but same objective. The efficiency of the single-axis is 54.74% and the dual-axis solar tracking system is 55.38% higher than the single-axis tracking system. Therefore, the dual-axis solar tracking system shows more improvement in terms of efficiency than the single-axis since it is more precious to track and detect sun intensity even if a cloud blocks it. It still shows the best performance when there are two servo motors use. This system was created by combining all the hardware and software that were used. As a result, the hardware and software architecture of this system is intended to improve upon the former system. Arduino Genuino Uno Board is used to control the servo motor for a solar tracking system based on the light intensity sensed by LDR while Arduino WiFi UNO ESP8266 WeMos D1 R2 act as Wi-Fi module to connect with ThingSpeak platform. IoT Platform is used as the data analytic to display the data from the sensor from DHT11 and INA219 through ThingSpeak. The Arduino WiFi UNO ESP8266 WeMos D1 R2 records the temperature, humidity, current, and voltage. The Adafruit INA 219 Voltage/Current Sensor and DHT11 have been used for this solar tracking system to sense and measure temperature, humidity, current, and voltage. This project also gives effective and real-time data on the installed solar tracking system's temperature, current, and voltage. In other words, any inaccurate data captured and gathered by the Arduino WiFi UNO ESP8266 WeMos D1 R2 could immediately reveal the system's discrepancy.

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REFERENCES

[1] A. Yusop, R. Mohamed, A. Ayob, and A. Mohamed, "Dynamic modeling and simulation of a thermoelectric-solar hybrid energy system using an inverse dynamic analysis input shaper," *Modelling and Simulation in Engineering,* vol. 2014, 2014.

[2] A. M. Yusop, R. Mohamed, and A. Mohamed, "Inverse dynamic analysis type of MPPT control strategy in a thermoelectric-solar hybrid energy harvesting system," *Renewable Energy,* vol. 86, pp. 682-692, 2016/02/01/ 2016.

[3] A. M. Yusop, R. Mohamed, N. A. Sulaiman, and A. S. Mohd Isira, "Performance analysis of shapeable-maximum power point tracking technique from thermoelectric-solar hybrid energy harvesting sources on mobile devices," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* pp. 1-14, 2021.

[4] A. Yusop, R. Mohamed, A. Ayob, and A. Mohamed, "Shapeable maximum-power point-tracking algorithm to improve the stability of the output behavior of a thermoelectric-solar hybrid energy-harvesting system," *Journal of the Association of Arab Universities for Basic and Applied Sciences,* vol. 22, pp. 1-8, 2017.

[5] G. Preethi, D. Lavanya, V. Sreesureya, and S. Boopathimanikandan, "Real time monitoring and controlling of solar panel using labview," *Int. J. Sci. Technol. Res.*, vol. 8, no. 8, pp. 1747–1752, 2019.

[6] A. Z. Hafez, A. Soliman, K. A. El-Metwally, and I. M. Ismail, "Tilt and azimuth angles in solar energy applications – A review," *Renew. Sustain. Energy Rev.*, vol. 77, no. April, pp. 147–168, 2017, doi: 10.1016/j.rser.2017.03.131.

[7] S. L. GBADAMOSI, "Design and implementation of IoT-based dual-axis solar PV tracking system," PRZEGLĄD ELEKTROTECHNICZNY, vol. 2021, p. 57, 2021.

[8] A. Ahrary, M. Inada, and Y. Yamashita, "Solar power monitoring system 'SunMieru,'" *Smart Innov. Syst. Technol.*, vol. 73, pp. 216–224, 2018, doi: 10.1007/978-3-319-59424-8_20.

[9] M. Suresh[1,] *et al.*, "Fault Detection and Monitoring of Solar PV Panels using Internet of Things," *Int. J. Ind. Eng.*, vol. 2, no. 6, pp. 146–149, 2018, [Online]. Available: http://ijie.gjpublications.com.

[10] N. Gheitasi, Alireza; Almaliky, Ali; Albaqawi, "Development of an Automatic Cleaning System for PV Plants," *IEEE PES Asian-Pacific Power Energy Eng. Conf.*, vol. 3, pp. 7–10, 2015.

[11] S. Adhya, D. Saha, A. Das, J. Jana, and H. Saha, "An IoT based smart solar photovoltaic remote monitoring and control unit," *2016 2nd Int. Conf. Control. Instrumentation, Energy Commun. CIEC 2016*, no. October, pp. 432–436, 2016, doi: 10.1109/CIEC.2016.7513793.

[12] T. C. M. Dönmez and E. Nigussie, "Security of Join Procedure and its Delegation in LoRaWAN v1.1," *Procedia Comput. Sci.*, vol. 134, no. January, pp. 204–211, 2018, doi: 10.1016/j.procs.2018.07.202.