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Solar Power IoT Based Smart Agriculture System Using NodeMCU ESP32

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Abstract

Recent global climatic changes have led to a severe worldwide food shortage, prompting households to address this concern by cultivating sufficient vegetables and crops, as emphasized by the Food and Agriculture Organization of the United Nations (FAO). To tackle the escalating demand for food and energy amid climate change and limited arable land, a proposed controller-based IoT system for greenhouses integrates a solar-based power solution. This system aims to boost efficiency, cut costs, and ensure optimal crop growth irrespective of weather conditions. Utilizing NodeMCU ESP32, data from the DHT11 sensor and soil moisture sensor detect humidity, temperature, and soil moisture, transmitting the information to a Blynk application accessible online. A high-resolution dataset collected at 15-minute intervals provides crucial insights into greenhouse atmospheric dynamics. The solar-powered system, exhibiting resilience, offers valuable optimization insights. Comparison with Weather Underground data highlights a strong correlation in temperature and humidity, affirming the system's reliability despite limitations in soil moisture data. Future enhancements are suggested to address data gaps and optimize system performance. In conclusion, the integration of solar energy and IoT-driven smart agriculture with NodeMCU ESP32 holds promise for revolutionizing farming, reducing carbon emissions, and enhancing crop management through real-time data access and automated control.

1. Introduction

The current global era grapples with a severe food shortage due to climate change, prompting households to cultivate crops to address the deficit. The Food and Agriculture Organization of the United Nations (FAO) emphasizes the need for an efficient food production system. Greenhouse control mechanisms play a crucial role in optimizing fruit production and plant growth. This initiative aims to enhance agriculture by focusing on key elements such as temperature, humidity, and soil moisture to improve plant development and productivity.

Rapid population growth, coupled with escalating food and energy demand, strains available resources. Climate change and limited arable land exacerbate the challenge. Greenhouses, designed for high-quality crop cultivation, require precise data for effective plant management. To address this, a proposed controller-based monitoring and controlling system, utilizing IoT and solar-based power, aims to reduce operating costs and human error. The focus on renewable energy sources aligns with experts' concentration on sun thermal energy to lower energy consumption and optimize plant output regardless of environmental conditions.

The project's objectives include developing a solar-based power system for smart greenhouses, designing a smart agriculture system using NodeMCU-ESP32, and analyzing the system's performance. The project scope involves monitoring and controlling environmental parameters like temperature, moisture, and humidity using NodeMCU-ESP32. It specifically applies to stand-alone photovoltaic solar systems, utilizes NodeMCU ESP32 for data processing from sensors, and conducts experimental works on chili plants.

2. Literature Review

This literature review focuses on the implementation of solar-based agriculture systems using the NodeMCU ESP32. The primary emphasis is on the background solar radiation in Malaysia, with subsequent exploration into works related to smart agriculture systems. The thesis delves into the essential elements and features integrated into solar-based agriculture systems, aiming to highlight potential advantages and challenges. The comprehensive study aids in identifying strong arguments supporting the proposed work technique outlined in methodology.

2.1 Solar Radiation Malaysia

Solar energy, with its eco-friendly attributes and surpassing historical energy consumption, stands as a vital alternative to fossil fuels. The global shift towards affordable, abundant, and environmentally minimal energy is accentuated by diminishing fossil fuel reserves. In Malaysia, an equatorial nation with favorable solar conditions, an annual solar irradiation of 1,643 kWh/m2 and daily radiation between 4,000–5,000 Wh/m2 is observed. [1] Despite these conditions, geographic factors and atmospheric conditions impact solar irradiation. The literature emphasizes the potential and challenges of solar power in Malaysia, reflected in annual average solar irradiance ranging from 1600 to 1900 kWh/m2 in Fig. 1. [2]

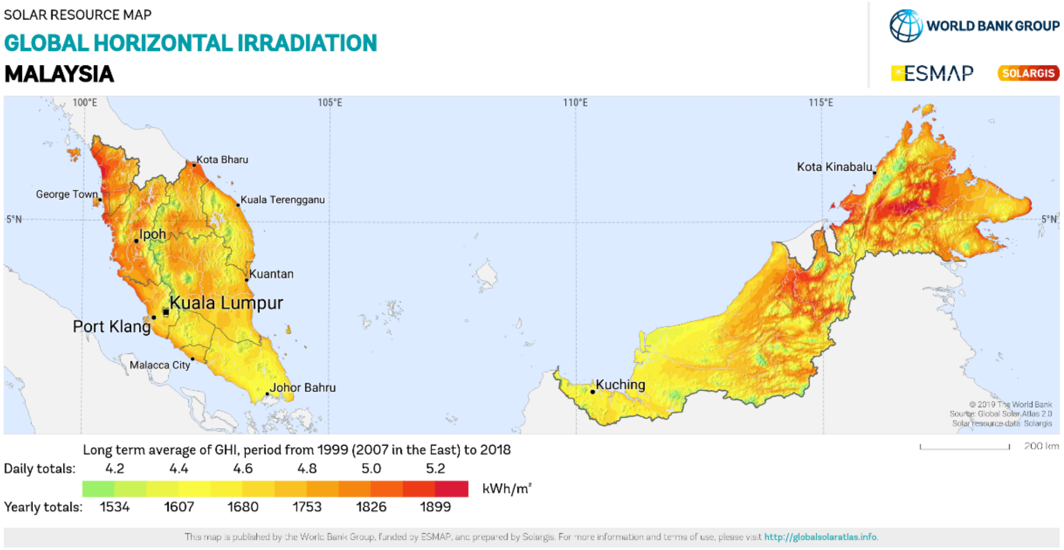


Fig. 1 *Annual Average Solar Irradiance of The Sunlight for Regions of Malaysia from Solargris*

Malaysia's tropical climate with high temperatures and solar radiation presents optimal conditions for solar energy utilization. [3] Despite regional variations and occasional monsoon impact, the nation actively embraces solar power. Government incentives drive widespread adoption, reflecting a commitment to carbon reduction and energy sustainability. [4] Malaysia strategically harnesses solar energy to meet its needs and reduce its carbon footprint.

2.2 Smart Monitoring Agriculture System Technologies

A groundbreaking agricultural monitoring system integrates IoT, remote sensing, data analytics, and automation to optimize farming practices and increase agricultural yield. [5], [6] Utilizing strategically placed IoT devices like sensors, it collects real-time data on soil moisture, temperature, and humidity. The focus is on an IoT-based automated watering system for chili plants, tackling challenges in maintaining crucial soil moisture levels during arid seasons. [7] Traditional methods are inconsistent, risking compromised plant health. The proposed system employs a soil moisture sensor for precise monitoring and automatic watering adjustments. The study emphasizes the optimal temperature range for chili plants, providing valuable insights for informed decision-making in agriculture.

2.3 Internet of Things (IoT)

The Internet of Things (IoT) concept involves connecting everyday objects to the internet for data collection and exchange, enabling the interaction between physical objects and the digital realm. [8] The increasing utilization of IoT, combined with data science, is anticipated to have a profound impact across various domains. In agriculture, as highlighted in a study, IoT is employed for diverse applications. [9] Firstly, it aids in predicting future crops by considering factors such as soil type and climate conditions. Secondly, IoT is crucial for monitoring crop condition and health through sensors, providing valuable insights to farmers and agricultural engineers. The versatility of IoT applications in agriculture is demonstrated through various directions illustrated in Fig. 2. [9]

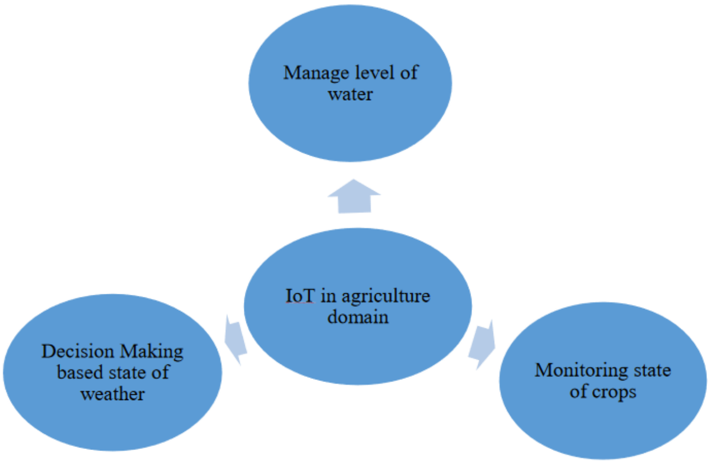


Fig. 2 *Role of IoT in agriculture domain*

3. Methodology

The Smart Agriculture Solar-based System employs NodeMCU ESP32, integrating solar power and IoT for precise agricultural monitoring. A solar panel converts sunlight to DC power stored in batteries, managed by a charge controller. The ESP32 wirelessly collects sensor data (DHT11, Moisture), sent to Blynk for real-time monitoring, and further displays it on Blynk and Google Sheet through IFTTT, offering immediate access to essential environmental parameters for efficient agricultural oversight. Fig. 3 below illustrates the overview of the system.

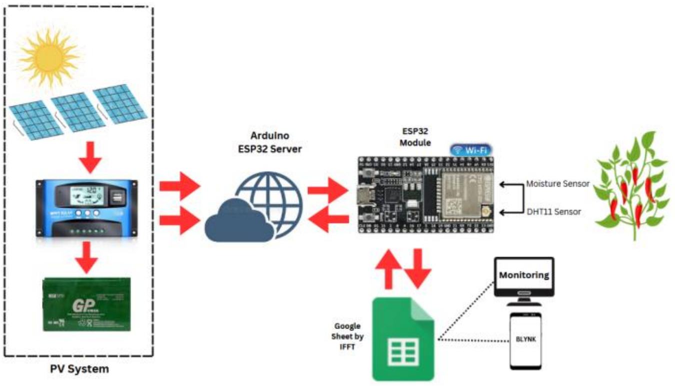


Fig. 3 *System Overview*

The flowchart in Fig. 4, illustrates the system's functionality, emphasizing the role of ESP32, Google Sheets via IFTTT, and the Blynk IoT platform. The system captures data on temperature, humidity, moisture, and light intensity, encrypts it using JSON payload, and sends it to IFTTT for logging in Google Sheets. The Blynk platform serves as an interface for users to manage and monitor IoT devices directly from smartphones, providing real-time data visualization. The IoT smart agriculture system reacts proactively to parameter changes, triggering

LED alarms for low soil moisture and non-ideal temperatures. Additionally, it autonomously activates a water pump for moisture maintenance and a fan for temperature control, enhancing plant growth. The system's real-time information is easily accessible to users via a mobile app, facilitating efficient monitoring and management of agricultural parameters.

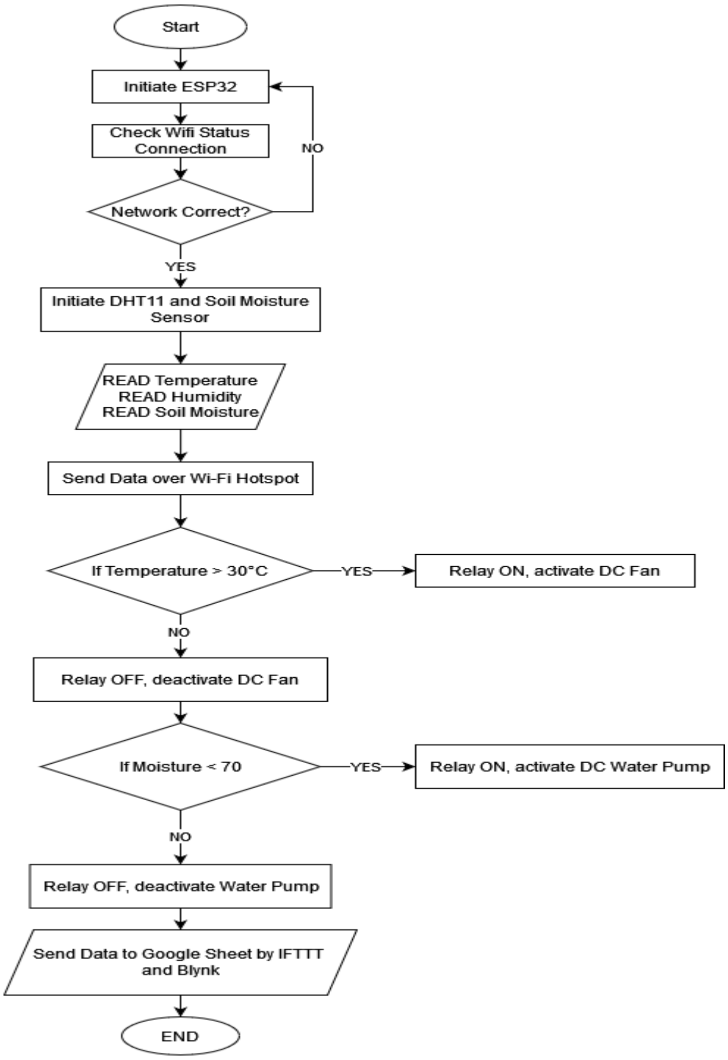


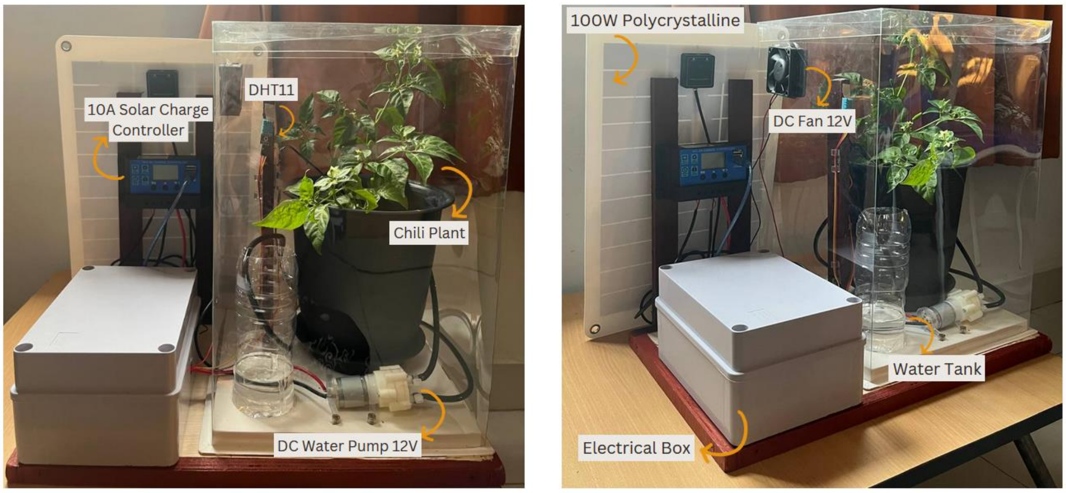
Fig. 4 *Flowchart of the system*

4. Results and Discussions

This section presents results from a solar-powered smart agriculture system with IoT technology, analyzing data to identify deviations from expected benchmarks throughout the day. Data validity is confirmed by cross-referencing with Weather Underground forecasting. The chapter concludes with insights for improvement and strategies to enhance system efficiency, offering valuable guidance for future advancements in agricultural technology.

4.1 Prototype Development

The prototype, showcased in Fig. 5, is a smart agriculture system using NodeMCU-ESP32 designed for efficient chili plant cultivation and precise parameter data collection. Enclosed in a transparent box with a height between 40 and 41 centimeters, the greenhouse structure incorporates a DC fan, water pump, and water tank for customizable crop care. Sensor adjustments, including relocating the DHT11 sensor among the crops, enhance data accuracy, while electronic components are housed in an adjacent electrical junction box for durability. The prototype's power source, a 100W polycrystalline solar panel with a 10A solar charge controller, aligns with environmentally conscious objectives, ensuring uninterrupted operation in remote locations.

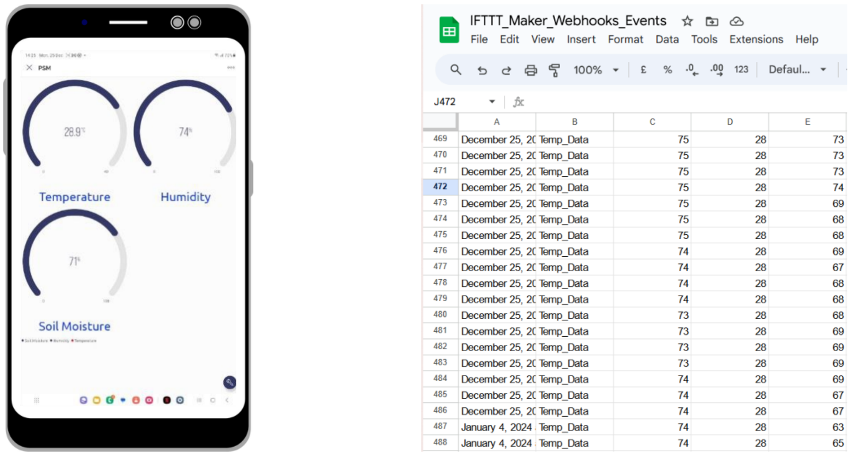


(a) (b)

Fig. 5 *Complete Prototype Design and Configuration (a) Front View and (b) Side View*

4.2 Data Collection

The system functioned by utilizing solar power as its primary energy source to monitor and control atmospheric conditions within a greenhouse. Through the integration of sensors, including those for temperature, humidity, and soil moisture, the system collected high-resolution data at 15-minute intervals over a continuous 24-hour period. The Blynk and IFTTT integration ensured a real-time stream of data, allowing for a detailed analysis of temporal changes in environmental parameters. Fig. 6 below shows the interface of Blynk application and IFTTT data storage.



	A	B	C	D	E
469	December 25, 20	Temp_Data	75	28	73
470	December 25, 20	Temp_Data	75	28	73
471	December 25, 20	Temp_Data	75	28	73
472	December 25, 20	Temp_Data	75	28	74
473	December 25, 20	Temp_Data	75	28	69
474	December 25, 20	Temp_Data	75	28	68
475	December 25, 20	Temp_Data	75	28	68
476	December 25, 20	Temp_Data	74	28	69
477	December 25, 20	Temp_Data	74	28	67
478	December 25, 20	Temp_Data	74	28	68
479	December 25, 20	Temp_Data	74	28	68
480	December 25, 20	Temp_Data	73	28	68
481	December 25, 20	Temp_Data	73	28	69
482	December 25, 20	Temp_Data	73	28	69
483	December 25, 20	Temp_Data	73	28	69
484	December 25, 20	Temp_Data	74	28	69
485	December 25, 20	Temp_Data	74	28	67
486	December 25, 20	Temp_Data	74	28	67
487	January 4, 2024	Temp_Data	74	28	63
488	January 4, 2024	Temp_Data	74	28	65

(a) (b)

Fig. 6 *Real Time Monitoring and Data Storage via (a) Blynk Application (b) IFTTT by Google Sheets*

4.2.1 Initial Day (24th December 2023)

On Day 1, hourly monitoring data in the greenhouse showed temperatures ranging from 22°C to 31°C, peaking at 12:00 AM and decreasing to 28°C in the following hour due to the fan's operation, maintaining optimal growth conditions for chili plants below 30°C. Humidity levels varied between 77% and 94%, reaching a peak at 1:00 PM, while soil moisture fluctuated from 57% to 72%, showing a restoration to ideal levels within a 2-hour period from 10:00 AM to 12:00 PM.

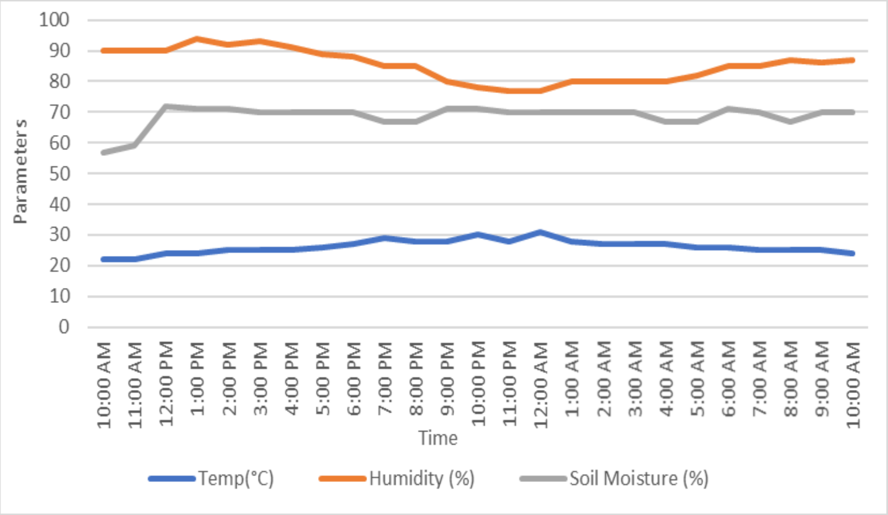


Fig. 7 *Hourly Monitoring Data for 24th December 2023*

4.2.2 Second Day (25th December 2023)

On Day 2, hourly monitoring data in the greenhouse indicated temperatures ranging from 22°C to 30°C, peaking at 9:00 PM and 10:00 PM. Subsequently, the temperature moderated to 29°C in the following hour, aligning with optimal growth conditions for chili plants below 30°C. Humidity levels fluctuated between 82% and 95%, reaching a peak at 1:00 PM, while soil moisture readings ranged from 67% to 73%. The data suggested a restoration of ideal soil moisture levels, increasing from 67% to 71% between 10:00 AM and 2:00 PM and from 69% to 70% between 7:00 PM and 10:00 PM.

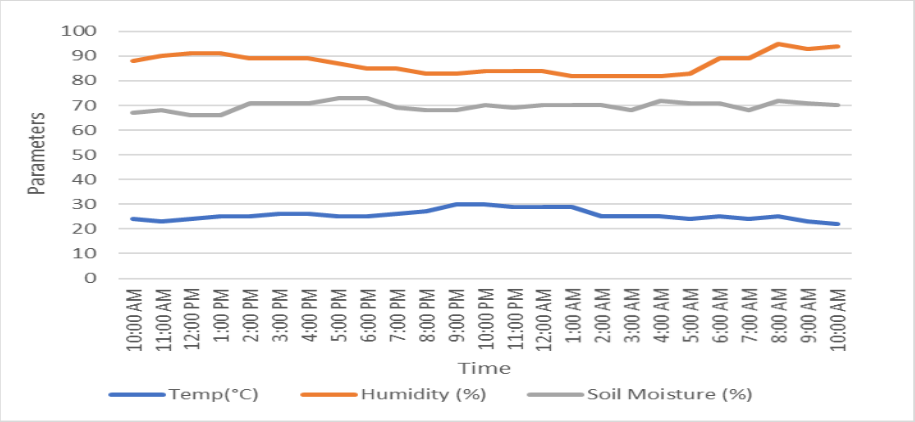


Fig. 8 *Hourly Monitoring Data for 25th December 2023*

4.3 Data Comparison with Weather Underground Data

The comparison between the smart agriculture monitoring system and Weather Underground, detailed in Appendix B, reveals a strong correlation in temperature and humidity, crucial parameters for chili plant growth. The monitoring system consistently aligns with Weather Underground's data, indicating its adeptness in capturing and archiving temperature variations. However, limitations arise due to the absence of soil moisture data, hindering a comprehensive assessment of the system's efficacy in evaluating chili growth. Despite this limitation, the comparison with Forecast Weather in Fig. 9 and 10 demonstrates notable correlations in temperature and humidity values, affirming the monitoring system's capability to acquire and relay accurate data. Future enhancements could focus on incorporating alternative sources or models to address data gaps and provide a more exhaustive evaluation of the system's performance.

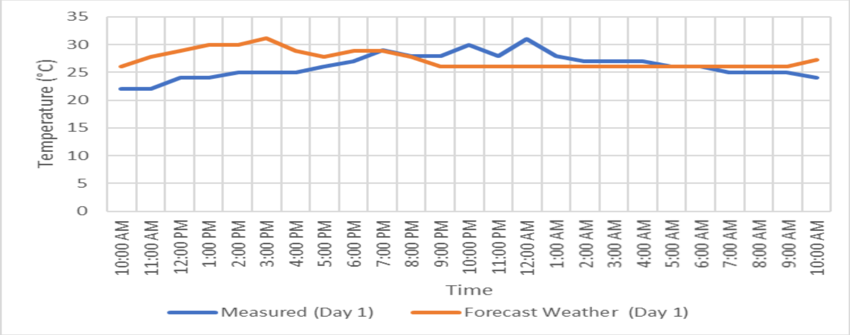


Fig.9 *Comparison of Temperature: Measured vs Forecast Weather*

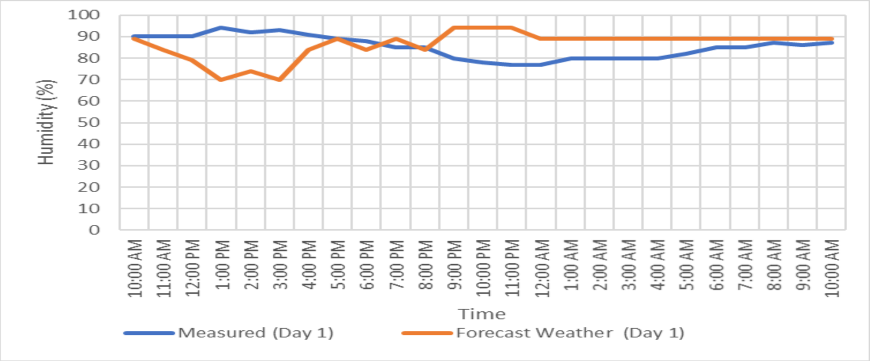


Fig. 10 *Comparison of Humidity: Measured vs Forecast Weather*

4.4 Analysis of Solar Panel Efficiency and Battery Charging

The smart agricultural system utilizes polycrystalline solar panels to capture sunlight and convert it into electrical energy. These panels are connected to a 10A charge controller, which plays a crucial role in regulating the flow of electricity from the solar panels to the battery. The battery functions as an energy reservoir, effectively storing excess energy for use during periods of reduced sunlight or at night when the solar panels are not generating electricity. The analysis of solar panel characteristics is detailed in Table 1.

Table 1 *Solar Panel Characteristics*

Time	Irradiance (W/m2)	Current (A)	Voltage (V)		
			Min	Max	Ave
8:00-10:00	492	0.101	11.83	11.88	11.86
10:00-12:00	521	0.134	11.85	11.92	11.89
12:00-13:00	532	0.143	12.15	12.49	12.32
13:00 – 14:00	527	0.127	11.97	12.21	12.09

5. Conclusions

In conclusion, the integration of solar energy and IoT-based smart agriculture using NodeMCU ESP32 has transformative potential for the agricultural industry. This approach reduces reliance on traditional electricity, lowers carbon emissions, and ensures sustainability. With NodeMCU ESP32 and IoT technologies, farmers can efficiently monitor and control agricultural processes, optimizing resource use and improving crop quality. Solar power provides a reliable energy source for IoT devices and sensors, enabling real-time data collection and remote management of crucial factors like soil conditions and light levels. The seamless connectivity of NodeMCU ESP32 facilitates data transfer to a cloud-based platform, allowing farmers access to vital information for informed decision-making. This comprehensive solution empowers farmers to overcome challenges associated with electricity supply, leading to increased productivity and proactive crop management through automated control systems.

To improve the project, expand the sensor network to include data on nutrient levels, weather, air quality, and disease detection for more comprehensive insights and accurate decision-making. Encourage collaboration among farmers for data sharing, enabling the discovery of valuable trends and optimal practices. This collaborative approach facilitates the creation of comprehensive agricultural models. Additionally, implement energy storage solutions to ensure a consistent power supply for IoT devices and sensors, enhancing the project's resilience and sustainability.

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References

[1] K. H. Solangi, M. R. Islam, R. Saidur, N. A. Rahim, and H. Fayaz, "A review on global solar energy policy," Renewable and Sustainable Energy Reviews, vol. 15, no. 4. pp. 2149–2163, May 2011. doi: 10.1016/j.rser.2011.01.007.
[2] Solargis, "Maps and GIS data - Download - Malaysia," [Online]. Available: https://solargis.com/maps-and-gis-data/download/malaysia. [Accessed: 29-Nov-2023]
[3] Jamaludin, N., Khamidi, M. F., Abdul Wahab, S. N., & Klufallah, M. M. A. (2014). Indoor Thermal Environment in Tropical Climate Residential Building. *E3S Web of Conferences*, *3*, 01026. https://doi.org/10.1051/e3sconf/20140301026
[4] Vaka, M., Walvekar, R., Rasheed, A. K., & Khalid, M. (2020). A review on Malaysia's solar energy pathway towards carbon-neutral Malaysia beyond Covid'19 pandemic. *Journal of Cleaner Production*, *273*, 122834. https://doi.org/10.1016/j.jclepro.2020.122834
[5] Abbasi, R., Martinez, P., & Ahmad, R. (2022). The digitization of agricultural industry – a systematic literature review on agriculture 4.0. *Smart Agricultural Technology*, *2*, 100042. https://doi.org/10.1016/j.atech.2022.100042
[6] Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine Learning in Agriculture: A Review. *Sensors (Basel, Switzerland)*, *18*(8), 2674. https://doi.org/10.3390/s18082674
[7] ---. "Automatic Chili Plant Watering Based on Internet of Things (IoT)." Journal of Applied Engineering and Technological Science (JAETS), vol. 3, no. 2, 13 June 2022, pp. 77–83, www.yrpipku.com/journal/index.php/jaets/article/view/532/412, https://doi.org/10.37385/jaets.v3i2.532. Accessed 26 Mar. 2023.
[8] M. S. Farooq, S. Riaz, A. Abid, K. Abid and M. A. Naeem, "A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming," in IEEE Access, vol. 7, pp. 156237-156271, 2019, doi: 10.1109/ACCESS.2019.2949703.
[9] Mohamed, Mona. "A Comparative Study on Internet of Things (IoT): Frameworks, Tools, Applications and Future Directions." *Journal of Intelligent Systems and Internet of Things*, vol. 1 2018, 2020, pp. 13–39, https://doi.org/10.54216/jisiot.010102. Accessed 8 Nov. 2021.