RiESTech
Recent in Engineering Science and Technology

MBI

Article

Real-Time Temperature Monitoring of Solar Power Systems Using Arduino and K-Type Thermocouples with LoRa Communication to ESP32

Danish Ramadhana Nugraha [1*], Tatun Hayatun Nufus [2] Anisa Ramadhani [3]

Citation: Ramadhana, Danish.; Tatun Hayatun Nufus ; Ramadhani Anisa Title. *RiesTech* **2022**, *00*, x. https://doi.org/00.000/xxxxx

Academic Editor: Firstname Lastname

Received: date
Accepted: date
Published: date

Publisher's Note: MBI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1 Affiliation 1; danish.ramadhana.nugraha.tm21@mhsw.pnj.ac.id
2 Affiliation 2; tatun.hayatun@mesin.pnj.ac.id
3 Affiliation 3; anisaramadhanic@gmail.com
* Correspondence: danish.ramadhana.nugraha.tm21@mhsw.pnj.ac.id

Abstract: Accurate temperature monitoring is critical for optimizing the performance and longevity of Solar Power Plants (PLTS) [1]. This study presents the design and implementation of a temperature monitoring system utilizing Arduino microcontrollers and K-type thermocouples to measure the temperature of key components within a PLTS. The system employs LoRa wireless communication technology to transmit real-time temperature data to an ESP32 microcontroller, enabling remote monitoring and visualization. The integration of LoRa ensures long-range, low-power data transmission suitable for solar plant environments. Experimental results demonstrate the system's capability to reliably capture and transmit temperature data with minimal latency, providing valuable insights for operational decision-making and preventive maintenance. This approach offers a cost-effective, scalable solution for enhancing the monitoring infrastructure of solar power installations, contributing to improved system efficiency and reliability.

Keywords: Temperature, LoRa Module, ESP32

1. Introduction

Solar Power Plants (PLTS) have become a critical component in the global transition towards renewable energy, especially in tropical regions where solar irradiance is abundant. The efficiency and longevity of PLTS systems are highly dependent on effective monitoring and management of operating conditions, among which temperature plays a pivotal role. Elevated temperatures can significantly reduce the performance of photovoltaic modules and other system components, leading to decreased power output and potential long-term damage [2].

Accurate and real-time temperature monitoring is therefore essential to optimize the operation and maintenance of solar power plants [3]. Traditional wired monitoring systems often face challenges related to installation complexity, high costs, and limited scalability, particularly in large or remote solar installations. Recent advances in Internet of Things (IoT) technologies, including low-power wireless communication protocols such as LoRa (Long Range), offer promising solutions for remote environmental monitoring with enhanced flexibility and reduced infrastructure requirements.

This study presents the design and implementation of a temperature monitoring system for PLTS using Arduino microcontrollers paired with K-type thermocouples for precise temperature measurement [4]. The system utilizes LoRa wireless communication to transmit real-time temperature data to an ESP32 microcontroller [5], enabling remote visualization and data logging. By integrating these technologies, the proposed solution aims to provide a cost-effective, scalable, and reliable method for continuous temperature monitoring in solar power plants, thereby supporting improved system performance and preventive maintenance strategies.

Figure 1 : PV System in site (Cileungsi)

The insights gained from this investigation are expected to inform the design and deployment of more efficient, climate-adaptive solar power systems tailored to the unique environmental conditions of tropical urban areas, thereby supporting Indonesia's renewable energy targets and sustainable development goals.

2. Experiment Methods

This study developed a temperature monitoring system for a Solar Power Plant (PLTS) using an Arduino microcontroller and K-type thermocouples to measure the temperature of critical components. The system architecture integrates LoRa wireless communication to transmit real-time temperature data to an ESP32 microcontroller for remote visualization.

Data Acquisition

Temperature measurements were obtained using K-type thermocouples connected to the Arduino board, which served as the main data acquisition unit [6].

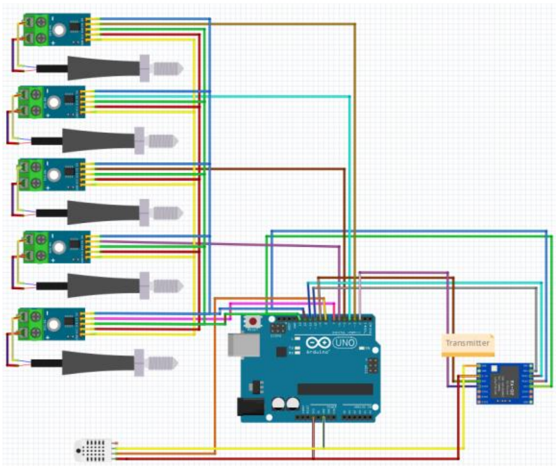

Figure 2 : Arduino system with 5 sensors

The Arduino converts the analog signals from the thermocouples into digital data for processing. The system continuously records ambient and module temperatures to capture variations during operation [7].

Communication and Visualization

Temperature data were transmitted wirelessly via LoRa protocol to an ESP32 microcontroller, which acts as a gateway and visualizes the data in real time [8].

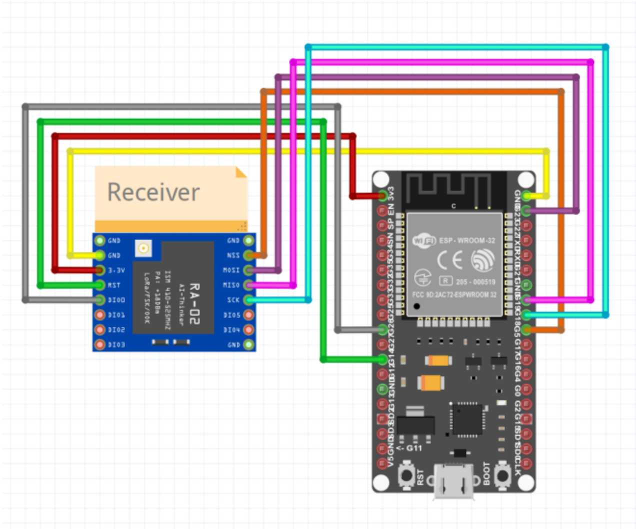

Figure 3 : LoRa Module

LoRa technology was selected for its long-range, low-power characteristics, making it suitable for solar plant environments where wired connections are impractical [9].

Source Code

The hardware design included the Arduino Uno R3 as the central controller interfacing with K-type thermocouples and the LoRa transceiver modules. The ESP32 microcontroller received data packets via LoRa and displayed temperature readings on an integrated user interface, enabling remote monitoring [10].

To integrate between LoRa and ESP, use the code below ;

- Receiver

```
#include <SPI.h>
#include <LoRa.h>
#include <DHT.h>

// Konfigurasi Sensor DHT21
#define DHTPIN D2
#define DHTTYPE DHT21
DHT dht(DHTPIN, DHTTYPE);

// Konfigurasi LoRa
#define LORA_SS   D8
#define LORA_RST  D0
#define LORA_DIO0 D1

// LED Indikator
#define LED_PIN 2
```

```
void setup() {
  Serial.begin(9600);
  dht.begin();

  pinMode(LED_PIN, OUTPUT);

  LoRa.setPins(LORA_SS, LORA_RST, LORA_DIO0);
  if (!LoRa.begin(433E6)) {
    Serial.println("Gagal memulai LoRa");
    while (true);
  }
  Serial.println("LoRa Siap");
}

void loop() {
  float suhuDHT = dht.readTemperature();
  float kelembaban = dht.readHumidity();

  String payload = "";

  if (!isnan(suhuDHT) && !isnan(kelembaban)) {
    payload += "DHT:" + String(suhuDHT, 2) + ";" + String(kelembaban, 2);
  }

  if (payload.length() > 0) {
    LoRa.beginPacket();
    LoRa.print(payload);
    LoRa.endPacket();

    digitalWrite(LED_PIN, HIGH);
    delay(100);
    digitalWrite(LED_PIN, LOW);

    Serial.println("Data terkirim: " + payload);
  } else {
    Serial.println("Tidak ada data valid untuk dikirim.");
  }

  delay(5000);
}
```

Data Analysis

Collected temperature data were logged and analyzed to evaluate system responsiveness and accuracy. Calibration of thermocouples was performed to ensure measurement precision [11]. The system's performance was validated by comparing recorded data with reference temperature sensors as below.

Table 1 : Data recorded

Day	Time	Amb (°C)	S1 (°C)	S2 (°C)	S3 (°C)	S4 (°C)	S5 (°C)	Avg Temp (°C)
	9.00	42.28	43.11	44.61	45.41	47.21	48.21	45.71
	10.00	34.64	35.76	37.26	38.06	39.86	40.86	38.36
21	11.00	38.77	41.90	43.40	44.20	46.00	47.00	44.50
	12.00	39.01	44.21	45.71	46.51	48.31	49.31	46.81
	13.00	38.31	44.52	46.02	46.82	48.62	49.62	47.12
	9.00	32.79	37.25	38.75	39.55	41.35	42.35	39.85
	10.00	33.98	41.95	43.45	44.25	46.05	47.05	44.55
22	11.00	40.34	44.20	45.70	46.50	48.30	49.30	46.80
	12.00	43.37	42.20	43.70	44.50	46.30	47.30	44.80
	13.00	38.00	43.00	44.50	45.30	47.10	48.10	45.60
	9.00	39.40	43.00	44.50	45.30	47.10	48.10	45.60
	10.00	40.05	44.20	45.70	46.50	48.30	49.30	46.80
23	11.00	38.51	39.00	40.50	41.30	43.10	44.10	41.60
	12.00	37.09	39.00	40.50	41.30	43.10	44.10	41.60
	13.00	30.79	31.20	32.70	33.50	35.30	36.30	33.80
	9.00	46.67	43.90	45.40	46.20	48.00	49.00	46.50
	10.00	37.29	44.50	46.00	46.80	48.60	49.60	47.10
24	11.00	36.01	42.00	43.50	44.30	46.10	47.10	44.60
	12.00	40.59	40.00	41.50	42.30	44.10	45.10	42.60
	13.00	38.78	42.00	43.50	44.30	46.10	47.10	44.60
	9.00	41.40	44.15	45.65	46.45	48.25	49.25	46.75
	10.00	40.47	41.50	43.00	43.80	45.60	46.60	44.10
25	11.00	39.38	43.00	44.50	45.30	47.10	48.10	45.60
	12.00	44.50	45.00	46.50	47.30	49.10	50.10	47.60
	13.00	39.30	42.50	44.00	44.80	46.60	47.60	45.10
26	9.00	34.54	39.00	40.50	41.30	43.10	44.10	41.60

	10.00	33.70	37.00	38.50	39.30	41.10	42.10	39.60
	11.00	31.27	33.00	34.50	35.30	37.10	38.10	35.60
	12.00	30.28	31.20	32.70	33.50	35.30	36.30	33.80
	13.00	37.15	40.00	41.50	42.30	44.10	45.10	42.60
	9.00	42.35	44.00	45.50	46.30	48.10	49.10	46.60
	10.00	47.98	46.00	47.50	48.30	50.10	51.10	48.60
27	11.00	38.67	44.00	45.50	46.30	48.10	49.10	46.60
	12.00	40.78	45.00	46.50	47.30	49.10	50.10	47.60
	13.00	36.52	44.50	46.00	46.80	48.60	49.60	47.10
	9.00	44.53	40.10	41.60	42.40	44.20	45.20	42.70
	10.00	40.28	43.00	44.50	45.30	47.10	48.10	45.60
28	11.00	38.83	44.10	45.60	46.40	48.20	49.20	46.70
	12.00	41.16	44.00	45.50	46.30	48.10	49.10	46.60
	13.00	42.86	40.00	41.50	42.30	44.10	45.10	42.60

3. Results and Discussion

The temperature graph above presents a comprehensive overview of the thermal behavior of a PLTS (Solar Power Plant) system over several consecutive days, with measurements taken at multiple sensor points labeled as Amb (ambient), S1, S2, S3, S4, and S5.

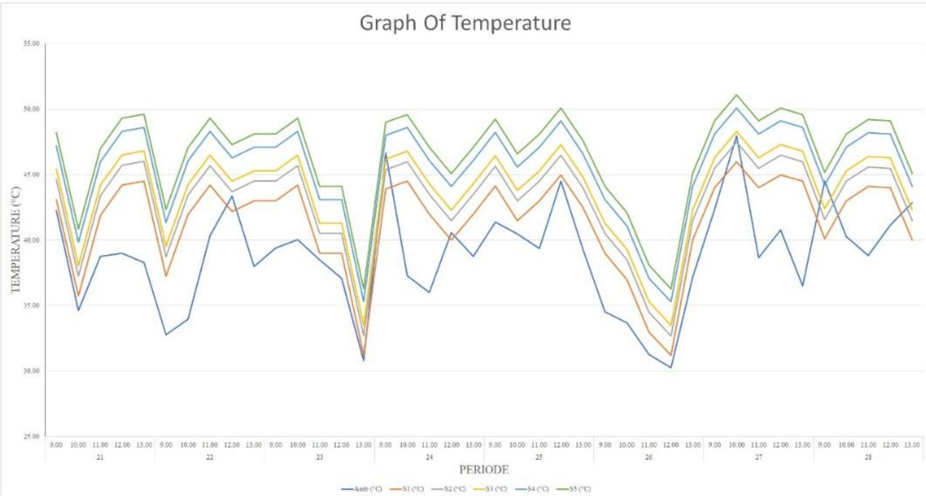

Figure 4 : Data recorded in a graph

The x-axis represents the time intervals across different dates, while the y-axis indicates the temperature in degrees Celsius. From the data, it is evident that all temperature profiles exhibit a pronounced diurnal cycle, with temperatures rising sharply in the late morning and peaking between 10:00 and 13:00 each day, which corresponds to the period of highest solar irradiance. The ambient temperature consistently records the lowest values among all the measured points, typically ranging from about 32°C to 47°C, while the panel or component sensors (S1–S5) register higher temperatures, often reaching or slightly exceeding 50°C during peak hours. This clear difference suggests significant heat accumulation within the system components compared to the surrounding environment, a phenomenon that is typical in photovoltaic installations exposed to direct sunlight. Notably, S5 generally records the highest temperatures among the component sensors, while S1 tends to show the lowest, indicating possible differences in exposure, material properties, or airflow at each sensor location. Throughout the monitoring period, sharp temperature drops are observed after 13:00, likely due to decreasing solar intensity or transient weather changes such as cloud cover, followed by a gradual decline into the evening. The pattern repeats daily, but with minor variations in both peak and minimum temperatures, reflecting the influence of fluctuating weather conditions, such as intermittent clouds or rainfall, which can moderate the thermal response of both the ambient environment and the system components. These observations highlight the importance of continuous, multi-point temperature monitoring in PLTS systems, as the thermal load experienced by the photovoltaic modules and associated components can directly impact system efficiency and longevity. The data underscores the need for effective thermal management strategies, such as improved ventilation or the use of materials with low temperature coefficients, to mitigate the adverse effects of high operational temperatures, especially in tropical climates. Overall, the graph provides valuable empirical evidence for understanding the relationship between environmental conditions and the thermal dynamics of solar power systems, supporting the development of more robust and efficient PLTS installations.

4. Conclusions

This study successfully designed and implemented an Arduino-based temperature monitoring system for Solar Power Plants (PLTS), utilizing K-type thermocouples for precise temperature acquisition and LoRa communication for real-time data transmission to an ESP32 microcontroller. The system was developed to address the critical need for accurate and continuous temperature monitoring in PLTS, which is vital for optimizing performance, ensuring longevity, and enabling timely preventive maintenance.

The implemented system effectively demonstrated its capability to reliably measure and transmit temperature data from key points within the PLTS environment. The integration of Arduino provided a flexible and accessible platform for data acquisition, while K-type thermocouples ensured high accuracy in temperature readings. Crucially, the deployment of LoRa technology proved highly effective in facilitating long-range, low-power wireless data transmission, making the system particularly well-suited for the often expansive and remote locations of solar power installations. The real-time visualization on the ESP32 allowed for immediate insights into the thermal conditions, highlighting its practical utility for operators and researchers.

In conclusion, the developed temperature monitoring system offers a robust, cost-effective, and scalable solution for enhancing the operational intelligence of solar power plants. By providing accurate, real-time temperature data remotely, it empowers stakeholders to make informed decisions regarding system optimization, fault detection, and proactive maintenance, thereby contributing to increased efficiency and reduced operational costs. Future work could involve integrating more sensor types, developing predictive analytics for thermal management, and exploring cloud-based data storage and analysis for broader accessibility and advanced insights.

5. References

[1] K. Bataineh and D. Dalalah, "Optimal Configuration for Design of Stand-Alone PV System," *Smart Grid and Renewable Energy*, vol. 03, no. 02, pp. 139–147, 2012, doi: 10.4236/sgre.2012.32020.

[2] M. Oota, Y. Iwafune, and R. Ooka, "Estimation of self-sufficiency rate in detached houses using home energy management system data," *Energies (Basel)*, vol. 14, no. 4, Feb. 2021, doi: 10.3390/en14040975.

[3] R. Ndegwa, J. Simiyu, E. Ayieta, and N. Odero, "A Fast and Accurate Analytical Method for Parameter Determination of a Photovoltaic System Based on Manufacturer's Data," *Journal of Renewable Energy*, vol. 2020, pp. 1–18, May 2020, doi: 10.1155/2020/7580279.

[4] J. Rekayasa Material, M. dan Energi, K. Umurani, A. Rudi Nasution, and Ms. Zufri, "Design And Implementation Of Temperature Measuring Device Using Max6675 And Thermocouple On Wet Cooling Tower," vol. 7, no. 2, pp. 335–342, 2024, doi: 10.30596/rmme.v7i2.19801.

[5] S. Hadiati, A. Pramuda, and M. Matsun, "Musschenbroek Learning Media with Arduino Based with Relay and Max6675 Sensor to Increase HOTS and Creativity," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 3, pp. 1006–1011, Mar. 2023, doi: 10.29303/jppipa.v9i3.2634.

[6] I. Ayu, N. I. Wikapti, I. Made, A. Nrartha, and A. B. Muljono, "Monitoring System Design for Off-Grid Solar Power Plant Based on Internet of Things ARTICLE INFO ABSTRACT," vol. 10, no. 1, pp. 14–23, 2023.

[7] S. P. Nalavade, A. D. Patange, C. L. Prabhune, S. S. Mulik, and M. S. Shewale, "Development of 12 channel temperature acquisition system for heat exchanger using MAX6675 and Arduino interface," in *Lecture Notes in Mechanical Engineering*, Pleiades journals, 2019, pp. 119–125. doi: 10.1007/978-981-13-2697-4_13.

[8] Z. Permana Muqorrobin, A. Nawawi, A. Aris Ardani, S. Putra Setia, and R. Rahmadian, "Off-Grid Solar System Monitoring based on ESP-32 and INA219 In Pesanggrahan Gordomulyo," *Vokasi Unesa Bulletin of Engineering, Technology and Applied Science*, pp. 26–37, Dec. 2024, doi: 10.26740/vubeta.v1i2.34859.

[9] Z. Permana Muqorrobin, A. Nawawi, A. Aris Ardani, S. Putra Setia, and R. Rahmadian, “Off-Grid Solar System Monitoring based on ESP-32 and INA219 In Pesanggrahan Gordomulyo,” *Vokasi Unesa Bulletin of Engineering, Technology and Applied Science*, pp. 26–37, Dec. 2024, doi: 10.26740/vubeta.v1i2.34859.

[10] Z. Permana Muqorrobin, A. Nawawi, A. Aris Ardani, S. Putra Setia, and R. Rahmadian, “Off-Grid Solar System Monitoring based on ESP-32 and INA219 In Pesanggrahan Gordomulyo,” *Vokasi Unesa Bulletin of Engineering, Technology and Applied Science*, pp. 26–37, Dec. 2024, doi: 10.26740/vubeta.v1i2.34859.

[11] *Proceeding of 2021 the 7th International Conference on Wireless and Telematics (ICWT2021) : 19-20 August 2021, Bandung, Indonesia*. IEEE, 2021.