Desain of an IoT-Based Hybrid System for Critical Medical Equipment Load Protection in Indonesian Hospitals

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International Conference on Electronics, Biomedical Engineering, and Health Informatics 2025
Homepage: icebehi.org; Vol. 6, No. 0, July 2025, pp: 000-000 e-ISSN: 1234-5678

RESEARCH ARTICLE OPEN ACCESS

Desain of an IoT-Based Hybrid System for Critical Medical Equipment Load Protection in Indonesian Hospitals

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Abstrack **Power supply instability to critical medical equipment in hospitals can lead to diagnostic failures and even fatal risks, including patient death. This issue is particularly prevalent in Indonesia, especially in regions with limited electrical infrastructure. This study proposes an Internet of Things (IoT)-based hybrid system that integrates the national grid (PLN) as the primary source, photovoltaic (PV) solar power as an alternative source, and an online double-conversion Uninterruptible Power Supply (UPS) as a backup source. The objective is to ensure continuous power supply in compliance with IEC 60364-7-710 and the Indonesian Ministry of Health Regulation No. 40 of 2022. The system provides a sustainable solution by combining renewable energy with real-time IoT monitoring, addressing the deficiencies in healthcare power infrastructure in Indonesia, particularly for Group 2 medical locations such as operating rooms. This implementation enables direct evaluation of IoT sensor performance and hybrid system operation before deployment in hospitals. The sensors used include the PZEM-004T, WCS1700, and SCT-013 for accurate monitoring of voltage, current, and battery capacity, as well as the DHT22 sensor to measure the ambient battery temperature. The results show that the system is capable of producing a stable 220 V ± 1% output with zero transfer time, reducing downtime by up to 90%, and lowering energy costs by up to 30% compared to diesel generators. The IoT sensor accuracy was recorded at a very high level, ranging from 97% to 99.17%, with the WCS1700 demonstrating the highest precision (99.17%). The main contribution of this research is the development of an IoT-based hybrid framework that not only complies with national regulations but also introduces a predictive preventive model and real-time monitoring. This framework can be widely implemented to enhance patient safety and promote energy sustainability in the healthcare sector.**

Keywords : **System Hybrid, Uninterruptible Power Supply (UPS), Medical Critical Load , Internet of Things (IoT), Solar Panel (PLTS)**

I. Introduction

Sistem A reliable and integrated electrical system in hospitals is crucial to ensure continuity of healthcare services and patient safety, particularly in critical load areas. Instability of power supply is a critical challenge in hospital operations, especially for medical equipment such as Magnetic Resonance Imaging (MRI), ventilators, heart monitors, Computed Tomography (CT) scanners, and operating rooms. Power disturbances, including outages and voltage

Manuscript received 8 April 2025; Revised 10 June 2025; 20 June 2025; Available online 27 June 2025
Digital Object Identifier (**DOI**): https://doi.org/10.35882/icebehi

Homepage: icebehi.org; Vol. 6, No. 0, July 2025, pp: 000-000 e-ISSN: 1234-5678

fluctuations, may cause equipment damage, potentially leading to misdiagnosis, treatment delays, or even fatal risks such as patient death [1]–[3].

In Indonesia, hospitals remain heavily dependent on the State Electricity Company (PLN) as the main energy source. However, PLN supply often faces problems such as outages in certain regions or voltage instability caused by high network loads. This condition is worsened by the growing demand for electricity in line with the advancement of modern medical technologies. For this reason, national regulation through the Regulation of the Minister of Health of the Republic of Indonesia Number 40 of 2022 requires every hospital to ensure the reliability of power supply to guarantee the functioning of critical medical equipment [4]. This regulation aligns with the international standard IEC 60364-7-710, which sets specific requirements for electrical installations in medical facilities to protect both patients and medical staff from risks due to power failures [5], The IEC standard classifies medical locations based on risk levels into three groups:

Non-Essential Load (Group 0): Equipment or rooms that can tolerate supply interruptions without direct impact on patient safety or critical functions. Example: storage rooms, waiting rooms, registration areas.

Essential Load (Group 1): Equipment or rooms that can tolerate short interruptions of around 15 seconds. However, loss of power in these loads may disturb other important functions. Example: observation rooms, anesthesia rooms.

Critical Load (Group 2): Equipment or rooms that must not experience any power interruption. Loss of supply in these loads may endanger patient safety and medical treatment effectiveness. Example: operating rooms, intensive care units, CT scan rooms.

Table 1.1 Medical Burden Groups Based on Tolerable Transfer Time

Category	Description	Example	Class Service	Maximum Outage Duration
Group 0	Locations where no medical equipment is in direct contact with patients	Registration Room	Class > 15 s	More than 15 seconds
Group 1	Locations where medical equipment is used externally or minimally invasive	Observation room, laboratory	Class 15 s	Maximum 15 seconds
Group 2	High-risk locations where power outages may endanger lives	Operating room, intensive care unit, critical medical equipment	Class 0 s or Class 0.5 s	No outage or maximum 0.5 seconds

Commonly used solutions include Uninterruptible Power Supply (UPS) and diesel generators. UPS with online double conversion topology has proven capable of maintaining stable and seamless supply, but its endurance is limited by battery life. Diesel generators can provide long-term backup, but they have startup delays, high operational costs, and significant environmental impacts. Recent studies show that integrating solar energy (PLTS systems) can reduce downtime and enhance energy resilience [6]. Furthermore, advancements in the Internet of Things (IoT) enable real-time monitoring of electrical systems, allowing early detection of risks in critical equipment [7] . However, conventional solutions still face limitations in terms of efficiency, cost, and predictive capability [8]–[11].

In Indonesia, several hospitals such as RSUD Karangasem (Bali), RSUP Dr. Sardjito (Yogyakarta), and RS Mata Makassar have begun adopting PLTS systems. However, their application has generally focused on energy and cost savings, rather than protecting Group 2 critical loads that demand uninterrupted supply. This gap underscores the urgency of this research: the need for a hybrid power system that not only relies on PLN and UPS, but also integrates PLTS systems as a sustainable alternative source, equipped with IoT-based monitoring to ensure continuity of supply in high-risk medical areas.

Based on these conditions, this study proposes the design of an IoT-based hybrid system integrating PLN–PLTS–online double conversion UPS. The system is designed to comply with national regulations (PERMENKES RI No. 40 of 2022) as well as international standards (IEC 60364-7-710). The focus is directed towards improving supply reliability in Group 2 medical locations, with the aim of minimizing downtime, protecting medical equipment, and ensuring patient safety.

The objectives of this research are:

(1) To design a hybrid system [12] integrating PLTS, UPS, and IoT in accordance with IEC 60364-7-710 and Regulation of the Minister of Health of the Republic of Indonesia No. 40 of 2022;

(2) To evaluate the effectiveness of the system through qualitative approaches and technical simulations; and

(3) To provide implementation recommendations for hospitals to enhance supply reliability while supporting the sustainable energy agenda.

Thus, this study is expected to contribute significantly to improving healthcare infrastructure reliability while

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strengthening the direction of sustainable energy transition in Indonesia.

II. Literature Review

A. Literature Review

This study aims to analyze the issue of power supply instability in critical medical equipment in hospitals, existing conventional solutions, and developments in renewable energy-based hybrid technologies such as Solar Power Plants (SPP) integrated with Automatic Transfer Switches (ATS), Uninterruptible Power Supplies (UPS), and Internet of Things (IoT)-based monitoring. This analysis is based on a review of relevant journals and scientific publications, with a focus on power reliability for critical loads in healthcare facilities. This approach identifies a gap in the literature, namely the lack of comprehensive hybrid system integration in the Indonesian context, in line with Indonesian Minister of Health Regulation No. 40 of 2022. The international standard IEC 60364-7-710 sets specific requirements for electrical installations in medical locations, including Group 0, Group 1, and Group 2 classifications. This standard emphasizes the importance of zero transfer time systems and critical load protection. Previous studies have only emphasized the use of UPS and generators, but have not fully integrated the requirements of IEC 60364-7-710 in the design of renewable energy-based hybrid systems [13].

A.1. Power Supply Instability

Power outages or voltage fluctuations affect hospital operations, especially critical medical equipment such as MRI, ventilators, and CT scanners. Research shows that power outages lasting more than 2 hours can increase patient mortality by up to 43% in healthcare facilities, due to disruptions in treatment and vital monitoring [14]. Analysis of power outages caused by natural disasters reveals challenges in accessing health services, maintaining frontline equipment, and providing community care, which often lead to increased deaths due to accidents or misdiagnosis.

A.2. Conventional Solutions for Power Reliability

Genset Generators and UPS have been widely used to overcome power outages in hospitals. However, generators have limitations such as high operational costs, environmental emissions, and long delays, while UPS only provides a temporary backup until the UPS battery runs out. Integrating UPS with generators can achieve 24/7 operational continuity for critical loads, but it still depends on sustainable fossil fuels. Under Ministerial Regulation No. 40 of 2022, healthcare facilities must provide additional power supply and, to maintain stability related to critical medical equipment, it is recommended to use online double conversion UPS. This type of UPS has zero transfer time [10] when the main power goes out.

A.3. Use of Renewable Energy and Hybrid Systems in the Health Sector

The shift to renewable energy, particularly solar power, has proven effective in improving power reliability in rural and urban health facilities [15]–[20]. A techno-economic analysis of hybrid renewable energy systems (HRES) for rural health centers in Bangladesh shows that integrating PLTS, batteries, and generators can reduce energy costs by up to 30% while ensuring a stable supply for medical equipment. [21] A similar study on PLTS/battery systems for health centers in Rohingya refugee camps emphasized resilience to blackouts, with a reduction in downtime of up to 90%. [journal] A comprehensive review of HRES in off-grid mini-grids highlights that solar-wind combinations with energy storage overcome the natural fluctuations of renewable sources, making them suitable for critical loads such as hospitals [22]. In developing countries, the implementation of solar power systems can provide reliable power for diagnosis and treatment, reducing dependence on the national grid.

A.4. Integration of PLTS, UPS, and IoT Technologies in Hybrid Systems

The integration of solar power systems and UPS in hybrid systems enables stable power supply. Meanwhile, IoT provides real-time monitoring to prevent failures. Controlling power in healthcare facilities enables remote monitoring of parameters such as voltage and battery capacity, optimizing the allocation of critical loads. [23]–[27] Sensor-based IoT systems can continuously detect power anomalies, reducing hospital downtime by up to 50% through preventive predictions. In a hybrid context, ATS ensures automatic transfer to alternative sources, while double conversion online UPS protects against voltage surges. Research on IoT in health monitoring systems shows improved service quality through real-time data, which can be applied to power infrastructure [28].

A.5. Gaps and Contributions of This Research

The literature shows that although hybrid systems are effective, the complete integration of solar power systems, UPS, and IoT in Indonesian healthcare facilities has yet to be fully explored, especially in terms of meeting national regulations. This study fills that gap with a hybrid system design that focuses on uninterrupted power stability, supporting sustainability and patient safety.

III. Method

B. Data Collection Methods

The data collection method in this study was conducted through a qualitative approach, emphasizing field

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Homepage: icebehi.org; Vol. 6, No. 0, July 2025, pp: 000-000 **e-ISSN: 1234-5678**

observations and document analysis. As a UPS technician assistant, the researcher carried out direct observations of online double conversion UPS installations in medical environments to evaluate output voltage stability, power source transfer time, and the integration of UPS with other backup sources. Document analysis was performed on national regulations (PERMENKES RI No. 40 of 2022), the international standard IEC 60364-7-710, as well as technical UPS manuals relevant to hospital applications. The data obtained from these observations and analyses served as the foundation for formulating the requirements of an IoT-based PLN–PLTS–UPS hybrid system, particularly in terms of reliability, safety, and compliance with standards.

C. System Design

This research adopts a qualitative approach combined with technical analysis to design and evaluate a hybrid system to ensure reliable power supply for critical medical equipment in hospitals (figure 2.1). The qualitative approach was applied to analyze system requirements based on regulations, namely the Regulation of the Minister of Health of the Republic of Indonesia No. 40 of 2022, as well as literature related to power stability and renewable energy technologies. Technical analysis was carried out through simulations to assess the performance of the hybrid system. This study is design-oriented, focusing on the development of a system that integrates Photovoltaic Power Plants (PLTS), Automatic Transfer Switch (ATS), Uninterruptible Power Supply (UPS) with online double conversion topology, and Internet of Things (IoT)-based monitoring.

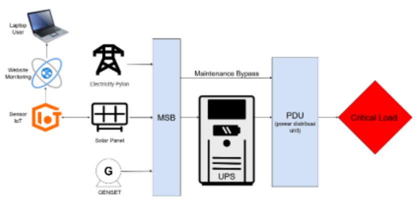

figure 2. 1 Desain Sistem Hybrid

II.1 State Electricity Company (PLN)

the event of a power outage from PLN, the PLTS battery automatically functions as a secondary alternative power source, ensuring continuity of power supply to medical equipment.

II.2 Solar Panel (PLTS)

Solar power plants are used as a secondary alternative power source to overcome the instability of electricity supply in environmentally friendly hospitals [6], [7], [29]. This study proposes an electrical system that integrates power supply from the State Electricity Company (PLN) with Solar Power Plants (PLTS) and Uninterruptible Power Supply (UPS) as backup power. This system is designed to ensure the reliability of power supply for critical medical equipment. The PLTS electrical system has three main modes, namely PLN Mode, Auto Mode, and PLTS Mode, which are described as follows:

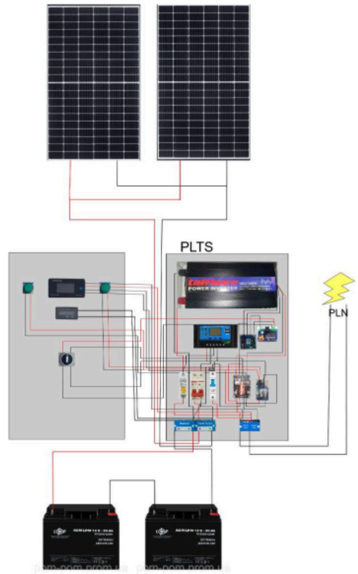

figure 2. 2 PLTS

A. PLN Mode

In PLN Mode, the main power supply comes from the PLN grid, which is directly connected to the load, such as critical medical equipment (MRI, ventilators, heart monitors, and CT scanners). Under normal conditions, this system prioritizes PLN as the main power source to ensure stable and efficient operations. However, in the event of a power outage from PLN, the PLTS battery automatically functions as a secondary alternative power source, ensuring continuity of power supply to medical equipment.

B. Auto Mode

Auto Mode is designed to optimize the use of PLTS batteries as the main power source, with PLN as a backup. In this mode, PLTS batteries can be set through the Low Voltage Disconnect (LVD) parameter to maintain battery life. The LVD setting allows the

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determination of the battery's operating voltage range, for example between 25 V and 22 V. When the battery voltage reaches the specified lower limit (for example, 22 V), the system automatically switches to PLN as the second power source. This setting aims to extend battery lifetime and prevent damage due to over-discharge.

C. PLTS Mode

The PLTS mode is activated when PLN experiences a prolonged power outage. In this mode, the PLTS battery becomes the main power source until its capacity is depleted. Although this mode ensures the availability of power supply for medical equipment during prolonged outages, using the battery until it is empty can reduce the battery's lifespan and potentially cause damage. Therefore, this mode is only used as an emergency solution until PLN's power supply is restored.

II.3 Uninterruptible Power Supply (UPS)

UPS, or Uninterruptible Power Supply, is a device or system that functions as a backup power source to maintain the continuity of electricity supply when the main power source (such as the PLN network) experiences interference, blackouts, or failures. Its purpose is to prevent damage to electronic equipment, data loss, or operational disruptions in systems that are sensitive to power fluctuations, such as computers, servers, medical equipment, or emergency lighting systems. The hybrid system used is an online double conversion UPS. This UPS has zero transfer time [10], [30]. Compared to offline UPS with a delay of 5-10 ms and Line-Interactive UPS with a delay of 2-4 ms.

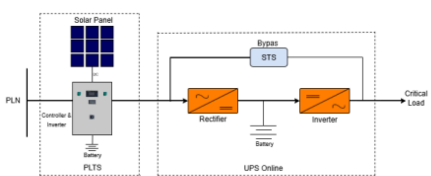

figure 2. 3 UPS Online

II.4 Internet Of Things (IoT)

IoT plays a role in monitoring hybrid electrical systems. When the electricity supply from PLN is interrupted, the Solar Power Plant (PLTS) functions as an alternative power source. In this context, IoT monitors the performance of the PLTS in real-time, detects anomalies, and ensures optimal operation. In addition, IoT monitors the battery power level that has been calibrated with the PLTS using a multimeter [7], [24], [28], [31]–[33]. When the battery is nearing depletion, the IoT monitoring system provides early warnings, allowing technicians to take immediate action. This ensures power supply reliability and minimizes the risk of power outages.

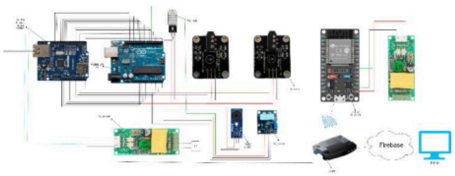

figure 2. 4 Sistem Monitoring

IV. Result

A. Testing of PLN – UPS – LOAD

The test results showed that the power supply from PLN produced a stable voltage in the range of 220–230 V. The online double conversion UPS maintained voltage stability at 220 V ± 1% and ensured zero transfer time during source switching. This configuration protected medical equipment from voltage fluctuations and transfer delays. Measurement data are presented in Figure 2.5 and the PLN–UPS test table, confirming the system's consistent performance under both normal and fault conditions.

B. UPS Testing – LOAD

Under PLN outage conditions, the UPS took over the power supply using its fully charged internal battery. The output voltage remained stable within specifications until the battery capacity approached its minimum limit. These results demonstrated that the UPS is effective as a short-term backup, although battery capacity remains a limitation for long-term operation.

Testing of PLN – PLTS – UPS – LOAD

The hybrid system was designed to integrate PLN, PLTS (Photovoltaic Power System), and UPS. Under normal conditions, PLN supplied power at 220–230 V, while PLTS was used to charge the backup battery. During a PLN outage, the PLTS system automatically supplied the load without interruption (zero transfer time), so the UPS was not immediately activated. If the PLTS battery capacity dropped below 20%, the IoT system sent notifications via a web dashboard and audio alarm. When the PLTS battery was fully depleted, the double conversion UPS automatically

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took over, maintaining a stable voltage at 220 V ± 1%. Measurement results are presented in figure 2.5 and 2.6.

The tests demonstrated that the hybrid system maintained seamless source transfer, kept voltage stable at 220 V ± 1%, and reduced downtime by up to 90%. Furthermore, the hybrid system reduced energy costs by 30% compared to conventional generator use.

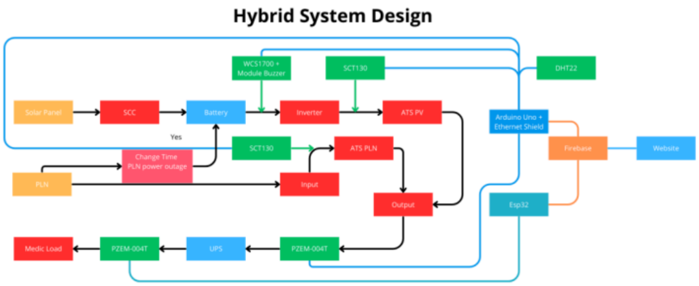

figure 2. 5 System Desain

Sensor accuracy testing was conducted by comparing voltage measurements with a digital multimeter as the reference standard under real operational conditions, including PLN input, inverter output, and PLTS output. This enabled sensor sensitivity adjustments to align results with the multimeter. The WCS1700 sensor showed the best performance in measuring low-voltage inverter output, with an average accuracy of 99.17%, making it the optimal choice for high-precision applications. The PZEM-004T sensor recorded consistent accuracy of 97% [34], [35] when measuring PLTS voltage and detected an average voltage drop of 3.67% (approximately 8.38 V) after passing through the UPS, confirming its reliability in renewable energy systems. Conversely, the SCT-013 sensor showed high accuracy [36], [37] at the PLN input voltage (average 98.33%, range 98%–100%) but was less stable at the inverter output with an average accuracy of 97.33% (range 85%–99%), likely due to the complexity of inverter signals. Overall, all three sensors demonstrated sufficient accuracy for voltage monitoring, with WCS1700 and PZEM-004T being superior in consistency, particularly at low voltages and within PLTS systems. Additional calibration is recommended to improve SCT-013 performance at the inverter output. figure 2.6 illustrates an example of real-time website-based monitoring implementation.

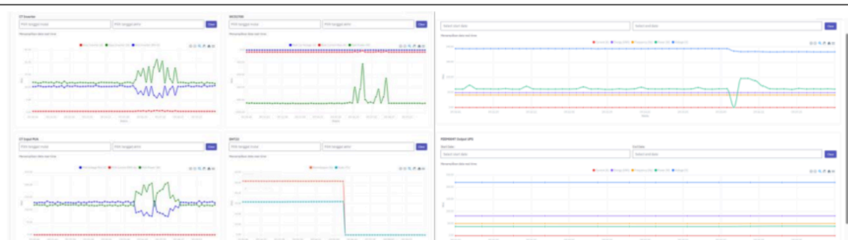

Figure 2. 5 Monitoring System

V. Discussion

This study demonstrates that the IoT-based PLN–PLTS–UPS hybrid system is capable of maintaining uninterrupted power supply (zero transfer time) with stable output at 220 V ± 1%, in compliance with IEC 60364-7-710 and the Regulation of the Minister of Health of the Republic of Indonesia No. 40 of 2022. Such reliability is crucial for operating rooms, intensive

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care units, and CT scanners, where power interruptions are unacceptable.

Compared to diesel generators, this system is more efficient, reducing downtime by up to 90% and lowering energy costs by approximately 30%. These findings are consistent with studies in Bangladesh and Rohingya refugee camps, which also highlighted the effectiveness of hybrid renewable energy systems in healthcare facilities. The high accuracy of IoT sensors (97–99.17%) further reinforces previous research on the importance of real-time monitoring in preventing power failures.

The implications for healthcare services include improved patient safety, uninterrupted functionality of medical equipment, and enhanced environmentally friendly energy efficiency.

However, this study has limitations: PLTS system performance is weather-dependent, initial implementation costs are relatively high, and the SCT-013 sensor demonstrated lower accuracy (97.33%) at the inverter output.

To address these challenges, integration with other renewable energy sources (e.g., wind or hydrogen) should be considered. Government policy support through incentives could help reduce investment costs. In addition, the development of artificial intelligence (AI)-based algorithms could assist in predicting power demand and optimizing energy usage, while further calibration could improve sensor accuracy. Large-scale trials across multiple hospitals are also needed to validate result consistency.

Overall, the IoT-based hybrid system has proven feasible, supports energy sustainability, and enhances the reliability of healthcare services in Indonesia.

VI. Conclusion

This study successfully developed the design of an IoT-based hybrid PLTS–UPS system to ensure a stable power supply for critical medical equipment [35], [38]–[41]. By integrating Arduino Uno and ESP32 microcontrollers with sensors (PZEM-004T, WCS1700, SCT013, and DHT22), the system achieved real-time monitoring with high accuracy (97–99.17%) for both electrical and environmental parameters. The implementation of three operational modes—PLN, Auto, and PLTS—ensures seamless power transitions, while the buzzer provides early warnings to prevent battery depletion. Real-time data transmission via Ethernet and WiFi enables effective visualization and decision-making through a web interface. The system improves power supply reliability, extends the lifespan of medical equipment, and supports patient safety by minimizing power disturbances.

Acknowledgment

I would like to express my deepest gratitude to Elvianto Dwi Hartono for his outstanding contribution to this research. He has kindly provided the space, equipment, and financial support that were essential for the development and testing of this thesis. His dedication and support have enabled us to carry out this research smoothly and achieve significant results. I deeply appreciate the time, resources, and guidance he has provided to support the success of this project.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability

No datasets were generated or analyzed during the current study.

Author Contribution

Dewa Rastafa Jati bertangung jawab dalam pembuatan sistem IoT, pengembangan proyek, serta integrasi perangkat keras dan perangkat lunak. Elvianto Dwi Hartono berkontribusi dalam pengembangan ide dan rancangan awal sistem hyrbid. Ery sadewa Yudha memberikan masukan teknis terkait kalibrasi sistem dan evaluasi akurasi sensor. Supangat berkontribusi dalam memberikan masukan dan saran terkait penulisan serta penyempurnaan naskah jurnal.

Declarations

Ethical Approval

Consent for Publication Participants.
Consent for publication was given by all participants

Competing Interests
The authors declare no competing interests.

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Homepage: icebehi.org; Vol. 6, No. 0, July 2025, pp: 000-000 e-ISSN: 1234-5678

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