

Performance Evaluation of ESP32 Sensors for Blynk-Based Smart Home Monitoring

Fitri Puspasari^{1*}, Unan Yusmaniar Oktiawati², Muhammad Arrofiq³, Imroatul Hudati⁴
^{1,2,3,4} Department of Electrical Engineering and Informatics Vocational College, Universitas Gajah Mada
*Corresponding author, e-mail: fitri.puspasari@ugm.ac.id¹

Received: August 3rd, 2026. Revised: August 23rd, 2026. Accepted: September 3rd, 2026
Available online: September 9th, 2026. Published: September 9th, 2026.

Abstract— This study presents a quantitative analytical evaluation of an integrated ESP32-based smart home system for environmental monitoring, hazard detection, and proximity sensing connected via the Blynk cloud platform. The prototype incorporates a DHT11 sensor for ambient temperature and relative humidity, an MQ-2 semiconductor sensor for LPG leak detection, and an HC-SR04 ultrasonic sensor for distance measurement. Experimental evaluation across repeated continuous trials demonstrated reliable real-time data acquisition and multi-channel alert delivery via Blynk push notifications and automated emails. Statistical analysis against reference instruments revealed high accuracy for the DHT11 sensor, achieving a Mean Absolute Error (MAE) of 1.05°C (RMSE = 1.15°C) for temperature and an MAE of 1.15% (RMSE = 1.27%) for relative humidity, both well within commercial manufacturer tolerances. The HC-SR04 ultrasonic sensor operated accurately over a 5 to 60 cm distance range with an overall MAE of 0.92 cm (RMSE = 0.96 cm). Overall, the proposed system delivers a robust, cost-effective solution for smart residential monitoring and serves as a highly practical instructional trainer kit for IoT and electrical engineering education.

Keywords: ESP32; Smart Home; DHT11; MQ-2; Blynk.

Copyright (c) 2026. Fitri Puspasari, Unan Yusmaniar Oktiawati, Muhammad Arrofiq, Imroatul Hudati.

I. INTRODUCTION

The rapid growth of the automation sector and the widespread availability of wireless connectivity have transformed modern residential environments into interconnected networks. Advancements in digital technology, particularly within the Internet of Things (IoT) domain defined as an ecosystem of physical devices connected via the internet for automated, real-time data exchange without direct human intervention (Al-Fuqaha et al., 2019) have significantly driven automation across diverse fields, including home automation, industrial control, environmental monitoring, agriculture, healthcare, and wearable electronics (Hercog et al., 2023). In today's digital era, IoT-based smart homes simplify daily routines across all age groups by enabling the remote control and monitoring of household features, such as lighting, fans, security systems, and safety features, from any location (Hasan et al., 2018; Media et al., 2019; Mustafa et al., 2021; Rabbani & Foo, 2022; Muskaan et al., 2022; Mamahit et al., 2023; Marathe et al., 2024; PBV et al., 2024; Bajgai et al., 2026; Kumar et al., 2026).

The efficacy of an IoT-based monitoring network fundamentally relies on two interconnected pillars: the precision and stability of gas and environmental sensors in capturing physical parameter fluctuations, alongside a resilient wireless transmission mechanism that delivers measurement

readings to a remote dashboard without data packet loss (Palmese et al., 2022; Pawar et al., 2024; Indrasari et al., 2026). Modern smart homes have evolved beyond isolated devices into comprehensive ecosystems that integrate diverse sensors (temperature, humidity, distance and gas) to deliver robust, real-time services while optimizing energy efficiency (DAŞ & ABABAKER, 2021; Jaya Lakshmi et al., 2022; Eltaleb et al., 2023).

In recent IoT applications, the integration of the NodeMCU ESP8266 microcontroller and HC-SR04 ultrasonic sensor has been shown to precisely control actuators via a cloud-based IoT interface with minimal measurement deviation (Walukow et al., 2025). To complement such architectures in remote environments, the implementation of a self-sustaining solar power supply demonstrates high power efficiency and operational sustainability for IoT-based monitoring systems in areas with limited grid power (Adeoye & Igwe, 2025). Furthermore, to construct such architectures cost-effectively without compromising functionality, microcontrollers like the ESP32 serve as a preferred hardware backbone due to their high processing power, rich sensor interface options, and built-in Wi-Fi/Bluetooth capabilities (Márquez-Vera et al., 2023). Pairing the ESP32 with platforms like Blynk facilitates seamless two-way communication, enabling users to configure, monitor, and interact with smart appliances through intuitive mobile interfaces. Numerous studies have explored

the implementation of smart home automation frameworks using various hardware and software configurations. For instance, Etuk et al. (2023) evaluated cloud-based IoT solutions for smart living, while Hermanu et al. (2020) reviewed dual-mode operation models featuring manual and automatic virtual switching via Blynk. Similarly, Islam et al. (2021) developed a home automation framework supporting real-time indoor and outdoor monitoring, security, and device control using smartphone and web interfaces linked to NodeMCU microcontrollers.

Despite these ongoing developments, ensuring overall system stability across multi-sensor deployment environments specifically balancing sensor accuracy, response latency, and wireless communication consistency remains a critical requirement for dependable real-world adoption. Most prior studies focus on functional prototype implementation, yet they lack comprehensive quantitative benchmarking against reference standards and do not evaluate the system's end-to-end latency. Furthermore, while these setups hold high potential for electrical engineering education as practical instructional tools, empirical validation of their performance in laboratory learning environments remains scarce. To bridge this gap, this study proposes a quantitative analytical evaluation of an integrated ESP32-based smart home system.

The novelty of this research lies in evaluating multi-sensor accuracy against calibrated instruments, analyzing end-to-end communication latency, and assessing the prototype's educational applicability as an IoT trainer kit for laboratory instruction. Specifically, this study aims to analyze an integrated ESP32-based smart home system equipped with sensors for temperature, humidity, object detection, and gas detection, and to comprehensively evaluate its performance in terms of response time, accuracy, operational stability, and instructional feasibility.

II. METHOD

A. System Design and Hardware Setup

The smart home monitoring system was built using an ESP32 microcontroller as the central processing unit, integrated with three primary sensors: a DHT11 sensor for ambient temperature and humidity monitoring, an MQ-2 semiconductor sensor for hazardous LPG gas leakage detection, and an HC-SR04 ultrasonic sensor for proximity and distance measurement. The system architecture also includes a 4-channel relay module to drive external actuators, an LCD I2C display for local data visualization, an audible buzzer alarm, and a Wi-Fi-based cloud interface linked to the Blynk application. The detailed

hardware circuit configuration is illustrated in Figure 1.

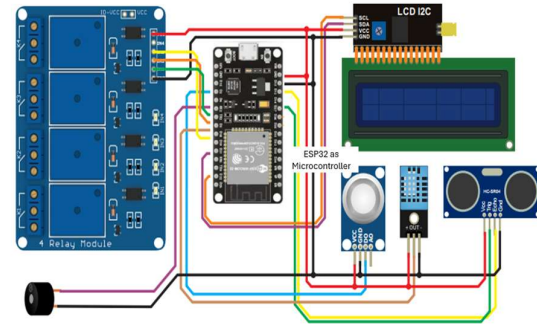


Figure 1. Hardware Schematic

B. Implementation

The ESP32 processes physical data acquired from the connected DHT11, MQ-2, and HC-SR04 sensors. Program logic written in C++ via the Arduino IDE evaluates input readings against defined safety thresholds. When a parameter exceeds normal limits (e.g., LPG gas detection or object threshold breach), the ESP32 activates local alerts (buzzer and LCD display) and simultaneously executes remote cloud synchronization. Data packet exchange and remote control are managed through the Blynk platform over a 2.4 GHz IEEE 802.11 b/g/n Wi-Fi local access point, delivering real-time graphical gauge displays, push notifications, and automated email alerts to the user's mobile device.

C. Experimental Procedures and Reference Testing

1. Temperature and Humidity: Readings from the DHT11 sensor were compared against a calibrated Digital Thermohygrometer HTC-1 (temperature measurement range: -10°C to 50°C , resolution: 0.1°C , accuracy: $\pm 1.0^{\circ}\text{C}$; humidity range: 10% to 99% RH, resolution: 1% RH, accuracy: $\pm 5\%$ RH).
2. Proximity/Distance: Measurements from the HC-SR04 ultrasonic sensor were evaluated against a standard Precision Steel Ruler / Measuring Tape (range: 0 – 100 cm, resolution: 0.1 cm, accuracy: ± 0.05 cm).
3. Gas Detection: The MQ-2 sensor was subjected to repeated controlled LPG exposure trials to verify threshold trigger reliability and alert success rates.

D. Data Collection and Analysis

Data collected across all n-trials were analyzed using descriptive statistics. Measurement error and system precision were quantified using Mean Absolute Error (MAE) and Root Mean Square Error (RMSE), defined as:

$$MAE = \frac{1}{n} \sum_{i=1}^n |Y_i - X_i|$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (Y_i - X_i)^2}$$

where X_i represents the value measured by the prototype sensor, Y_i is the reference measurement value, and n is the total number of experimental iterations.

E. Validation

The validation process was conducted through repeated testing and comparison with reference data or high-precision measurement instruments. This approach ensures that the obtained results are reliable and not influenced by unintended external factors, thereby confirming the robustness of the proposed system.

III. RESULTS

The designed smart home system has been evaluated based on sensor testing results and the ESP32s capability to manage various IoT devices. The test results indicate that the ESP32 reliably processes sensor data and transmits it to the Blynk application in real-time. The MQ-2 sensor demonstrates high sensitivity in detecting gas leaks and provides early warnings through the Blynk application. This enables timely alerts to potential gas hazards. The DHT11 sensor accurately measures temperature and humidity, with real-time monitoring available through the Blynk app.



Figure 2. Monitoring Interface in the Blynk Application

The IoT-based monitoring system effectively displays sensor data in real-time through the Blynk application. Parameters such as gas detection, temperature, and humidity are monitored with high accuracy. Figure 2 illustrates the Blynk application's

intuitive interface, which simplifies user monitoring of home environmental conditions directly from mobile devices.

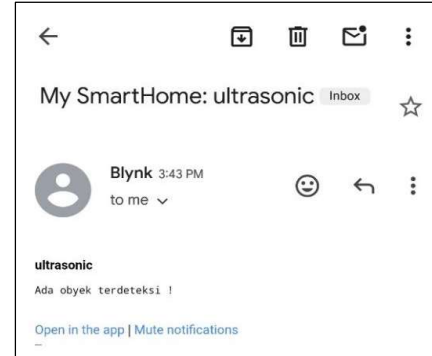


Figure 3. Email Notification Display

Figure 3 shows the email notification display. This feature enhances user safety and convenience, enabling prompt action in emergency situations. The integration of Blynk application notifications with email alerts was successfully tested and functioned effectively during system evaluation.

A. Sensor Test Results

The response time of the DHT11 sensor was evaluated by measuring the duration required for the sensor to provide temperature and humidity data following a change in environmental conditions.

B. Accuracy and Observations

The accuracy of the DHT11 sensor was assessed by comparing its readings against a calibrated digital thermos-hygrometer reference across $n = 13$ sampling iterations.

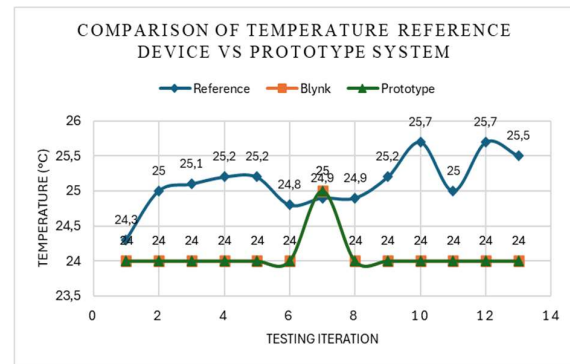


Figure 4. Temperature Test Results for the DHT11 Sensor

Figure 4 illustrates the variation between the reference temperature measurements and the temperature readings recorded by the DHT11 sensor, as displayed on the Blynk application and Serial Monitor. The differences range from 0.3°C to 1.7°C. These results indicate that the accuracy of the DHT11

sensor, as reported by both Blynk and the Serial Monitor, remains within the acceptable error margin of $\pm 2^{\circ}\text{C}$, thus confirming its reliability for basic environmental monitoring.

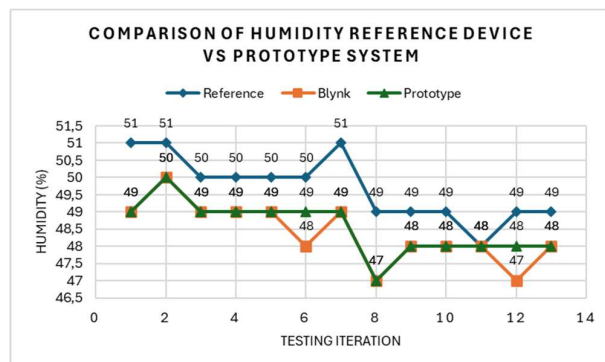


Figure 5. Humidity Test Results for the DHT11 Sensor

Figure 5 depicts the variation in humidity readings between the reference measurements and those recorded by the DHT11 sensor, as shown in the Blynk application and Serial Monitor. The observed error ranges from 0% to 2%, reflecting the sensor's precision and accuracy in humidity measurement.

As summarized in Table 1, the sensor demonstrated a Mean Absolute Error (MAE) of 1.05°C (RMSE = 1.15°C) for temperature and an MAE of 1.15% (RMSE = 1.27%) for relative humidity. Although minor deviations occurred, all error metrics remained strictly within the manufacturer's commercial specification limits ($\pm 2.00^{\circ}\text{C}$ and $\pm 5.00\%$ RH), confirming the sensor's adequacy for general ambient monitoring.

Table 1. Statistical Performance Evaluation of DHT11 Sensor ($n = 13$)

Statistical Parameter	Temperature ($^{\circ}\text{C}$)	Humidity (% RH)
Reference Mean	25.12 $^{\circ}\text{C}$	49.69%
Prototype Mean	24.08 $^{\circ}\text{C}$	48.54%
Prototype Std Dev (σ)	0.28 $^{\circ}\text{C}$	0.78%
Maximum Error	1.70 $^{\circ}\text{C}$	2.00%
MAE	1.05 $^{\circ}\text{C}$	1.15%
RMSE	1.15 $^{\circ}\text{C}$	1.27%
Manufacturer Specification	$\pm 2.00^{\circ}\text{C}$	$\pm 5.00\%$

C. MQ2 Sensor

The MQ2 sensor is designed to detect the presence of LPG gas. Test results indicate that the sensor effectively identifies gas at specific concentrations and generates notifications when gas levels exceed the predefined threshold.



Figure 6. Gas detection notification in email

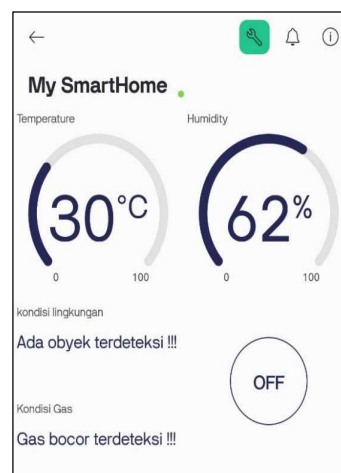


Figure 7. Monitoring view in Blynk

Since the MQ2 sensor performs detection rather than quantitative measurement, a specific response time measurement was not recorded. When gas is detected, the system triggers a gas leak notification in the Blynk application and also sends an alert via email. These notifications are illustrated in Figure 6 and Figure 7.

The functional performance of the MQ-2 gas sensor was evaluated based on its capability to detect gas leakage and trigger multi-channel alerts (Table 2). Upon threshold activation caused by the presence of target gas, the system successfully executes two primary actions: triggering the local hardware response and transmitting remote alerts. The IoT notification pipeline was verified through two active communication channels: push notifications via the Blynk application and automated alert messages sent to the user's registered email address. Experimental testing confirmed that both Blynk notifications and email alerts were reliably delivered without missing event triggers, ensuring effective real-time hazard monitoring.

Table 2. Functional Performance and Alert Integration of MQ-2 Gas Sensor

Evaluation Parameter	Operational Specification & Result
Primary Function	LPG / Gas Leakage Detection
Detection Mechanism	Digital Threshold Trigger (Gas Presence / Leakage)
System Output / Actuation	Local Alarm Activation & IoT Alert Dispatch
Notification Channels	1. Blynk Push Notification 2. Automated Email Alert
Functional Verification	Successful (Alerts reliably received on Blynk & Email upon gas detection)

D. Distance Accuracy and Error Analysis of the HC-SR04 Sensor

The measurement accuracy of the HC-SR04 ultrasonic sensor was evaluated by comparing prototype readings with a physical reference.

Table 3. Point-by-Point Accuracy and Error Analysis of the HC-SR04 Ultrasonic Sensor

Reference Distance (cm)	Measured Distance (cm)	Relative Error (%)
5.0	4.0	20.00%
10.0	9.0	10.00%
15.0	14.0	6.67%
20.0	19.0	5.00%
25.0	24.0	4.00%
30.0	29.0	3.33%
35.0	34.0	2.86%
40.0	39.0	2.50%
45.0	44.0	2.22%
50.0	49.0	2.00%
55.0	54.0	1.82%
60.0	60.0	0.00%

As summarized in Table 3, The measurement accuracy of the HC-SR04 ultrasonic sensor was evaluated across an effective operational range of 5 cm to 60 cm against a precision reference scale (Table 3). Within the evaluated spectrum, the sensor demonstrated a Mean Absolute Error (MAE) of 0.92 cm, an RMSE of 0.96 cm. A +1.00 cm correction for measurements obtained within the 5–55 cm tested sub-range.

IV. DISCUSSIONS

To validate the performance of the distance measurement system, an accuracy test was carried out by comparing the HC-SR04 sensor readings with those obtained from a standard reference instrument (Figure 9). The HC-SR04 is a widely used, low-cost ultrasonic proximity sensor that converts electrical signals into ultrasonic sound waves using integrated

transmitter and receiver units to measure object distances (Hirzi, 2023). Although extended-range applications often rely on LIDAR sensors (Thornton et al., 2014; Zováthi et al., 2022), conventional ultrasonic setups are optimized for close-range detection. Unlike previous work by Budiarto (2015), which evaluated ultrasonic sensing up to 374 cm without specifying hardware details or error margins, our experimental evaluation provides a rigorous performance benchmark.

The experimental evaluation confirms that integrating an ESP32 microcontroller with low-cost sensors yields a practical, responsive IoT monitoring setup. Figure 8 compares the prototype's distance readings against reference values, showing high linearity.

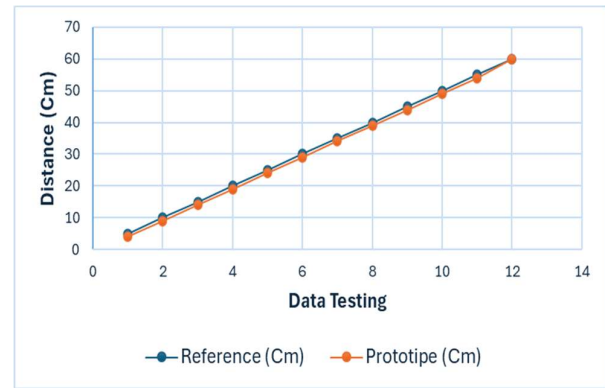


Figure 8. Graph of HCSR04 sensor test results

The DHT11 sensor yielded an MAE of 1.05°C for temperature and 1.15% for relative humidity. The slight temperature error (maximum error of 1.70°C) stems from internal Negative Temperature Coefficient (NTC) thermistor tolerances and non-linear dielectric drift in the low-cost polymer capacitive humidity sensor. Nevertheless, because performance remained within manufacturer thresholds ($\pm 2.00^\circ\text{C}$ and $\pm 5.00\%$ RH), the DHT11 remains appropriate for basic indoor residential monitoring.

V. CONCLUSION

This study successfully designed, implemented, and quantitatively evaluated an integrated ESP32-based smart home monitoring system using the Blynk cloud platform. Experimental validation across continuous trials confirmed the system's accuracy, operational stability, and reliable threat-detection performance.

The DHT11 sensor demonstrated high reliability for indoor ambient monitoring, achieving a Mean Absolute Error (MAE) of 1.05°C (RMSE = 1.15°C) for temperature and 1.15% (RMSE = 1.27%)

for relative humidity, both remaining strictly within the manufacturer's specified operational tolerances ($\pm 2.00^\circ\text{C}$ and $\pm 5.00\%$ RH). The MQ-2 gas sensor reliably detected LPG leaks and executed real-time local actuations (buzzer alarm and LCD display) alongside remote multi-channel notifications. Automated email alerts and Blynk push notifications were transmitted without data packet loss or missed event triggers upon threshold breach. The HC-SR04 ultrasonic sensor performed accurately over an operational range of 5 cm to 60 cm, exhibiting an MAE of 0.92 cm and RMSE of 0.96 cm. A consistent systematic offset of -1.00 cm observed within the 5–55 cm sub-range indicates that measurement precision can be further enhanced via a simple $+1.00$ cm software offset calibration.

In summary, the developed system provides a low-cost, scalable, and responsive solution for residential Internet of Things (IoT) monitoring. Furthermore, its transparent architectural design and rigorous performance metrics support its feasibility as an effective hands-on educational trainer kit for undergraduate laboratories in electrical and computer engineering. Future work will focus on integrating edge-AI predictive models, optimizing power consumption for battery-operated nodes, and evaluating secure communication protocols under high network traffic conditions.

REFERENCES

- Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2019). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 21(1), 34–56. <https://doi.org/10.1109/COMST.2019.2899352>
- Bajgai, R., Thapa, M., Sakr, H. A., Fouda, M., & Ashour, A. F. (2026). Performance benchmarking of ESP32-based smart home systems for latency, power, and reliability. In *Proceedings of the IEEE ICM* (pp. 1–5).
- Budiarsa, Z. (2015). Implementasi sensor ultrasonik untuk mengukur panjang gelombang suara berbasis mikrokontroler. *Jurnal Teknologi Informasi DINAMIK*, 20(2), 171–177.
- Daş, R., & Ababaker, T. (2021). An implementation for smart home system based on Internet of Things. *European Journal of Technology*, 11(1), 34–42. <https://doi.org/10.36222/ejt.931161>
- Eltaleb, A., Khaleel, M., Abulifa, S., Abdelkareem, D. A., & Abodwair, A. (2023). Smart home sensor systems: Advancements and applications. *International Journal of Electrical Engineering and Sustainability*, 1(3), 120–128.
- Etuk, U. E., Omenaru, G., Inyang, S. J., & Umoren, I. (2023). Towards sustainable smart living: Cloud-based IoT solutions for home automation. *Journal of Information Systems & Informatics*, 5(4), 1743–1763. <https://doi.org/10.51519/journalisi.v5i4.621>
- Hasan, M., Anik, M. H., & Islam, S. (2018). Microcontroller based smart home system with enhanced appliance switching capacity. In *Information Technology Trends Emerging Technologies Artificial Intelligence* (pp. 364–367). <https://doi.org/10.1109/CTIT.2018.8649518>
- Hercog, D., Lerher, T., Truntiĉ, M., & Težak, O. (2023). Design and implementation of ESP32-based IoT devices. *Sensors*, 23(15), 6739. <https://doi.org/10.3390/s23156739>
- Hirzii, M. F., Pasaribu, S. A., Sabila, P. C., & Parlindungan, M. R. (2023). Performance sensor analysis of HC-SR04 proximity sensor on distance measuring device with fuzzy logic method. *Journal of Computer Science Research (JoCoSiR)*, 1(3), 92–97.
- Indrasari, N., et al. (2026). Analisis performa protokol MQTT pada sistem monitoring gas berbahaya menggunakan sensor MQ135 terintegrasi Android. *Jurnal Media Elektro, Genarsih*(1), 16. <https://doi.org/10.35508/jme.v0i0.28118>
- Islam, S. F., Hasan, M. I., Akter, M., & Uddin, M. S. (2021). Implementation and analysis of an IoT-based home automation framework. *Journal of Computer and Communications*, 9(3), 143–157. <https://doi.org/10.4236/jcc.2021.93011>
- Jaya Lakshmi, M., Sameen, C. S., Maneesha, D., Dharani, G., Mubeena, K. F., & Dean, A. (2022). Smart home using Blynk app based on IoT. *International Journal of Creative Research Thoughts*, 10(5), 341–345.
- Kumar, H., Kurmi, A., Vishwakarma, G., Nigam, D., & Kurmi, U. S. (2026). IoT-based smart home automation system using ESP32 and Blynk cloud platform. *International Journal of Research and Technology*, 14(2), 907–912.
- Mamahit, A., Wauran, A., Manoppo, F., Seke, F., & Ticoh, J. (2023). Smart home with voice control lights using Arduino Uno R3. *Jurnal*

- Edunitro: Jurnal Pendidikan Teknik Elektro, 3(2), 97–104.
- Marathe, A. A., Sharma, L., Sailo, L., Limdiyawala, M., & Mate, A. (2024). MotionGuard: ESP32 CAM-powered smart flooring system for enhanced security. In 2024 International Conference on Integration of Emerging Technologies for the Digital World (ICIETDW) (pp. 1–7). IEEE.
- PBV, R. R., Mandapati, V. S., Pilli, S. L., et al. (2024). Home security with IOT and ESP32 Cam - AI Thinker module. In 2024 International Conference on Cognitive Robotics and Automation (ICCRA) (pp. 1–6). IEEE.
- Márquez-Vera, M. A., Martínez-Quezada, M., Calderón-Suárez, R., Rodríguez, A., & Ortega-Mendoza, R. M. (2023). Microcontrollers programming for control and automation in undergraduate biotechnology engineering education. *Digital Chemical Engineering*, 9, 100122. <https://doi.org/10.1016/j.dche.2023.100122>
- Media, E. S., & Rif'an, M. (2019). Internet of Things (IoT): Blynk framework for smart home. *KnE Social Sciences*, 3(12), 579. <https://doi.org/10.18502/kss.v3i12.4128>
- Mustafa, B., Iqbal, M. W., Saeed, M., Shafqat, A. R., Sajjad, H., & Naqvi, M. R. (2021). IoT based low-cost smart home automation system. In *HORA 2021 Proceedings*. <https://doi.org/10.1109/HORA52670.2021.9461276>
- Muskaan, M., Madhushree, M., Bai, J. S., Begum, S. H., & Gouda, S. (2022). Home automation using Blynk. *International Journal of Advanced Research in Science, Communication and Technology*, 13, 355–356. <https://doi.org/10.48175/IJARSCT-5352>
- Palmese, F., Redondi, A. E. C., & Cesana, M. (2022). Adaptive quality of service control for MQTT-SN. *Sensors*, 22(22), 8852. <https://doi.org/10.3390/s22228852>
- Pawar, S., Jadhav, D. B., Lokhande, M., Raskar, P., & Patil, M. (2024). Evaluation of quality of service parameters for MQTT communication in IoT application by using deep neural network. *International Journal of Information Technology*, 16(2), 1123–1136. <https://doi.org/10.1007/s41870-023-01664-2>
- Rabbani, N. A., & Foo, Y. L. (2022). Home automation to reduce energy consumption. *International Journal of Technology*, 13(6), 1251–1260. <https://doi.org/10.14716/ijtech.v13i6.5930>
- Walukow, T. K., Mamahit, C., & Ticoh, J. (2025). Perancangan Sistem Otomasi Penyiraman Pestisida Menggunakan Sensor Ultrasonik Berbasis IoT. *Jurnal Edunitro*, 5(2), 113–122.
- Adeoye, Y., & Igwe, I. (2025). Solar-Powered IoT Smart Bin Deployment in Lagos: A Scalable Model for Sustainable Waste Management in Developing Cities. *Jurnal Edunitro*, 5(2), 141–150.
- Zováthi, Ö., Nagy, B., & Benedek, C. (2022). Point cloud registration and change detection in urban environment using an onboard Lidar sensor and MLS reference data. *International Journal of Applied Earth Observation and Geoinformation*, 110(October 2021), 102767. <https://doi.org/10.1016/j.jag.2022.102767>

