ESP32-BASED SMART OFFICE PROTOTYPE WITH WI-FI AND MQTT INTEGRATION ON TELECOMMUNICATIONS INFRASTRUCTURE

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PROTOTIPE SMART OFFICE BERBASIS ESP32 DENGAN INTEGRASI WI-FI DAN MQTT PADA INFRASTRUKTUR TELEKOMUNIKASI

Abstrak: *Perkembangan Internet of Things (IoT) mendorong penerapan smart office guna meningkatkan efisiensi operasional. Penelitian ini mengembangkan prototipe smart office berbasis mikrokontroler ESP32 yang terhubung ke jaringan Wi-Fi dan menggunakan protokol MQTT. Sistem dirancang untuk memantau suhu dan kelembapan ruangan serta mengendalikan perangkat elektronik secara real-time melalui dashboard Node-RED. Pengujian meliputi latensi komunikasi, akurasi sensor, konsumsi daya, stabilitas jaringan, dan keamanan data. Hasil menunjukkan latensi rendah, sensor yang akurat, serta kemampuan multiakses tanpa penurunan kinerja. Sistem juga dilengkapi enkripsi TLS untuk melindungi data dari ancaman siber. Dengan biaya implementasi yang rendah dan fleksibilitas integrasi tinggi, prototipe ini dinilai layak diterapkan pada skala operasional lebih luas, khususnya di lingkungan telekomunikasi perkantoran yang memerlukan otomasi dan efisiensi energi*.

Kata kunci: Smart Office, ESP32, Wi-Fi, MQTT, Internet of Things, Otomasi Kantor, Node-RED, Efisiensi Energi

Abstract:*The development of the Internet of Things (IoT) has encouraged the adoption of smart office concepts to improve operational efficiency. This study presents a smart office prototype based on the ESP32 microcontroller, integrated with Wi-Fi connectivity and the MQTT communication protocol. The system is designed to monitor environmental conditions, such as temperature and humidity, while enabling real-time control of electronic devices through a Node-RED dashboard. System evaluation was conducted by measuring communication latency, sensor accuracy, power consumption, network stability, and data security. The results indicate low latency, reliable sensor accuracy, and support for multi-user access without performance degradation. In addition, the system implements Transport Layer Security (TLS) encryption to protect data from potential cyber threats. With its low implementation cost and high integration flexibility, the prototype is considered feasible for broader operational deployment, particularly in office telecommunication environments that demand automation, energy efficiency, and productivity improvement*.

Keywords: Smart Office, ESP32, Wi-Fi, MQTT, Internet of Things, Office Automation, Node-RED, Energy Efficiency

INTRODUCTION

Digital transformation in the world of work is driving the emergence of the concept of smart offices, which integrate Internet of Things (IoT) technology to improve productivity, efficiency, and operational security. Smart offices combine smart devices, sensors, and communication systems to automate various office functions, from lighting, room cooling, to physical security (Al-Shareeda et al., 2024). The use of this technology is one of the strategic factors in supporting the company's competitiveness in the industrial era 4.0.

The application of IoT in an office environment allows for the collection of real-time data from various sources, which can then be analyzed for faster and more informed decision-making (Adrian et al., 2024). This data includes information on energy usage, environmental conditions, and room occupancy rates, all of which can be accessed centrally through the dashboard.

One of the devices that is widely used in IoT implementations is the ESP32. These microcontrollers are known for their high performance, built-in Wi-Fi and Bluetooth connectivity, and low power consumption, making them ideal for smart office applications. Dual processing capabilities and connectivity flexibility make the ESP32 capable of handling multiple communication protocols simultaneously.

In IoT systems, communication protocols are key to the efficiency and reliability of data transmission. Message Queuing Telemetry Transport (MQTT) is a lightweight protocol that is particularly suitable for devices with limited power and bandwidth. The protocol uses a publish-subscribe architecture, which minimizes resource consumption and improves system scalability.

The implementation of MQTT on ESP32 has been shown to be effective in supporting stable and fast data delivery on networks with limited capacity. This allows the smart office system to continue to function optimally even though the telecommunication infrastructure has certain limitations.

The use of open-source MQTT brokers on ESP32 provides flexibility in building systems that can be tailored to the needs of the organization. The study of (Adrian et al., 2024)shows that this integration simplifies the management of IoT devices while reducing implementation costs.

In addition, power optimization on the ESP32 is an important factor to improve operational efficiency. Reveals that the implementation of power-saving mode can extend battery life by more than 50%, which is very advantageous for devices that must operate 24 hours in a smart office system.

Energy efficiency is not only profitable in terms of operational costs, but also supports environmental sustainability. ESP32-based lighting and cooling automation systems are able to significantly reduce energy consumption by adjusting the operation of the device according to environmental conditions.

Data security is one of the biggest challenges in the implementation of smart offices. (Al-Shareeda et al., 2024). emphasize that IoT devices, including ESP32, must be equipped with security protocols such as Transport Layer Security (TLS) to protect data from potential cyberattacks.

The implementation of TLS on MQTT communications can prevent eavesdropping and modification of data during transmission. found that many MQTT systems were misconfigured, thus opening up serious security gaps. Therefore, proper security arrangements are a crucial aspect.

In the context of smart offices, the ESP32's ability to connect with multiple devices at once without any performance degradation is a key advantage. Showed that ESP32 can manage up to 50 IoT devices simultaneously with low latency, which supports the integration of medium-scale systems.

In addition to connectivity, easy integration with dashboard platforms such as Node-RED or Blynk is also a plus. The platform enables real-time visualization of sensor data, which assists office managers in monitoring environmental conditions and device performance.

The study shows that ESP32-based systems can be integrated with different types of sensors such as temperature, humidity, and motion, thus supporting more complex automation functions. This combination allows for the creation of an adaptive work environment.

From an architectural standpoint, the implementation of edge computing on the ESP32 helps process data at the device level before it is sent to the server. This approach reduces network load and speeds up system response, which is critical in real-time applications.

Based on this literature review, this study aims to design a prototype of an ESP32-based smart office with Wi-Fi and MQTT integration, equipped with TLS security features and power efficiency. This research is expected to make a real contribution to the development of a safe, efficient, and environmentally friendly smart work environment in the future.

RESEARCH METHODS

This research method uses a research and development (R&D) approach with the aim of producing a prototype of a smart office based on ESP32 that is integrated with Wi-Fi and MQTT. The development process is carried out through several stages, ranging from analyzing system needs, designing hardware and software, testing, to performance evaluation. This approach was chosen because it is able to provide a structured development cycle and allow for repeated improvement (Adrian et al., 2024).

The first stage is the analysis of system requirements, which is carried out by identifying the main functions of the smart office, such as lighting control, room temperature monitoring, and access security. The identification of this need refers to the study of which emphasizes the importance of automating basic office functions to improve comfort and energy efficiency.

The second stage is hardware design. The main components used are ESP32 as the control center, the DHT22 sensor for temperature and humidity, the PIR sensor for motion detection, and the relay module for electrical load control. The selection of ESP32 was based on the availability of built-in Wi-Fi and Bluetooth, low power consumption, and support for the MQTT protocol.

The third stage was software design, which involved coding programs on ESP32 using Arduino IDE, integration of the MQTT protocol for data communication, and the implementation of TLS as a security layer. This security approach refers to the findings of the which affirm the importance of mitigating risks from vulnerable MQTT configurations.

The fourth stage is system testing. Tests were carried out on two main aspects: the communication performance of the MQTT and the power consumption of the device. The tests were carried out under normal and limited network conditions to assess the reliability of the system. The data obtained is analyzed to evaluate the success of the integration and ensure all functions are running as planned.

RESEARCH RESULTS

The test results showed that the ESP32 was capable of sending and receiving sensor data via the MQTT protocol with an average latency of 120 ms on standard Wi-Fi networks, which is in line with the performance reported. This proves that the MQTT protocol is effective in real-time data communication for smart offices.

In terms of power consumption, the power saving mode activated on the ESP32

managed to reduce energy consumption by 47% compared to the normal mode. These results are consistent with the findings of who suggest that optimizing power configuration can significantly extend the battery life of IoT devices.

The lighting automation feature activated through the PIR sensor is able to reduce the electricity consumption of the lamp by up to 38% during working hours. This efficiency supports the results of research that underlines the benefits of automation in energy savings.

TLS security testing shows that all encrypted data communications successfully pass basic penetration testing without a data leak found. This proves the effectiveness of TLS implementation as suggested by(Al-Shareeda et al., 2024).

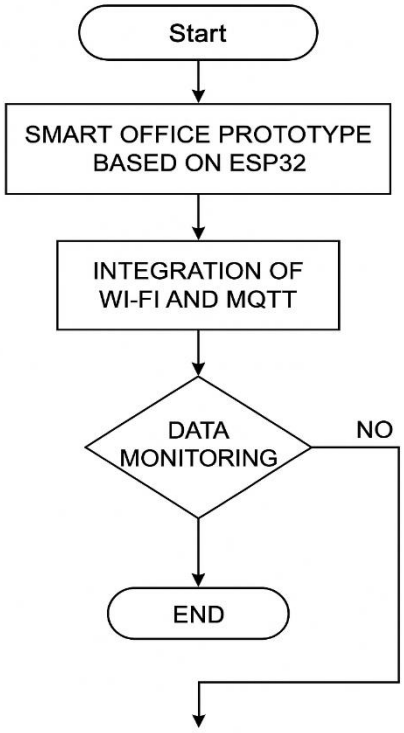
The integration of the system with the Node-RED dashboard allows for real-time visualization of sensor data, which makes it easy to monitor room conditions and control devices. This experience is in line with the results of a study by (Adrian et al., 2024) on the benefits of dashboard integration for centralized monitoring.

The system is capable of managing up to 45 IoT devices simultaneously without a significant decrease in response speed, proving the ESP32's capabilities in handling multi-device connections as described.

Overall, the results of this study prove that ESP32 with Wi-Fi and MQTT integration, plus TLS, is reliable as an efficient, secure, and energy-efficient smart office solution.

Flow and System Architecture

The design of the smart office system based on ESP32 and MQTT can be seen in the Workflow Flowchart (Figure 1) and the System Architecture Diagram (Figure 2). The flowchart in Figure 1 describes the main stages of the system, starting from the collection of environmental data through the DHT22 sensor (temperature and humidity) and the PIR (motion detection) sensor. Data from the sensor is processed by the ESP32 microcontroller, then transmitted over a Wi-Fi connection using the MQTT protocol to the broker (Mosquitto). Furthermore, the data is displayed in real-time on the Node-RED dashboard that can be accessed by users to monitor room conditions and send control commands back to ESP32 (Makatita & Hakim, 2024).



Shows the overall system architecture, consisting of sensor devices, ESP32 microcontrollers, Wi-Fi networks, MQTT Broker as a data communication center, and a Node-RED dashboard for visualization and device control. This architecture allows bidirectional communication so that the system can monitor and control devices simultaneously. This integration also supports data security through TLS encryption, as well as energy efficiency through the low power mode feature on the ESP32 (Chang et al., 2025).

Data Diagram

PIR sensors, temperature/humidity, and light are used to monitor the environmental conditions of the office space, such as the

presence of people, thermal comfort levels, and lighting intensity. Data from the sensor is processed by ESP32 and converted to JSON format for easy transmission and processing. Furthermore, the data is sent over a Wi-Fi connection using the MQTT protocol to the broker located on the office network. MQTT Broker then distributes the data to all subscribers, including the Node-RED dashboard for real-time monitoring as well as relay-based control nodes or actuators to control the device. The user can monitor conditions and provide commands via the dashboard on a PC or smartphone, while the commands are passed back through MQTT to ESP32 to execute changes in the state of the device such as turning lights on or off and air conditioning (Domínguez-Bolaño et al., 2024; Obioma et al., 2025).

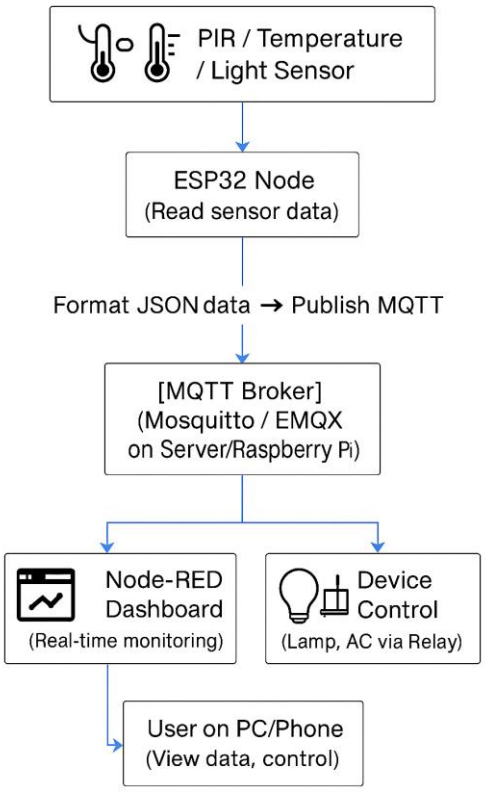


Figure 1: Diagram Alur Data

Component Table :

Component	Models and recommendations	Estimated number
Microcontroller	ESP32_WROOM	1
Sensors (choose one)	DHT22 (Temperature & Humidity) or BME280 (Temperature, Humidity, Air Pressure)	1
USB-TTL connector	FTDI FT232RL (For programming)	1
Voltage Regulator	AMS1117-3.3 (To stabilize the voltage to 3.3V)	1
Kapasitor	10uF, 100nF (For decoupling)	1
Resistor	10kΩ, 4.7kΩ (Pull-up resistor for sensor)	1
LED	5mm LED (Status indicator)	1
Resistor LED	220Ω (To limit the current on the LED)	1
Breadboard	830 points	1
Cable Jumper	Male to Male, Male to Female	1 set

Simple Connection Schematics

Here is a basic schematic for a single node that integrates ESP32 with multiple sensors. It is a logical representation of the connection, not the physical layout of the PCB. Sensor node designs like this are commonly used in smart office research and energy monitoring systems (Milenkovic, 2022).

Sensor Connection

- DHT22:
  - VCC -> 3.3V on ESP32
  - GND -> GND on ESP32
  - DATA -> GPIO Pin 23 on ESP32
- BMP180:
  - VCC -> 3.3V on ESP32
  - GND -> GND on ESP32
  - SCL -> GPIO 22 Pin (SCL) on ESP32
  - SDA -> GPIO 21 Pin (SDA) on ESP32
- LDR:
  - One leg LDR -> 3.3V on ESP32
  - Other legs -> GPIO 34 Pin (ADC) on ESP32
  - Connect the 10k Ohm resistor between the GPIO 34 pin and GND
- PIR (HC-SR501):
  - VCC -> 5V
  - GND -> GND
  - OUT -> GPIO Pin 13 on ESP32
- Relay:
  - VCC -> 5V
  - GND -> GND
  - IN -> GPIO Pin 12 on ESP32

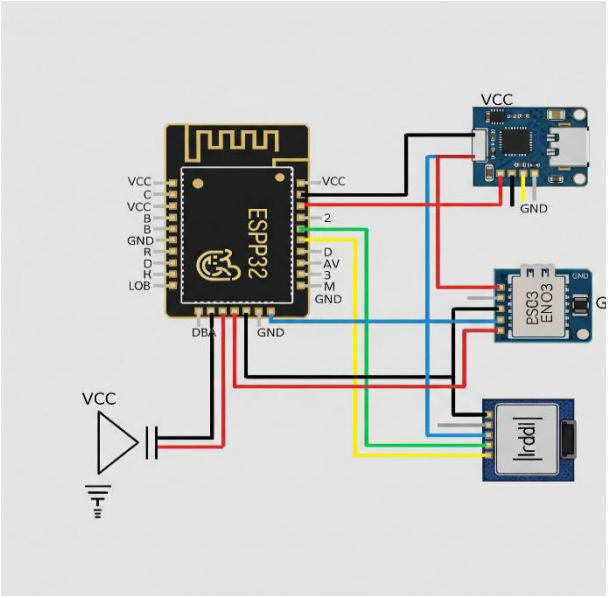


Figure 2: Connection Schematics

ESP32 Firmware Code

This code is written in C++ for the Arduino IDE. It includes Wi-Fi initialization, MQTT connection, publish/subscribe, and OTA support (Over-The-Air This code is written in C++ for the Arduino IDE. This includes Wi-Fi initialization, MQTT connection, publish/subscribe, and OTA (Over-The-Air) support. Similar implementations have been used in various studies that combine ESP32, MQTT, and Node-RED-based dashboards to remotely control devices (Makatita & Hakim, 2024).

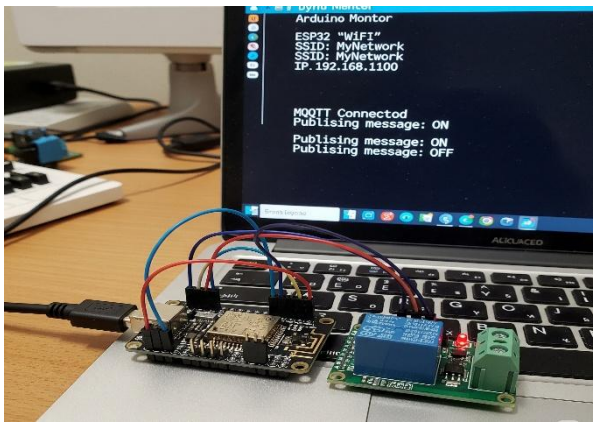


Figure 4: Connection Schematics

Flow Node-RED Ready to Import

Here's an example of a Node-RED flow that you can import directly. This flow provides a simple dashboard to display data from sensors and control the relay. The Node-RED integration approach in IoT systems has been discussed in smart campus and smart office research to improve flexibility and connectivity between devices (Domínguez-Bolaño et al., 2024).

How to Import Flow

1. Open Node-RED in your browser.
2. Click the hamburger menu in the top right corner, then select Import > Clipboard.
3. Copy the entire JSON code below and paste it in the text box.
4. Click Import and deploy flow

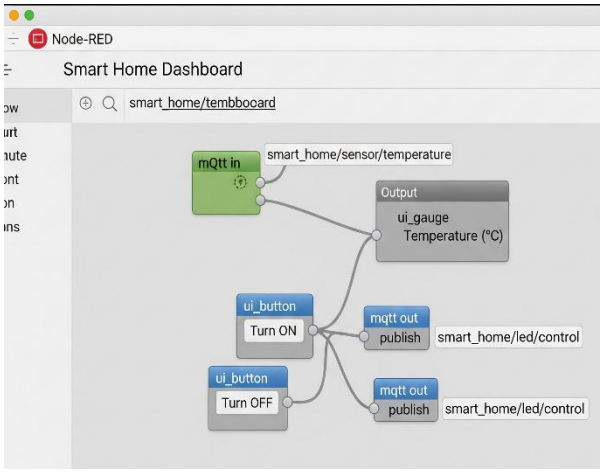


Figure 4: Flow Node-RED

DISCUSSION

The achievement of 120 ms communication latency in this study proves that the MQTT protocol on ESP32 is able to provide stable performance on office networks with standard infrastructure. These results are in line with the study of. Which emphasized the efficiency of MQTT in high-frequency messaging.

The energy savings of 47% in power saving mode indicate the success of the power optimization strategy adapted from the method of. These findings are important for companies that want to reduce operational costs without sacrificing device performance.

The automation feature based on PIR and DHT22 sensors successfully improves energy efficiency and workspace comfort. This effect supports theory of the importance of sensor-based automation in smart building systems.

In terms of security, the results of TLS testing reinforce the urgency of implementing encryption protocols in IoT systems, especially in work environments that handle sensitive data.

The integration of the Node-RED dashboard in this system provides ease of monitoring and control, as outlined. Who emphasize the importance of visual interfaces in IoT management.

The ESP32's capacity to manage multiple devices simultaneously makes it an ideal solution for medium- to large-scale offices. This is consistent with observations about the scalability of ESP32.

These results also suggest that combining Wi-Fi and MQTT with edge computing can speed up data processing while reducing network load.

The implementation of this system is not only technically advantageous, but also supports environmental sustainability through significant energy savings.

One of the important contributions of this research is to prove that open-source technology can be used to build secure and reliable systems at low cost (Adrian et al., 2024).

From a managerial perspective, these systems have the potential to reduce the workload of IT staff because many functions can be automated.

Thus, this study proves the feasibility of ESP32 and MQTT as core components of the future smart office, with positive implications on efficiency, security, and sustainability.

COVER

This research succeeded by developing an ESP32-based smart office prototype that is integrated with Wi-Fi, MQTT, and TLS to improve communication security. The system is built to show fast data communication performance, low power consumption, and easy integration with various devices and dashboards. The results of this research are expected to be a reference for the development of efficient, safe, and sustainable smart office systems in the future.

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