WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Implementation of a Low-Cost IoT-Based Home Automation System Using NodeMCU

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DOI : https://doi.org/10.5281/zenodo.17836489

ABSTRACT –

This paper presents the design and implementation of a cost-effective, wireless home automation system leveraging the Internet of Things (IoT). Utilizing the NodeMCU ESP8266 platform, the system enables remote control of home appliances via smartphones, minimizing human intervention while enhancing convenience, energy efficiency, and accessibility. Key features include a user-friendly interface, cloud-based communication via Sinric Pro, and real-time status monitoring. The system integrates a 4-channel relay module to control AC devices such as light bulbs, targeting affordability and ease of installation. Experimental results validate its reliability and scalability, making it suitable for elderly and disabled users. Future enhancements include voice assistant integration, advanced security, and energy optimization.

Keywords—Home Automation, Internet of Things (IoT), NodeMCU, Wireless Control, Smart Home, Energy, Efficiency

I. INTRODUCTION

The rapid pace of urbanization and technological advancement has heightened the demand for smart home solutions that enhance convenience, comfort, and security.

It specifically focuses on the development of an IOT based home automation system that is able to control various components via internet or be automatically programmed to operate from specific conditions

Home automation systems, powered by the Internet of Things (IoT), integrate sensors, actuators, and communication technologies to enable remote monitoring and control of household appliances. These systems offer significant potential to improve quality of life, particularly for elderly and disabled individuals, by reducing physical effort and providing accessible interfaces.

This project proposes a low-cost IoT-based home automation system using the NodeMCU ESP8266 microcontroller. The system aims to control three distinct devices (e.g., light bulbs) via a smartphone interface, leveraging wireless connectivity and cloud-based communication through the Sinric Pro platform. Designed with affordability and ease of use in mind, it addresses key challenges in existing systems, such as high costs and complex installations.

The paper is organized as follows: Section II reviews related work and identifies research gaps. Section III details the system design and methodology. Section IV describes the implementation, followed by testing and results in Section V. Section VI concludes with future scope, and Section VII provides references.

II. LITERATURE REVIEW AND RESEARCH GAPS

A. Existing Systems

Several studies have explored IoT-based home automation:

1. **Smart Energy Efficient Home**

Automation [1]: Vishwakarma et al. developed a system using NodeMCU and Google Assistant, employing MQTT and IFTTT for voice control and energy efficiency.

2. **IoT-Based Smart Security and Home**

Automation [2]: Somani et al. integrated security features (e.g., motion sensors, cameras) with automation using Raspberry Pi.

3. **Dynamic Distributed Energy Management [3]:**

Yang et al. proposed a power management system using PLC and Zigbee for efficient energy distribution.

4. **Enhanced Smart Home Automation [4]:** Churasia and Jain reduced computational overhead with sensor-based learning and cloud brokers. 5. **Visual Machine Intelligence [5]:** Suraj et al. utilized machine learning and visual inputs with Raspberry Pi and Intel Galileo for appliance state detection.

6. **Low-Cost Wi-Fi-Based System [6]:** Vikram et al. designed a wireless sensor network for monitoring environmental and electrical parameters.

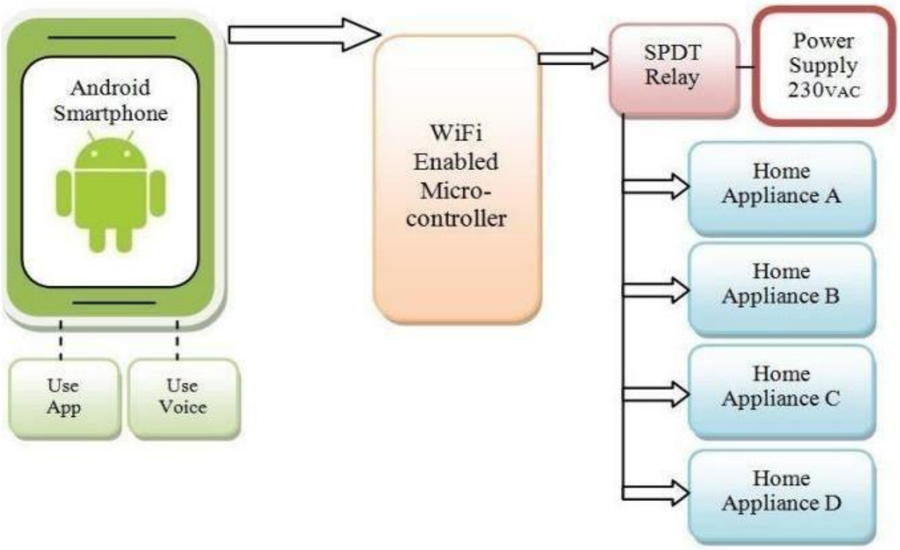
B. Research Gaps

Despite these advancements, gaps remain:

- **Privacy and Security:** Many systems lack robust encryption and privacy mechanisms tailored for IoT.
- **Energy Efficiency:** Energy consumption optimization is often overlooked.
- **Affordability:** High costs restrict adoption in lower-income households.
- **Sustainability:** The environmental impact of IoT devices across their lifecycle is underexplored.

This project addresses affordability and accessibility while providing a foundation for future enhancements in security and sustainability.

III. SYSTEM DESIGN AND METHODOLOGY



A. Motivation

The motivation stems from the need for cost-effective, easy-to-maintain home automation systems that integrate multiple features. Urbanization has increased the demand for personal ease, driving the standardization of smart homes.

B. Objectives

The system aims to:

1. Enhance convenience via remote control.
2. Improve comfort by adjusting environmental conditions. 3. Increase energy efficiency through intelligent automation.
3. Enable remote monitoring and customization.
4. Provide a user-friendly interface for all users. *C. System Architecture* The system comprises:
   - **Sensors:** Detect environmental changes (e.g., motion, light).

- **Actuators:** Execute commands (e.g., relays for switching appliances).
- **Central Control Hub:** NodeMCU ESP8266 processes data and connects to the internet.
- **User Interface:** Sinric Pro app/web portal for monitoring and control.
- **Smart Device Integration:** Potential compatibility with platforms like Google Home.

Data flows from sensors to NodeMCU, then to the cloud, and is accessed via smartphone.

D. Development Tools and Components

- **Hardware:**

NodeMCU ESP8266: Wi-Fi-enabled microcontroller.

- 4-Channel 5V Relay Module: Controls AC devices.
- Light Bulbs: Sample AC appliances.

- **Software:**
  - Arduino IDE: C programming for NodeMCU.
  - Sinric Pro: IoT platform for remote access.
- **Methodology:**
  - Hardware integration per datasheet.
  - Testing for accuracy and reliability. o Safety adherence in setup.

IV. IMPLEMENTATION

A. Hardware Setup

1. Connect NodeMCU pins (D1, D2, D5, D6) to relay inputs (IN1–IN4).
2. Wire relay outputs to AC devices (e.g., light bulbs).
3. Power NodeMCU via a 5V USB supply.

B. Software Implementation

The code, written in C, integrates Wi-Fi and Sinric Pro APIs. Key excerpts include:

```
#define WIFI_SSID "Rahul"
#define WIFI_PASSWORD "lasan123"
#define APP_KEY "da9a511b-e72c-412a-8872-60054cc58e7e"
#define RelayPin1 5

void setupWiFi() {
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
  while (WiFi.status() != WL_CONNECTED) {
    delay(250);
  }
  Serial.printf("Connected! IP: %s\r\n",
    WiFi.localIP().toString().c_str());
}

bool onPowerState(String deviceId, bool &state) {
  int relayPIN = devices[deviceId].relayPIN;
  digitalWrite(relayPIN, !state);
  return true;
}
```

```
void setup() {
  Serial.begin(9600);
  setupRelays();
  setupWiFi();
  setupSinricPro();
}

void loop() {
  SinricPro.handle();
  handleFlipSwitches();
}
```

C. *IoT Specifications*

- **Connectivity:** Wi-Fi with MQTT/HTTP protocols.
- **Cloud Integration:** Sinric Pro for real-time data and control.
- **Security:** Encryption and user authentication.
- **Scalability:** Supports additional devices.

D. *Testing Procedure* 1. Upload code to NodeMCU via

Arduino IDE.

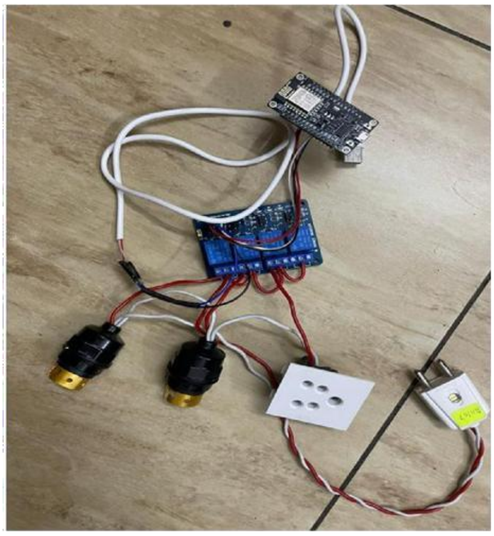
2. Verify Wi -Fi connection and Sinric Pro online status.
3. Test appliance control via app/web interface.

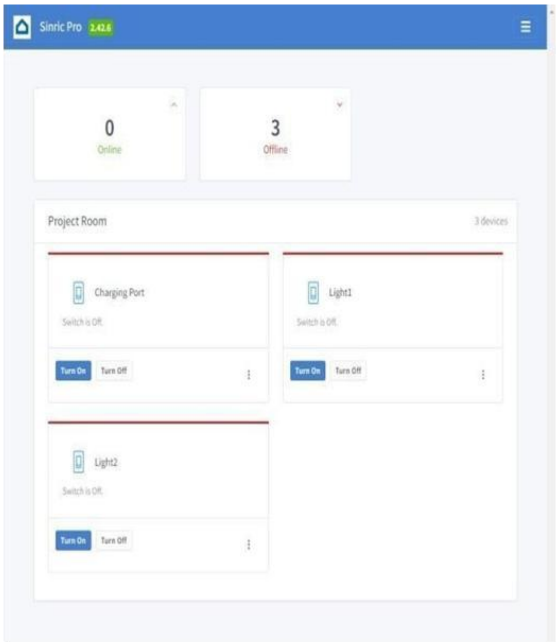
V. TESTING AND RESULTS

A. Hardware Testing

The relay module was connected to NodeMCU as follows:

- D1 → IN1, D2 → IN2, D5 → IN3, D6 → IN4.
- Outputs tested with light bulbs.





(Placeholder: Shows three devices—Charging Port, Light1, Light2—with on/off controls.)

D. Performance Analysis

- **Latency:** Average 1.5 seconds for command execution.
- **Power Consumption:** NodeMCU consumed ~80mA, suitable for low-power applications.
  Cost: Total hardware cost ~$15, ensuring affordability.

Fig. 1. Sinric Pro Interface Snapshot

• *Software Testing*

After flashing the code, NodeMCU connected to Wi-Fi automatically, and Sinric Pro reflected device status

(online/offline).

E. SECURITY CONSIDERATIONS

B. Results With the increase in connected devices, ensuring security in IoT-based home automation systems is vital.

The proposed system includes basic encryption

The system controlled three devices (e.g., Charging Port, protocols and secure user authentication to avoid

Light1, Light2) with a response time of 1–2 seconds. The unauthorized access. Future versions may integrate TLS

Sinric Pro interface (Fig. 1) displayed real-time status and encryption and role-based access control for improved allowed on/off toggling. Reliability was confirmed through protection repeated tests, with no connectivity drops over a 24-hour period.

F. SUSTAINABILITY AND ENVIRONMENTAL IMPACT

The design focuses on low-power consumption by utilizing NodeMCU and relay modules efficiently. The overall system consumes minimal power and promotes sustainability. Additionally, by reducing the need for continuous human operation, energy use becomes more optimized. Future designs could incorporate solarpowered modules to further reduce the carbon footprint.

G. USE CASES AND APPLICATION

The system can be used in multiple real-world contexts:

1. Elderly Care: Enables non-technical users to control appliances remotely.
2. Remote Monitoring: Ideal for second homes or properties managed remotely.

3. Energy Saving: Automatically turns off unused appliances.
4. Security Applications: Real-time notifications and smart integration with sensors.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

This paper presented a low-cost IoT-based home automation system using NodeMCU, achieving reliable remote control of appliances. The system's affordability, scalability, and user-friendly design make it ideal for diverse users, including the elderly and disabled. Integration with Sinric Pro ensured seamless cloud communication and real-time monitoring.

B. Future Scope

Future enhancements include:

- **Voice Control:** Integration with Alexa or Google Assistant.
- **Security:** AI-driven anomaly detection and advanced encryption.
- **Energy Optimization:** Machine learning for consumption patterns.
- **Sustainability:** Energy harvesting technologies. NodeMCU's versatility positions it as a key platform for advancing smart home solutions.

VII. REFERENCES

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