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IoT-Enabled Smart Home Automation and Energy Management System using Raspberry Pi

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Abstract **- The increasing demand for intelligent residential infrastructure has accelerated the development of Internet of Things (IoT)-based home automation technologies. Smart homes provide automated monitoring and control of household appliances through interconnected sensing and communication systems. This paper presents the implementation of an IoT-enabled home automation framework developed using Raspberry Pi, wireless sensors, and cloud-based monitoring architecture. The proposed system integrates appliance control, environmental sensing, motion-based automation, and safety mechanisms into a unified platform accessible through a web interface. Various sensors including temperature, gas leakage, and motion detectors were interfaced with the controller to automate household operations dynamically. Experimental evaluation carried out in a real-time residential environment demonstrated improved energy efficiency, reduced manual intervention, and reliable remote accessibility. The developed system achieved significant energy savings while maintaining low response latency and stable operational performance. The proposed architecture Keywords - component; formatting; style; styling; insert**

key words : Smart Home, IoT, Raspberry Pi, Automation, Energy Efficiency, Wireless Sensors, Remote Monitoring.

I. INTRODUCTION

The rapid advancement of embedded computing and wireless communication technologies has significantly transformed conventional living environments into intelligent and connected systems. Modern homes increasingly rely on automation technologies to improve comfort, optimize energy utilization, and enhance residential security. In this context, the Internet of Things (IoT) has emerged as one of the most influential technological paradigms enabling communication among physical devices through internet connectivity [1].

A smart home environment consists of interconnected electronic appliances, sensors, and controllers capable of autonomous operation and remote accessibility. Traditional electrical systems require continuous human interaction for switching and monitoring appliances, resulting in unnecessary power consumption and limited operational flexibility. IoT-based automation addresses these limitations by introducing intelligent control mechanisms that operate according to environmental conditions and user preferences [2].

Recent developments in low-cost microcontrollers and single-board computers have facilitated the implementation of affordable smart home systems. Raspberry Pi has become a preferred platform because of its computational capability, networking support, GPIO interfaces, and compatibility with cloud technologies [3]. By integrating wireless sensors with Raspberry Pi, real-time data acquisition and remote appliance management can be achieved efficiently.

Despite the growing popularity of smart home technologies, existing systems often encounter challenges associated with implementation cost, interoperability, cybersecurity vulnerabilities, and limited scalability [4]. Many conventional solutions focus only on remote switching functionality without incorporating intelligent sensing and energy optimization mechanisms.

To address these challenges, this research proposes an integrated IoT-based home automation architecture capable of:

- Real-time appliance monitoring
- En ironmental sensing
- ccupancy-based automation
- Emergency gas leakage detection
- emote web-based control
- En rgy consumption optimization

The developed prototype demonstrates reliable automation performance suitable for modern residential environments.

II. LITERATURE REVIEW

The evolution of smart home technologies has accelerated significantly with the emergence of IoT, embedded systems, cloud computing, and wireless communication protocols [1]. Researchers across the world have proposed various intelligent automation systems aimed at improving residential comfort, energy efficiency, safety, and remote accessibility [2].

Early home automation systems mainly utilized wired communication methods and microcontroller-based switching mechanisms. These systems were limited in scalability, flexibility, and remote monitoring capability [3]. With the introduction of IoT technologies, home automation systems became more intelligent and internet-enabled, allowing users to remotely access household appliances through smartphones and cloud platforms [4].

Researchers have extensively explored low-cost embedded platforms such as Arduino and Raspberry Pi Foundation for smart home applications. Arduino-based systems are generally preferred for simple automation tasks due to their lower power

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consumption and simplicity, while Raspberry Pi offers superior processing capability, multitasking performance, networking support, and compatibility with advanced IoT frameworks [5].

Satapathy et al. proposed an Arduino-based IoT home automation system integrated with IP connectivity for appliance control and security monitoring [6]. Their system emphasized low implementation cost and wireless communication for residential automation. However, the architecture was limited in terms of processing power and scalability for handling multiple simultaneous tasks.

Kumar et al. developed a Raspberry Pi-based smart home automation framework controlled through a web browser interface [7]. Their work demonstrated that IoT-enabled home automation systems improve user convenience and remote accessibility while reducing manual operation.

Stolojescu-Crisan et al. developed a comprehensive IoT-based smart home architecture integrating sensors, actuators, and cloud-based communication systems [8]. Their work focused on interoperability among connected devices and intelligent automation processes. The study reported that modern smart homes significantly simplify daily household operations while improving energy utilization efficiency.

Recent studies have increasingly focused on energy-efficient home automation systems. Ahmed et al. designed an IoT-enabled automation framework using Raspberry Pi integrated with environmental sensors and a web-based dashboard [9]. Their experimental analysis demonstrated significant energy savings through automated appliance management and sensor-driven control mechanisms.

Security and privacy remain major concerns in IoT-enabled smart homes. Gupta et al. proposed a secure home automation prototype using Raspberry Pi integrated with SMTP communication protocols for secure device interaction [10]. Their research emphasized reducing communication complexity while improving system reliability and user authentication.

Several researchers also investigated cloud-enabled smart home monitoring frameworks. Bohara et al. developed a Blynk-based IoT smart home system where NodeMCU acted as a gateway device while Raspberry Pi functioned as the local server [11]. Their architecture enabled appliance control through smartphones and automatic device operation based on sensor readings.

Artificial intelligence and machine learning techniques are now being integrated into home automation systems to improve predictive control and intelligent decision-making [12]. AI-assisted smart homes can optimize energy utilization and improve residential safety using behavioral analysis techniques.

Although numerous studies have demonstrated the advantages of IoT-based home automation, several challenges still exist including interoperability issues, cybersecurity risks, communication latency, and deployment cost [13]. Most existing systems focus only on appliance switching and fail to integrate environmental monitoring, emergency safety management, and energy optimization into a unified platform.

The proposed research work addresses these limitations by developing a low-cost and scalable IoT-based home automation system integrating:

- Temperature monitoring
- Motion-based lighting control
- Gas leakage detection
- Remote dashboard monitoring
- Intelligent energy management

The developed system combines environmental sensing, automation, and safety mechanisms into a centralized smart home architecture suitable for modern residential applications.

III. Proposed Methodology

A. *System Design*

The proposed smart home automation framework was developed using Raspberry Pi as the primary processing unit. Sensors and electrical appliances were interfaced through GPIO-controlled relay modules. The entire system communicates through a wireless internet connection enabling remote monitoring through a web-based dashboard.

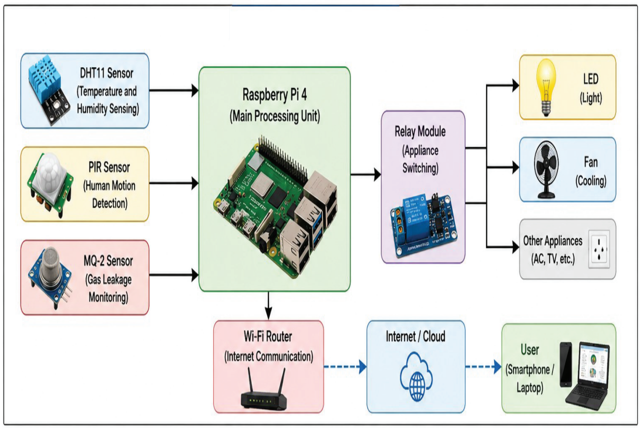

Fig. 3.1 Architecture of proposed work

The architecture consists of three major layers:

a) Sensing Layer

This layer includes:

- DHT11 temperature and humidity sensor
- PIR motion detection sensor
- MQ-2 gas leakage sensor

b) Processing Layer

The Raspberry Pi processes sensor data and executes automation logic according to predefined threshold conditions.

c) Application Layer

A cloud-connected dashboard enables users to monitor environmental conditions and control appliances remotely through smartphones or computers.

B. *Hardware Components*

The proposed IoT-based smart home automation system consists of multiple sensing, processing, communication, and control components integrated with the Raspberry Pi 4

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platform. The hardware configuration used in the developed prototype is illustrated in the circuit diagram shown above. Each component performs a specific role in enabling intelligent monitoring and appliance automation.

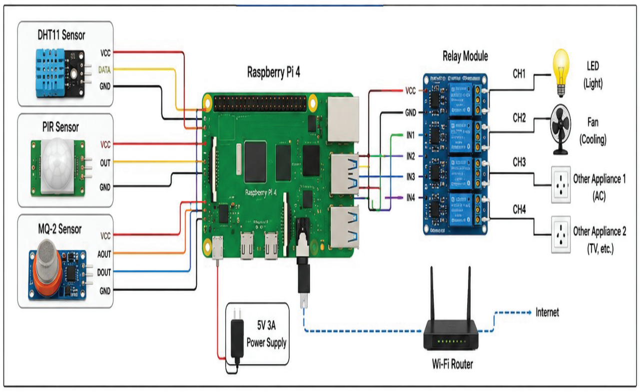

Fig. 3.2 Circuit diagram of proposed work

a) Raspberry Pi 4 – Main Processing Unit

Raspberry Pi Foundation Raspberry Pi 4 acts as the central controller of the proposed smart home automation system. It collects sensor data, processes automation logic, communicates with the cloud dashboard, and controls connected appliances through relay modules. The Raspberry Pi platform was selected because of its high processing capability, built-in Wi-Fi support, GPIO interface, multitasking ability, and compatibility with Python programming

The controller continuously receives environmental data from the sensors and makes automation decisions according to predefined threshold conditions. Raspberry Pi also enables remote appliance control through internet communication.

b) Relay Module – Appliance Switching Unit

The relay module is used to control high-voltage electrical appliances such as lights, fans, and other home devices through low-voltage GPIO signals from the Raspberry Pi. The relay acts as an electrically isolated switching interface between the controller and AC appliances.

In the proposed system:

- Channel 1 controls LED lighting
- Channel 2 controls the cooling fan
- Additional channels can control other household appliances

The relay module enables automatic appliance switching based on sensor readings and remote commands.

c) DHT11 Sensor – Temperature and Humidity Monitoring

The DHT11 sensor is used for real-time monitoring of indoor temperature and humidity conditions. Environmental parameters collected by the sensor are transmitted to the Raspberry Pi for intelligent climate control.

When the room temperature exceeds the predefined threshold value:

- The cooling fan is activated automatically
- Environmental data is updated on the dashboard

The DHT11 sensor provides low-cost environmental sensing suitable for residential IoT applications.

d) PIR Sensor – Human Motion Detection

The Passive Infrared (PIR) sensor detects human movement within the room by sensing infrared radiation emitted from the human body. The sensor is primarily used for occupancy-based lighting automation.

When motion is detected:

- Room lights automatically switch ON
- Appliances remain active during occupancy
- When no movement is detected for a predefined duration:
- Lights automatically switch OFF to reduce energy wastage

e) MQ-2 Sensor – Gas Leakage Detection

The MQ-2 gas sensor is used to detect combustible gases such as LPG, methane, propane, and smoke within the residential environment. The sensor continuously monitors gas concentration levels and provides emergency safety functionality.

During abnormal gas leakage conditions:

- Alarm notification is activated
- Exhaust fan switches ON automatically
- Emergency alerts can be transmitted to users remotely

The MQ-2 sensor enhances residential safety and accident prevention.

f) Wi-Fi Router – Internet Communication

The Wi-Fi router enables internet connectivity between the Raspberry Pi system and cloud-based monitoring dashboard. Through wireless communication, users can remotely:

- Monitor sensor data
- Control appliances
- Receive safety alerts
- Access automation status

The router acts as the communication gateway between local hardware and remote users.

g) LED and Fan – Automated Home Appliances

The LED lighting unit and cooling fan represent household appliances controlled through the relay module. Their operation is automated according to environmental and occupancy conditions.

Examples:

- Lights operate based on PIR motion detection
- Fan operation depends on room temperature

The automation mechanism reduces manual operation and improves energy utilization efficiency.

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C. Operational Flow

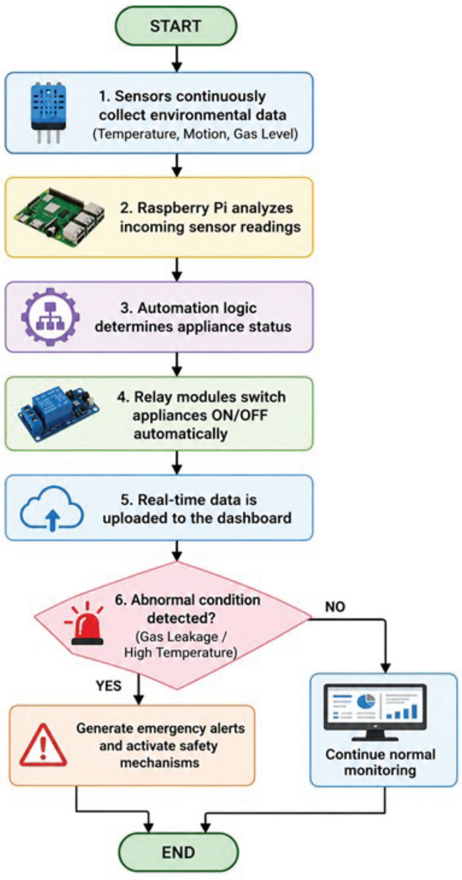

Fig. 3.3. Flow Chart of proposed work

IV. EXPERIMENTAL SETUP

The developed prototype was deployed in a residential room environment consisting of:

- Smart lighting system
- Automated ceiling fan
- Motion sensing unit
- Gas leakage monitoring setup
- Wireless dashboard interface

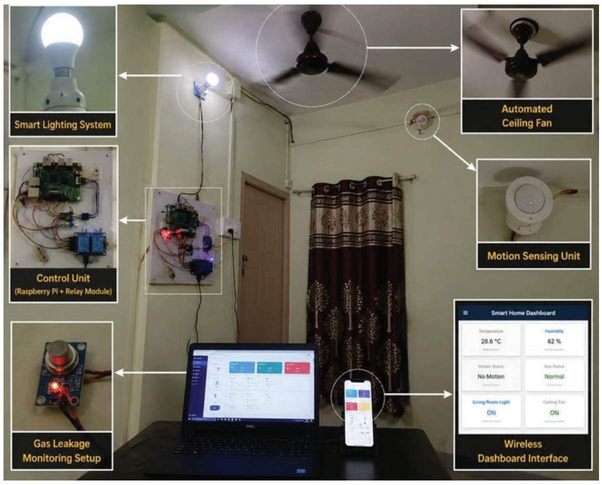

Fig. 4.1 Actual prototype model

The system was tested continuously for 30 days under real-time operating conditions.

Parameters evaluated during experimentation included:

- Appliance response time
- Sensor accuracy
- Power consumption
- System reliability
- Automation efficiency

V. RESULTS AND DISCUSSION

A. Temperature-Based Automation

Table 5.2 Motion Detected Vs Light Status

Time	Temperature (°C)	Fan Status
08:00	26	OFF
12:00	31	ON
15:00	34	ON
19:00	28	OFF

The cooling system automatically activated when room temperature exceeded 30°C, improving thermal comfort and reducing unnecessary energy consumption

B. Motion-Controlled Lighting

Table 5.3 Gas Level Vs Alarm Vs Exhaust Fan

Test No.	Motion Detected	Light Status
1	Yes	ON
2	Yes	ON
3	No	OFF
4	Yes	ON

The PIR sensor achieved approximately 96% motion detection accuracy during real-time testing.

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C. Gas Leakage Detection

Table 5.3 Gas Level Vs Alarm Vs Exhaust Fan

Gas Level	Alarm	Exhaust Fan
Normal	OFF	OFF
Medium	ON	ON
High	ON	ON

The MQ-2 sensor effectively identified LPG leakage and activated emergency safety mechanisms immediately.

D. Energy Consumption Analysis

Table 5.4 Gas Level Vs Alarm Vs Exhaust Fan

System Type	Monthly Consumption
Conventional Home	180 kWh
IoT Automated Home	129 kWh

The proposed smart home system achieved nearly 28% reduction in electricity consumption through intelligent appliance control.

E. Response Time Analysis

Table 5-5 Operation Vs Avg. Resp. Time

Operation	Average Response Time
Light Switching	1.5 sec
Fan Switching	1.8 sec
Dashboard Update	2.1 sec

The overall system response remained below 2 seconds, demonstrating reliable real-time performance.

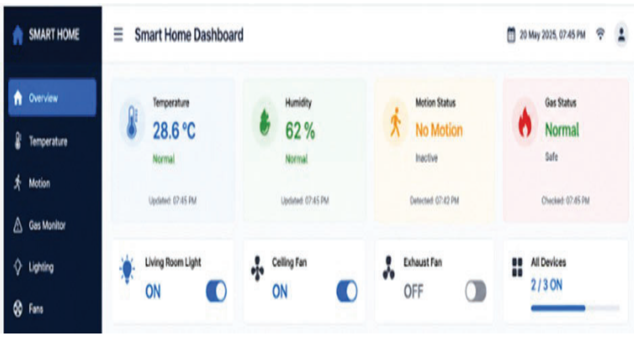

Fig. 5.1 Dash board of proposed work

VI. Advantages of Proposed System

The developed smart home automation system provides several advantages:

- Remote appliance control
- Reduced electricity consumption
- Enhanced home safety
- Real-time monitoring
- Low implementation cost
- Scalable architecture
- Improved user convenience

VII. Limitations

Although the proposed system demonstrated efficient performance, certain limitations still exist:

- Dependence on internet connectivity
- Cybersecurity concerns
- Sensor range limitations
- Initial setup complexity

Future work can focus on AI-based automation and advanced encryption mechanisms for improved security.

VIII. Future Scope

Future enhancements may include:

- Voice assistant integration
- AI-enabled predictive automation
- Smart energy analytics
- Solar energy integration
- Advanced surveillance systems
- Mobile application development

IX. Conclusion

This research presented the implementation of an IoT-enabled smart home automation system utilizing Raspberry Pi and wireless sensing technologies. The developed framework integrated appliance control, environmental monitoring, occupancy sensing, and emergency safety features into a centralized automation platform. Experimental analysis demonstrated improved operational efficiency, reduced electricity consumption, and reliable remote accessibility. The proposed system offers a scalable, economical, and energy-efficient solution for intelligent residential automation applications.

ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

REFERENCES

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EXAMPLE FOR REFERANCES

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