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A Hybrid RF–WiFi smart apartment control system for building electrical training

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Abstract

The rapid development of the Internet of Things (IoT) has accelerated the growth of smart home and intelligent building systems in modern residential infrastructures. However, many electrical engineering laboratories still mainly focus on conventional residential wiring practices and lack integrated smart control technologies that reflect modern smart apartment environments. This paper presents the design and implementation of a hybrid RF–WiFi smart apartment training system developed for practical teaching in electrical engineering education. The proposed system integrates two WT06 RF 4-channel relay controllers operating at 433 MHz together with a Broadlink RM-Pro smart gateway to establish a hybrid wireless control architecture for residential electrical loads. By combining the two WT06 relay modules, the system provides eight independent wireless control channels for controlling multiple residential electrical devices. In the proposed configuration, the WT06 relay controllers perform RF-based switching operations, while the Broadlink RM-Pro receives commands through a WiFi network and transmits RF control signals to the relay controllers. The developed platform simulates a residential apartment electrical system, including lighting circuits, electrical outlet circuits, ventilation loads, water heater loads, and air-conditioning loads. Experimental results demonstrate the stable and reliable operation of the proposed hybrid smart control system under various wireless control scenarios. The proposed platform provides a practical and low-cost educational solution for studying residential electrical systems and IoT-based smart home technologies in engineering laboratories.

Keywords: Smart Apartment; IoT; RF Relay Controller; Broadlink RM-Pro; Smart Home System; Building Electrical Engineering; Engineering Education.

1. Introduction

The rapid advancement of digital technologies and the Internet of Things (IoT) has significantly transformed modern residential electrical systems and intelligent building infrastructures. In recent years, smart homes have increasingly incorporated wireless communication technologies, cloud-based services, and intelligent electrical devices to enhance energy efficiency, operational flexibility, user convenience, and remote monitoring capabilities [1], [2]. Previous studies have shown that IoT-based smart home systems can effectively support residential automation, intelligent energy management, wireless device control, and real-time monitoring in modern living environments [3]–[5].

Among various wireless communication technologies applied in smart home systems, radio-frequency (RF)-based wireless control remains one of the most practical and cost-effective solutions due to its simple implementation, stable communication performance, and compatibility with residential electrical applications. RF relay controllers operating at 315 MHz or 433 MHz are widely used in wireless lighting systems, remote switching applications, and household automation platforms [6], [7]. However, conventional RF relay systems are generally limited to local wireless communication and typically lack Internet-based remote monitoring and smart control capabilities.

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To overcome these limitations, recent smart home studies have explored hybrid communication architectures that combine RF wireless control with WiFi-based IoT technologies [8], [9]. In such architectures, WiFi-enabled smart gateways receive control commands from mobile applications or cloud platforms and subsequently transmit RF signals to local relay controllers. This hybrid approach combines the simplicity and reliability of RF communication with the flexibility, scalability, and remote accessibility of Internet-based smart home management systems.

Despite these technological developments, the integration of smart home technologies into engineering education remains relatively limited. Conventional electrical engineering laboratories still mainly focus on traditional residential wiring practices and basic electrical installation experiments, which may not adequately reflect the complexity of modern smart apartment systems and intelligent residential infrastructures [10], [11]. Recent studies in engineering education emphasize the importance of practical laboratory platforms, experiential learning environments, and project-based educational approaches that enable students to interact directly with real engineering systems and modern industrial technologies [12], [13].

Several previous studies have investigated IoT-based smart home laboratory platforms for engineering education [14]. Most existing educational systems rely heavily on microcontrollers, embedded processors, and relatively complex programming architectures to implement intelligent control functions. Although these approaches provide high flexibility and advanced functionalities, they may increase learning complexity for students whose primary focus is residential electrical systems and building electrical installations rather than embedded programming and software development.

To address this issue, this study proposes the design and implementation of a hybrid RF–WiFi smart apartment training platform for engineering laboratories. Unlike conventional smart home educational models that mainly focus on standalone IoT demonstrations, the proposed platform integrates both traditional residential electrical installations and hybrid wireless smart control technologies within a unified experimental environment. The developed system combines two WT06 RF 4-channel relay controllers operating at 433 MHz with a Broadlink RM-Pro smart gateway to establish a hybrid wireless control architecture for residential electrical loads [15], [16].

By integrating two WT06 relay modules, the platform provides eight independent wireless control channels for managing lighting circuits, electrical outlet systems, ventilation systems, water heater loads, and air-conditioning loads. In addition, conventional wall-mounted switches are preserved to support manual operation alongside IoT-based wireless smart control. This hybrid configuration enables students to compare traditional residential electrical systems with modern IoT-based smart home technologies through practical laboratory experiments.

The main contributions of this study include:

- Design and implementation of a hybrid RF–WiFi smart apartment training platform for engineering education.
- Integration of dual WT06 RF multi-channel relay controllers for wireless residential load control applications.
- Development of a hybrid smart control architecture combining RF communication and WiFi-based IoT technologies.
- Establishment of a practical laboratory environment for studying residential electrical systems, wireless communication, and smart home automation technologies.
- Support for both conventional manual control and IoT-based remote operation within a unified educational platform.

2. Training Platform Description

2.1. System Architecture

The proposed training model simulates the electrical power supply system of a residential apartment while integrating IoT-based intelligent control. The model represents a simplified apartment layout with functional areas such as a living room, bedroom, kitchen, and bathroom, creating a realistic environment for studying building electrical systems. Figure 1 illustrates the apartment layout used in the training model.

The electrical system includes lighting circuits, electrical outlet circuits, water heater loads, and air-conditioning loads. The wiring configuration follows common residential electrical installation practices to ensure safe operation during laboratory exercises [17], [18].

Figure 1 Apartment layout used in the training model

To support both conventional and intelligent control technologies, the system adopts a hybrid architecture consisting of three main subsystems: power distribution, load control, and intelligent communication. Electrical loads can be operated either through mechanical switches or through relay-based smart control via an IoT platform. Figure 2 shows the smart home electrical training model used in the laboratory.

Figure 2 Smart home electrical training model

This architecture allows the simulation of modern residential electrical systems while supporting practical training in both traditional electrical installations and smart home technologies [17], [18].

2.2. WT06 RF Relay Controller

To implement wireless smart control functionality, the proposed system integrates a WT06 RF 4-channel relay controller operating at 433 MHz RF communication frequency. The WT06 module serves as the primary wireless switching controller in the smart apartment system.

The WT06 controller provides four independent relay channels capable of controlling residential electrical loads such as lighting systems, ventilation systems, water heater loads, and other household electrical devices. The module supports several operating modes including toggle mode, momentary mode, and interlock mode, enabling flexible smart control configurations.

Each relay channel is connected to a corresponding residential electrical load through conventional electrical wiring systems. This arrangement allows the smart control architecture to maintain compatibility with traditional residential electrical installations while supporting wireless RF switching operations. Figure 3 presents the WT06 RF relay controller integrated into the apartment training platform.

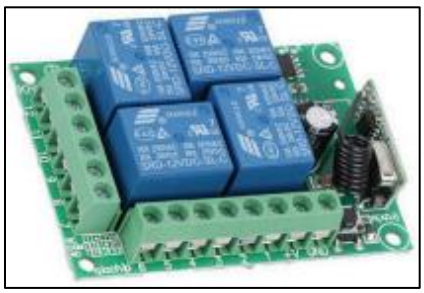

Figure 3 WT06 RF relay controller

Due to its simple structure, low implementation cost, and stable RF communication capability, the WT06 module is suitable for educational smart home experiments and residential automation demonstrations.

2.3. Broadlink RM-Pro Smart Gateway

To provide Internet-based smart control capability, the proposed system integrates the Broadlink RM-Pro smart gateway. The Broadlink RM-Pro operates as a WiFi-enabled universal smart controller capable of transmitting both infrared (IR) and radio-frequency (RF) control signals. By functioning as an intermediate communication device between the user interface and local control hardware, the gateway extends the capability of conventional RF relay systems to support Internet-based monitoring and control.

Figure 4 Broadlink RM-Pro smart gateway

In the developed architecture, the Broadlink RM-Pro receives user commands from a smartphone-based mobile application through a WiFi network and subsequently transmits RF control signals to the WT06 relay controllers. This configuration enables remote monitoring and switching of residential electrical loads using mobile applications while preserving the simplicity and reliability of RF-based load control.

The Broadlink RM-Pro also supports cloud-based smart home services, allowing users to remotely access and manage residential electrical systems from both local and remote locations. Through this arrangement, students can investigate practical smart home technologies and understand how modern residential electrical systems integrate wireless

communication networks with conventional electrical installations. Figure 4 presents the Broadlink RM-Pro smart gateway integrated into the developed smart apartment training platform.

2.4. Hybrid RF–WiFi Control Architecture

The proposed hybrid RF–WiFi smart apartment control system consists of four major components:

- Mobile application interface.
- WiFi communication network.
- Broadlink RM-Pro smart gateway.
- WT06 RF relay controller and residential electrical loads.

The control process operates as follows:

- The user transmits a control command through the smartphone application.
- The command is transmitted through the WiFi network to the Broadlink RM-Pro gateway.
- The Broadlink RM-Pro converts the command into a 433 MHz RF signal.
- The WT06 relay controller receives the RF signal and switches the corresponding electrical load.

This hybrid architecture combines the advantages of RF-based relay control and WiFi-enabled IoT communication. RF communication provides stable local wireless switching capability, while WiFi connectivity enables flexible remote smart home management. Figure 5 presents the overall architecture of the proposed hybrid RF–WiFi smart apartment control system.

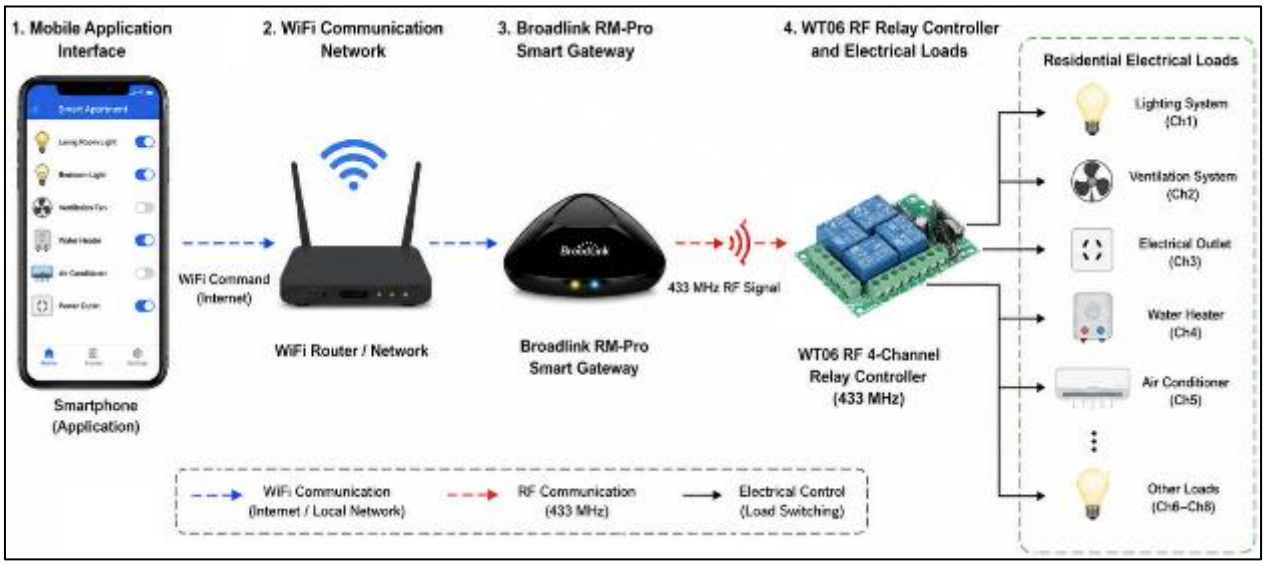

Figure 5 Overall architecture of the proposed hybrid RF–WiFi smart apartment control system

3. Experimental Implementation

3.1. Laboratory Setup

Based on the proposed architecture, the hybrid RF–WiFi smart apartment control system was implemented in the Electrical Engineering laboratory using the developed training platform.

The apartment model simulated residential electrical loads including lighting circuits, electrical outlets, ventilation systems, water heater loads, and air-conditioning loads. Two WT06 RF 4-channel relay controllers operating at 433 MHz were installed to provide eight wireless control channels for residential electrical devices.

A Broadlink RM-Pro smart gateway was integrated to provide WiFi-based remote control through a smartphone application. In the proposed system, control commands were transmitted through the WiFi network to the Broadlink gateway, which subsequently converted them into RF control signals for the WT06 relay controllers.

The platform also preserved conventional wall-mounted switches for manual operation. Therefore, the developed system supported both conventional manual control and IoT-based wireless smart control within a unified laboratory environment.

3.2. Wireless Control Scenarios

Several wireless control scenarios were implemented to evaluate the operation of the proposed hybrid RF–WiFi smart apartment control system in the laboratory environment. The experiments simulated practical smart home operations commonly used in modern residential buildings.

The lighting circuits, ventilation systems, electrical outlets, water heater loads, and air-conditioning loads were connected to the WT06 RF relay controllers. Using a smartphone application, users could remotely switch electrical loads ON or OFF through the WiFi network. In the proposed architecture, the Broadlink RM-Pro gateway received control commands from the mobile application and subsequently transmitted 433 MHz RF signals to the WT06 relay controllers for load switching operations.

Experimental observations demonstrated stable wireless communication and reliable relay switching performance for various residential electrical loads. The developed system was able to manage multiple electrical devices simultaneously while maintaining stable operation within the laboratory environment.

The proposed platform also supported Internet-based remote operation through the WiFi network. This functionality allowed students to study practical IoT-based smart home technologies and wireless residential automation systems. In addition, the WT06 relay controllers maintained local RF control capability during temporary WiFi network interruptions, improving operational reliability and reducing dependence on Internet connectivity.

Conventional wall-mounted switches were also preserved in the developed platform. Therefore, electrical devices could be operated using either traditional manual switching or wireless smart control technologies. This hybrid configuration enabled students to compare conventional residential electrical systems with modern IoT-based smart home architectures within a unified experimental environment.

Table 1 Summarizes the main operating modes of the proposed hybrid RF–WiFi smart apartment control system

Control Mode	Description	Operation Method
Manual control	Conventional switching	Wall switches
RF smart control	Local wireless switching	WT06 RF controller
WiFi smart control	Smartphone-based remote switching	Broadlink RM-Pro
Hybrid control	Combined operation	Manual + RF + WiFi

4. Conclusion

This paper presented the design, implementation, and experimental evaluation of a hybrid RF–WiFi smart apartment training platform for electrical engineering education. The developed system integrated WT06 RF relay controllers and a Broadlink RM-Pro smart gateway to establish a practical residential smart control environment supporting both conventional electrical installations and IoT-based wireless automation.

Experimental implementation demonstrated stable wireless communication, reliable relay switching performance, and flexible control capability for multiple residential electrical loads including lighting systems, ventilation systems, electrical outlets, and air-conditioning loads. The developed platform also enabled students to study practical smart home technologies, RF communication systems, and Internet-based residential automation within a unified laboratory environment.

Compared with conventional smart home educational models, the proposed platform provides several advantages including low implementation cost, simple deployment, hybrid wireless communication capability, and compatibility with traditional residential electrical systems.

Future work will focus on integrating environmental monitoring sensors, energy management functions, cloud-based data analytics, and artificial intelligence algorithms to further enhance the educational and practical capabilities of the smart apartment training platform.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

The use of AI or AI-assisted technologies

During the preparation of this work, the authors used ChatGPT to paraphrase text and improve sentence clarity and grammar. After using this tool, the authors reviewed and edited the content as necessary and takes full responsibility for the content of the publication.

Statement of Ethical approval

The present research work does not contain any studies performed on animals or human subjects by any of the authors.

References

[1] International Telecommunication Union. Measuring digital development: Facts and figures 2023. Geneva: ITU; 2023.

[2] Statista. Number of Internet of Things (IoT) connected devices worldwide. 2024. Available from: https://www.statista.com

[3] Marikyan D, Papagiannidis S, Alamanos E. A systematic review of the smart home literature: A user perspective. Technol Forecast Soc Change. 2019;138:139-154. DOI: 10.1016/j.techfore.2018.08.015.

[4] Alaa M, Zaidan AA, Zaidan BB, Talal M, Kiah MLM. A review of smart home applications based on Internet of Things. J Netw Comput Appl. 2017;97:48-65. DOI: 10.1016/j.jnca.2017.08.017.

[5] Stolojescu-Crisan C, Crisan C, Butunoi BP. An IoT-based smart home automation system. Sensors. 2021;21(11):3784. DOI: 10.3390/s21113784.

[6] Van den Beemt A, Groothuijsen S, Ozkan L, Hendrix W. Remote labs in higher engineering education: Engaging students with active learning pedagogy. J Comput High Educ. 2023;35:320-340. DOI: 10.1007/s12528-022-09331-4.

[7] Yar H, Imran AS, Khan ZA, Sajjad M, Kastrati Z. Towards smart home automation using IoT-enabled edge-computing paradigm. Sensors. 2021;21(14):4932. DOI: 10.3390/s21144932.

[8] Sepasgozar SM, Karimi R, Farahzadi L, et al. A systematic content review of artificial intelligence and the Internet of Things applications in smart home. Appl Sci. 2020;10(9):3074. DOI: 10.3390/app10093074.

[9] Gubbi J, Buyya R, Marusic S, Palaniswami M. Internet of Things (IoT): A vision, architectural elements, and future directions. Future Gener Comput Syst. 2013;29(7):1645-1660. DOI: 10.1016/j.future.2013.01.010.

[10] Johri A, Olds BM. Situated engineering learning: Bridging engineering education research and the learning sciences. J Eng Educ. 2011;100(1):151-185. DOI: 10.1002/j.2168-9830.2011.tb00007.x.

[11] Hernández-de-Menéndez M, Guevara AV, Tudón Martínez JC, Hernández Alcántara D, Morales-Menendez R. Active learning in engineering education: A review of fundamentals, best practices and experiences. Int J Interact Des Manuf. 2019;13:909-922. DOI: 10.1007/s12008-019-00557-8.

[12] Vodovozov V, Raud Z, Petlenkov E. Challenges of active learning in a view of integrated engineering education. Educ Sci. 2021;11(2):43. DOI: 10.3390/educsci11020043.

[13] Heradio R, de la Torre L, Dormido S. Virtual and remote laboratories in education: A bibliometric analysis. Comput Educ. 2016;98:14-38. DOI: 10.1016/j.compedu.2016.03.010.

[14] Rahman AM, et al. Development of an IoT-based smart home laboratory platform for engineering education. IEEE Access. 2022;10:24560-24572.

[15] WT06. 433 MHz RF 4-channel relay controller user manual. Shenzhen; 2023.

[16] Broadlink. RM-Pro smart universal remote controller user guide. Hangzhou: Broadlink Technology Co.; 2023.

[17] Nguyen HPH, Do AV, Ta VQ, Tran TD, Pham NH. Evaluation of an IoT-based smart apartment training platform for electrical engineering education. Int J Sci Res Arch. 2026;18(3):1011-1017. DOI: 10.30574/ijsra.2026.18.3.0570.

[18] Pham NH, Do AV, Nguyen HPH, Tran TD, Ta VQ. Design and implementation of a smart apartment electrical training model using WIFI-based relay controllers. Int J Sci Res Arch. 2026;18(3):764-770. DOI: 10.30574/ijsra.2026.18.3.0524.