Smart Occupancy Detection and Activity Recognition Using RF Transmissions

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Publication Date: 2026/03/27

Abstract: This work proposes a smart occupancy detection and activity recognition system for monitoring human presence in indoor environments. The system integrates Passive Infrared (PIR) sensors and Radio Frequency (RF) sensing to identify whether a room is occupied and to observe basic human activities. Sensor data is collected and analyzed using activity recognition techniques to provide real-time information about room usage. Such monitoring can be useful in environments like offices, hospitals, educational institutions, and residential buildings where efficient space utilization is important. Based on the detected occupancy status and activity patterns, the system can automatically manage electrical devices such as lighting, heating, ventilation, and other appliances. This approach helps ensure that devices operate only when required, thereby reducing unnecessary energy consumption and improving overall efficiency. Unlike conventional occupancy detection systems that mainly depend on PIR sensors or pressure-based methods and only detect simple presence, the proposed approach also examines changes in RF signals caused by human movement. This enables the system to detect occupancy and identify activity without requiring wearable devices, providing a convenient, non-intrusive, and privacy-conscious solution for modern smart building applications.

Keywords: *Smart Occupancy Detection, Radio Frequency (RF) Sensing, Internet of Things (IoT), Wireless Sensors, Energy Efficiency.*

How to Cite: R. Anand; R. Nithin Reddy; R. Sai Kiran; R. Om Sai Varshitha; Dr. Mohassin Ahmed (2026) Smart Occupancy Detection and Activity Recognition Using RF Transmissions. *International Journal of Innovative Science and Research Technology,* 11(3), 2269-2274. https://doi.org/10.38124/ijisrt/26mar1295

I. INTRODUCTION

Building occupants are often assumed to follow deterministic schedules in building performance simulation programs. Therefore, to accurately capture the dynamic nature of the occupants' movement patterns, researchers have proposed various indoor localization technologies to infer occupancy information with varying degrees of accuracy and resolution. This paper provides a review of occupancy measurement techniques and also discusses research trends and challenges. Additionally, a novel privacy preserved occupancy monitoring solution is also proposed in this paper. Security analyses of the proposed scheme reveal that the new occupancy monitoring system is privacy preserved compared to other traditional schemes. Building occupancy is of great importance for energy efficient control of buildings. A large number of works have been developed for the estimation and detection of building occupancy. In this paper, we present a comprehensive review on building occupancy estimation and detection. Reducing energy demand in the residential sector is an important problem worldwide. This study focused on the awareness of residents to energy conservation and on the potential of reducing energy demand through energy-saving activities.

II. LITERATURE REVIEW

Conventional occupancy detection heavily leans on PIR sensors and physical pressure mats. While somewhat effective for basic presence detection, these traditional tools lack the precision needed for complex environments and cannot reliably categorize specific human movements. Furthermore, camera-based solutions inherently violate user privacy, restricting their use in sensitive locations like residential and healthcare facilities. There is a clear need for a monitoring solution that bridges the gap between deep behavioral insight and strict privacy preservation propose a scalable system using Bluetooth Low Energy (BLE) signals to detect and analyze occupancy patterns in office environments. Their approach enables non-intrusive, cost-effective profiling of occupant behavior to support energy efficiency and smart building management [1]. provide a

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1295

comprehensive review of methods for building occupancy detection and estimation, covering sensors, data-driven models, and their applications in energy management [2]. investigate the impact of an energy-consumption information system on household energy savings using monitored data [3]. These studies collectively indicate the need for accurate, real-time, and privacy-friendly occupancy detection systems, motivating the proposed RF-based approach present an integrated automation system designed to improve energy efficiency in buildings, particularly in the tertiary (service) sector. The study demonstrates how combining monitoring, control, and decision-support tools can optimize energy use and reduce operational costs [6].

III. REASEARCH METHODOLOGY

We propose an RF-based architecture that analyzes radio signal fluctuations to map human presence and activity. Because the human body alters RF signal propagation, tracking these changes allows the system to identify whether a room is occupied and classify the type of activity occurring in real-time. Crucially, this method functions entirely device-free—meaning users do not need to wear any tags or carry smartphones—offering a highly accurate, non-intrusive alternative for smart spaces.

➢ *System Architecture*

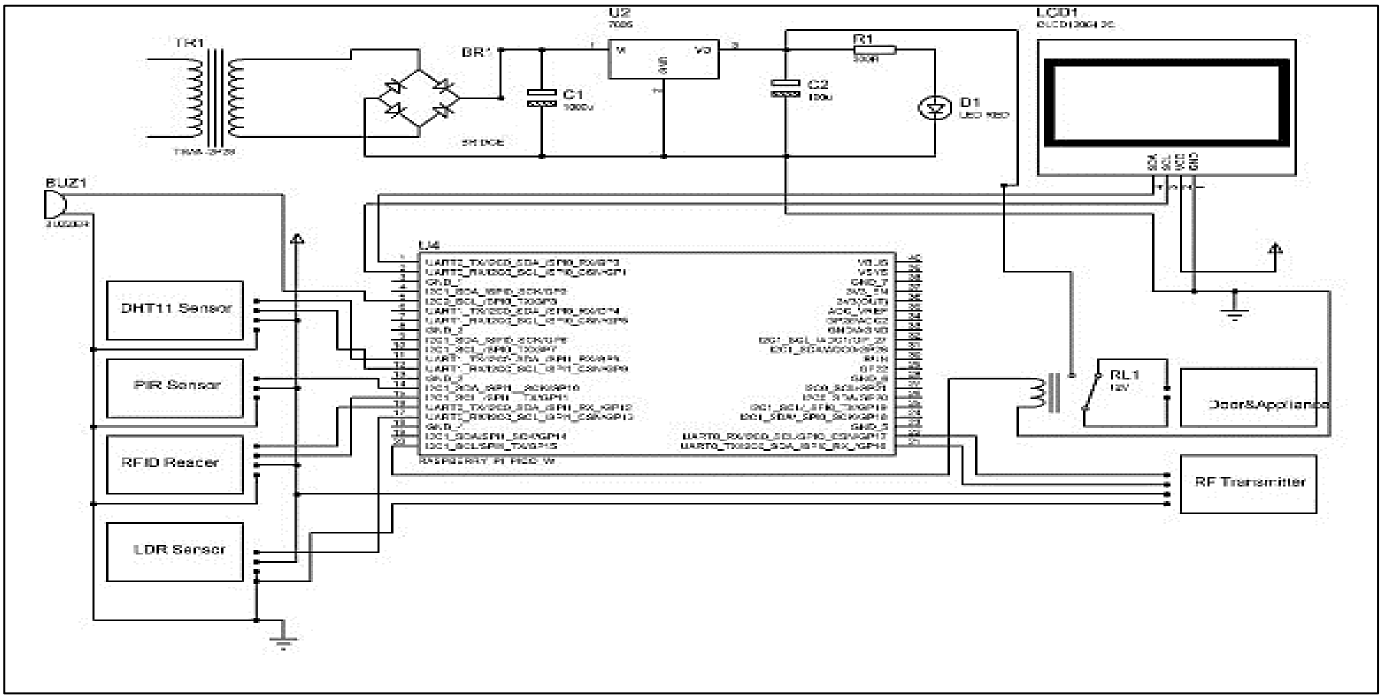

Fig 1a. Schematic Architecture of Transmitter

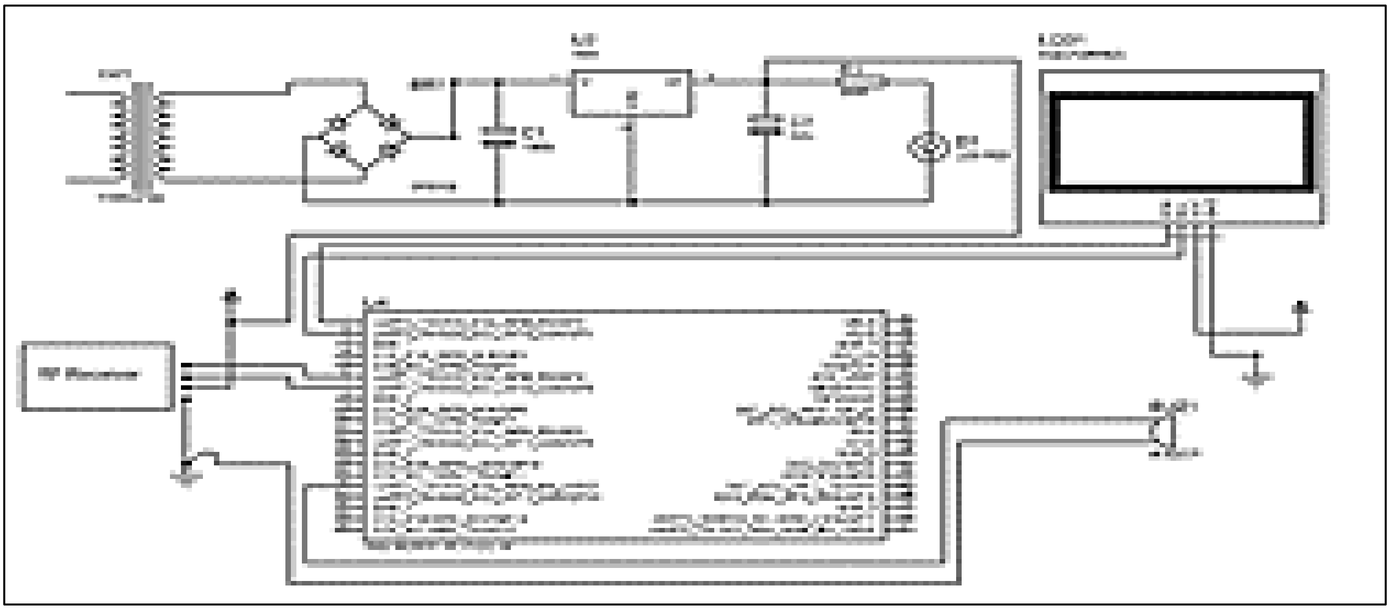

Fig 1b Schematic Architecture of Receiver

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1295

The Fig.1a &1b represents the overall architecture of the proposed smart occupancy detection and activity recognition system. It illustrates the interaction between various sensors, the microcontroller, and output devices for real-time monitoring and control. The system processes sensor inputs to detect occupancy and automatically manage appliances, ensuring energy efficiency and smart automation.

➢ *Hardware Components*

The following are the hardware components of our proposed model:

- Microcontroller,
- DHT11 Sensors,
- PIR sensors,
- LDR sensors,
- RFID reader and tag,
- RF module,
- OLED,
- Driver circuit,
- Motor, Buzzer

➢ *Software Requirements*

The following are the software requirements of our project:

- Python
- Thonny IDE
- Circuit Python

IV. SYSTEM DESIGN / IMPLEMENTATION

The fig 2a and 2b illustrate the transmitter and receiver architecture of the proposed smart occupancy detection system. The transmitter unit integrates multiple sensors with a microcontroller to collect environmental and occupancy data, which is then sent via an RF transmitter. The receiver unit processes the received data to control appliances and trigger alerts, enabling efficient automation and real-time monitoring.

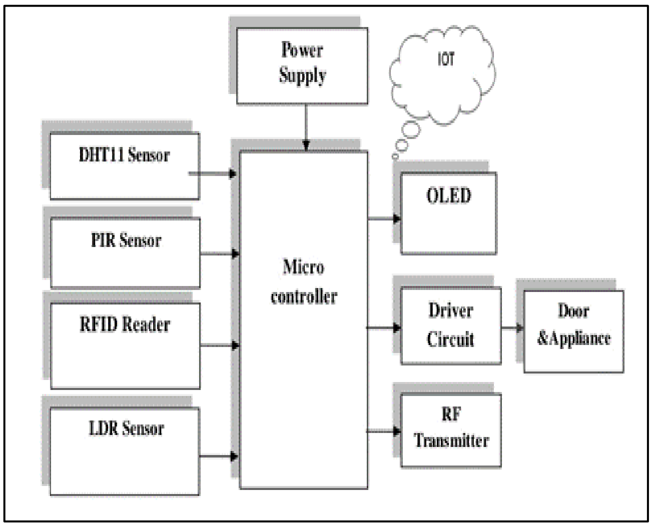

Fig 2b. Block Diagram of Transmitter

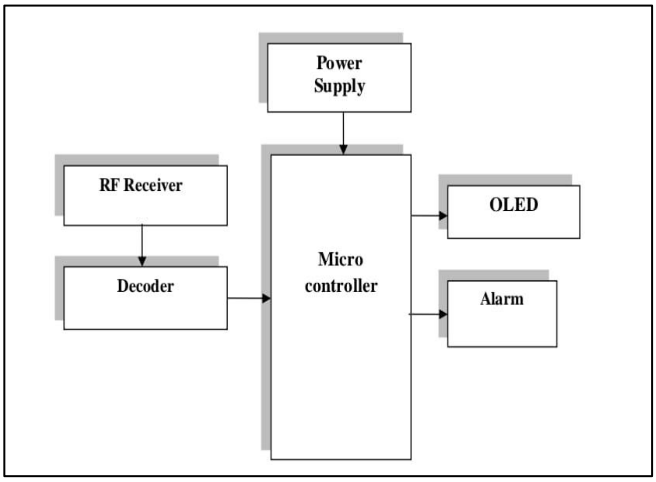

Fig 2b. Block Diagram of Receiver

➢ *Working Model*

The fig 3a and 3b show the hardware implementation of the proposed smart occupancy detection and activity recognition system. It includes a microcontroller board interfaced with sensors such as PIR, RFID, and RF modules, along with an OLED display and power supply unit. The setup demonstrates real-time data acquisition and control of appliances based on occupancy detection.

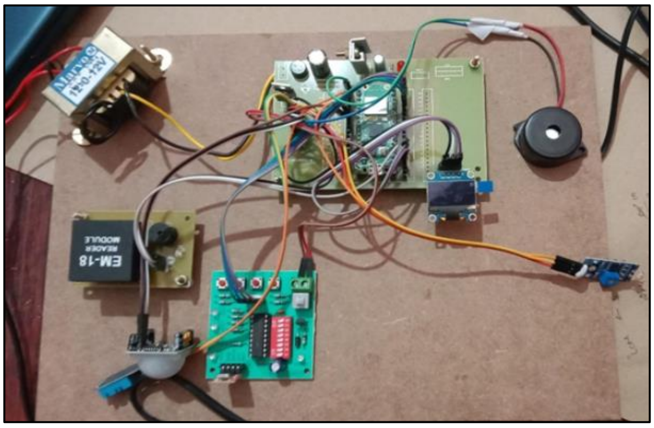

Fig 3a. Transmitter of Smart Occupancy Detection &Activity Recognition

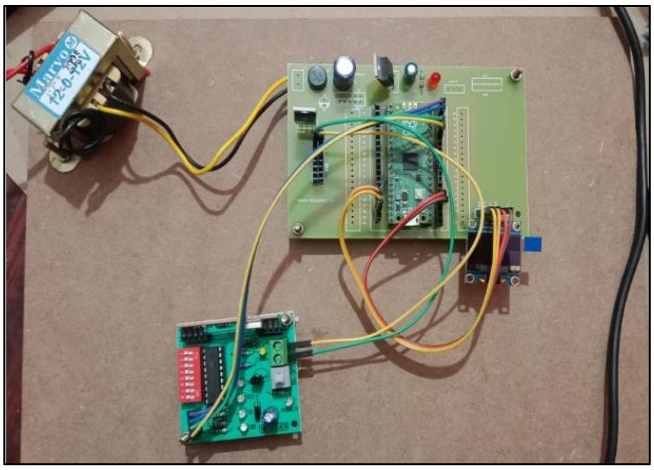

Fig.3b. Receiver of Smart Occupancy Detection & Activity Recognition

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1295

➢ *Working Principle:*

This section explains the working principle of the proposed model. The hardware architecture is separated into a transmitter and receiver network to accurately capture and process data.

- *Core Controller:*

The system is powered by a Raspberry Pi Pico W, utilizing the RP2040 microcontroller for its dual-core processing and native wireless capabilities.

- *Sensing Layer:*

Environmental parameters are captured using a DHT11 sensor for temperature and humidity, a Light Dependent Resistor (LDR) for ambient light monitoring, and a PIR sensor for baseline motion tracking.

- *Identification & Display:*

An RFID system operates at 125 kHz to authenticate or track specific assets, while an OLED screen provides local data visualization.

- *Communication:*

Data packets are transmitted via a TWS-434A RF transmitter module and received by an RWS-434 RF module. Encoding and decoding are handled securely by HT12E and HT12D ICs, respectively.

- *Actuation:*

The system drives physical outputs—such as DC motors, buzzers, and relays for high-power appliances—using a ULN2003 driver circuit.

V. RESULT AND DISCUSSION

The fig4a and 4b illustrates the real-time monitoring of environmental parameters using the DHT11 sensor in the proposed smart occupancy detection system. The graphs represent variations in temperature and humidity over time, indicating changes in indoor conditions due to human presence and activity.

Fig 4a. Temperature Reading

Fig 4b. Humidity Readings

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26mar1295

The fig 4c and 4d shows the real-time output of the PIR and LDR sensors used in the proposed system. The PIR sensor graph indicates continuous detection of motion, confirming human presence, while the LDR sensor graph reflects variations in light intensity over time. These sensor readings support accurate occupancy detection and enable automatic control of lighting based on environmental conditions.

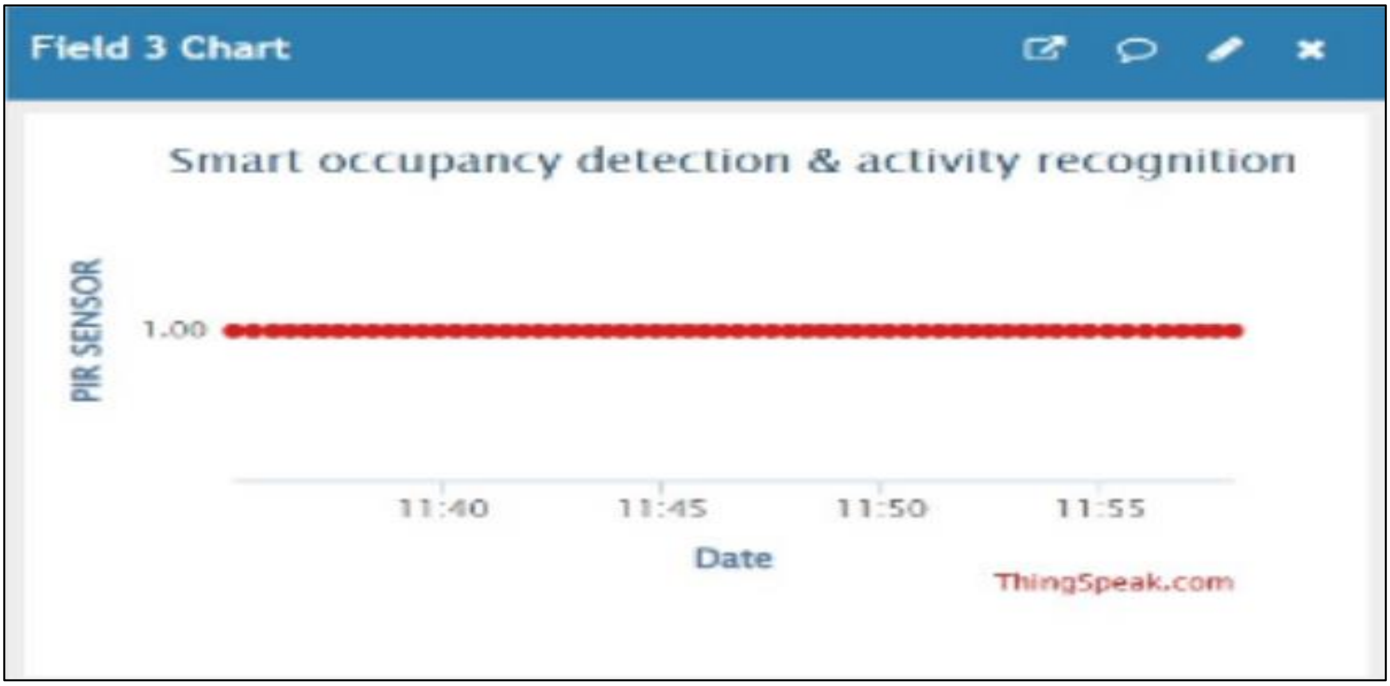

Fig 4c. PIR Readings

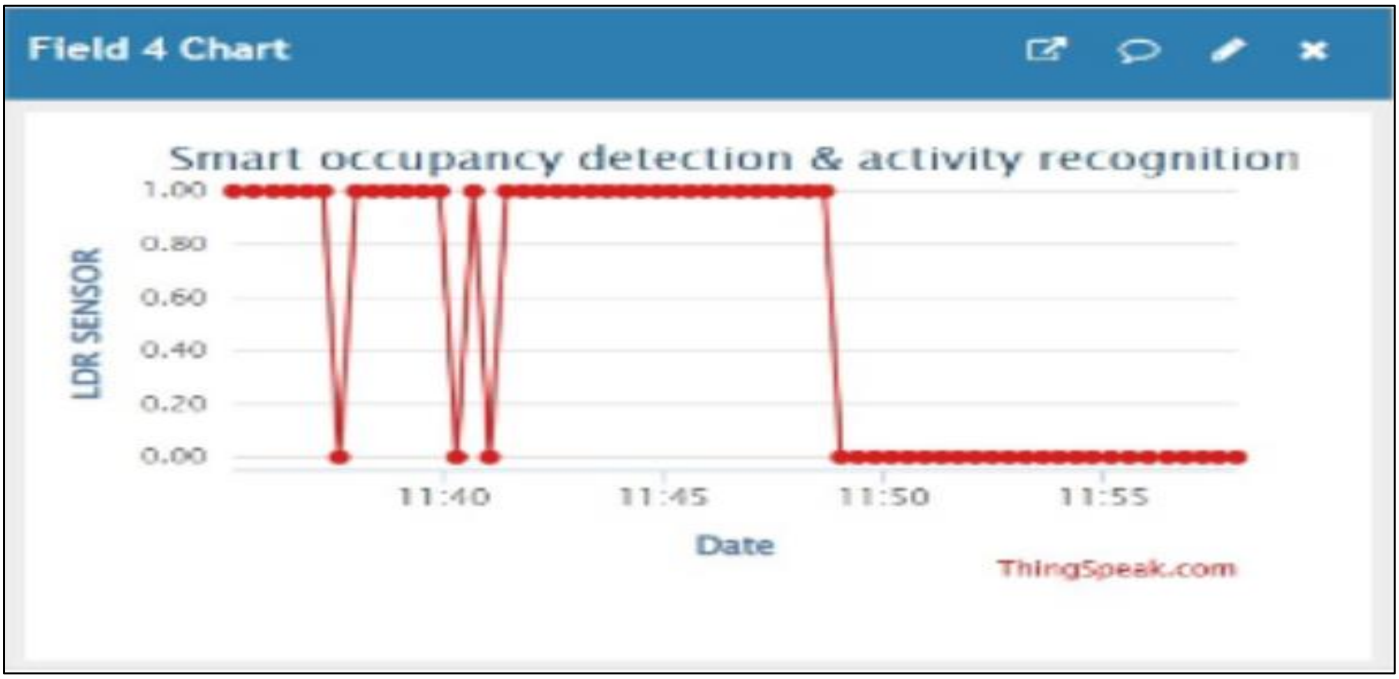

Fig 4d. LDR Readings

➢ *Advantages and Applications*

* *System Benefits:*

The primary advantage of this design is its respect for user privacy; it operates entirely without cameras. It is also "wearable-free," reducing the friction of user adoption. By interfacing directly with building utilities, it actively drives down energy consumption.

* *Real-World Applications:*

This framework is highly suitable for modern smart city infrastructures, capable of scaling across hospital wards, corporate office spaces, educational campuses, and smart homes.

VI. CONCLUSION

The proposed model successfully outlines a viable, privacy-first approach to smart occupancy detection. By shifting away from cameras and relying on an integration of RF and environmental sensors, building managers can achieve granular control over HVAC and lighting systems. The resulting reduction in energy waste proves that intelligent automation can be both cost-effective and respectful of occupant privacy. Ultimately, this system supports the broader global initiative to build sustainable, smart infrastructures.

FUTURE SCOPE

Future development could focus on integrating machine learning models directly into edge devices (like the Raspberry Pi Pico W) to recognize more complex behavior patterns. Connecting this localized data to a broader cloud-based smart city grid would further optimize large-scale resource allocation across metropolitan areas.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to all those who have supported me in the successful completion of this project on “Smart Occupancy Detection and Activity Recognition using RF Transmissions.”First, I would like to thank my project guide for their valuable guidance, continuous support, and encouragement throughout the development of this project. Their suggestions and insights helped me improve my understanding and complete the work effectively.

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