Smart Room Occupancy Counter

Wendy Wang, Yonghe Hu, Leon Nel Nel, Srinath Rajan
University of Western Australia, Australia
23904899@student.uwa.edu.au; 24108102@student.uwa.edu.au; 24268801@student.uwa.edu.au; 24318358@student.uwa.edu.au

Abstract— This project presents a smart room occupancy counter designed for real-time monitoring in dynamic environments such as classrooms. By integrating dual-sensor logic, mmWave radar, and cloud-based visualization, the system accurately tracks the number of people entering and exiting a room. It automates lighting control, issues overcrowding alerts, and provides remote data access through a web dashboard. The design emphasizes modularity, scalability, and privacy, making it suitable for smart building management and future commercial deployment.

Keywords— IoT, Occupancy Monitoring, Smart Room, Real-Time Control, Sensor Fusion

I. Introduction

A. Group Title

Smart Room Occupancy Counter

B. Group Information

TABLE I

Group 21 Information

No.	Name	Student Number
1	Wendy Wang	23904899
2	Yonghe Hu	24108102
3	Leon Nel Nel	24268801
4	Srinath Rajan	24318358

C. Project Overview

1) What is the problem?

Traditional people-counting systems often fail to track occupancy accurately in real-time, especially in dynamic environments like classrooms, where people may enter or exit unpredictably or in groups. THere systems also lack automation features and data integration for space management.

2) Why is solving important?

- Helps reduce energy waste by automating lighting based on occupancy
- Enables better room and space utilization
- Supports real-time crowd monitoring for safety and comfort
- Provides data-driven insights for smart facility management

3) What is expected impact of the solution?

- Enhanced user experience and safety in shared spaces
- Improved energy efficiency through automated environment control

- Scalable to commercial settings, supporting smart attendance, access control, and customer flow analysis
- Lays foundation for commercial use in places like gas station

II. Related Work Research

Occupancy monitoring helps businesses optimize space usage, improve resource allocation, and enhance user experience, making it an essential tool in smart building management. In the context of smart buildings [1], occupancy monitoring is achieved through various types of sensors that capture real-time data on space utilization by detecting the presence or movement of individuals. Commonly employed sensors include Passive Infrared (PIR) sensors, which detect simple occupancy status; infrared sensors, capable of detecting bi-directional motion across entry points; and vision-based sensors, which utilize cameras and computer vision algorithms to track movement, albeit with potential privacy concerns. Thermal sensors detect human body heat to estimate occupancy, while WiFi and Bluetooth-based systems monitor the presence of devices to infer occupancy levels. More recently, LiDAR sensors have emerged, offering precise, camera-free, three-dimensional occupancy monitoring [2]. The selection of an appropriate sensor depends on the specific application requirements and the desired level of accuracy.

TABLE II

Comparisons Of Related Works

Product	Sensor Type	Key Features	Advantages	Disadvantages
OneSight	PIR, Thermal, Vision-based	Real-time people counting, space utilization analysis	Flexible deployment	Privacy concerns
SmartViz	PIR, Vision, WiFi, Thermal, LiDAR	Occupancy analytics, energy optimization	Comprehensive analytics	Privacy issues with vision sensors
Smarter Technologies	LiDAR, PIR	Flow monitoring, desk occupancy, heat-mapping	Wireless, easy integration	Requires Orion network
Axis People Counter	Vision-based (Overhead Video)	People counting, queue management, privacy protectio	High accuracy, GDPR-compliant	Limited to people counting
Milesight	Vision + AI	AI-powered people counting, crowd management	AI-enhanced accuracy	Limited environmental sensing
Hiome	WiFi + Magnetic + Motion	Privacy-focused, smart home integration	Privacy-preserving	Not suitable for large buildings
HALO 3C-PC	Multi-sensor (Air Quality + Occupancy)	Occupancy + air quality detection, security monitoring	Multi-functional	Higher cost

Various smart occupancy monitoring solutions have been developed to enhance space utilization, energy efficiency, and user experience across different environments. Common sensor technologies include Passive Infrared (PIR), thermal, vision-based, LiDAR, and WiFi/Bluetooth-based systems. [3]-[9] For example, SmartViz [4] and OneSight [3] provide comprehensive solutions combining multiple sensor types to deliver real-time occupancy analytics and space management capabilities. Smarter Technologies[5] focuses on agile workplaces with LiDAR-based flow monitoring and desk occupancy tracking, while Axis People Counter [6] specializes in accurate people counting using vision sensors, emphasizing GDPR compliance. Milesight [7] integrates AI-powered vision sensors for crowd management, and Hiome [8] targets smart homes with privacy-preserving occupancy detection. Additionally, HALO 3C-PC [9] offers a unique multi-sensor system, combining occupancy monitoring with air quality and security detection. Each system presents trade-offs in terms of accuracy, privacy, cost, and suitability for specific application scenarios.

However, the requirements of our project presented specific challenges, including the need for directional people counting, resilience against edge cases like simultaneous entries and exits, and adaptability to high-traffic environments such as classrooms and campus buildings. In addition, privacy protection and real-time control were critical considerations, especially in educational settings.

After evaluating the available solutions, we found that commercial systems either lacked sufficient flexibility to handle our identified edge cases or introduced privacy concerns due to the reliance on vision-based sensing. Therefore, instead of adopting an off-the-shelf solution, we decided to develop a custom system tailored to the unique requirements of our project.

III. Design Approach

A. Design Objective

The primary goal of this project is to build a real-time classroom occupancy monitoring system that automatically counts the number of people in a room, triggers warnings when overcrowding is detected, controls lights accordingly, and provides visualized data. This system must operate reliably in dynamic, real-world conditions-where users may behave unpredictably, multiple people may move at once, and direction may not always be clear.

Our methodology is based on a problem-driven modular design, where each functional requirement is mapped to a system module, then evaluated under normal and edge-case conditions to ensure robustness.

B. Overall Design Methodology

We adopted a four-layered design methodology:

1. Sensing Layer - detect physical motion and presence
2. Processing Layer - determine occupancy logic and trigger conditions
3. Communication Layer - send data to the dashboard
4. Visualization Layer - provide display of the occupancy data

C. Step-by-Step Process

1) Requirement Analysis: We began by translating user needs and usage scenarios into measurable system requirements:

- Directional people counting
- Multi-person detection
- Automated control (lights, warnings)
- Data transmission and visualization
- Real-time response with edge-case resilience
- Scalability for classroom and campus-wide use

This analysis revealed two major challenges to address:

- Ambiguity when people use the same door for entry and exit
- Inability to distinguish multiple individuals moving simultaneously

2) Initial Sensor Mechanism: The foundational design for occupancy tracking is based on the use of dual sensing points positioned at both the entrance and exit. Each entry point consists of two aligned detection zones that register sequential movement. When a person enters the room, their presence is detected first at the outer point and then at the inner point—indicating an entry. Conversely, when a person leaves the room, the detection occurs in reverse order.

This sequence-based logic allows the system to increment or decrement the internal occupancy counter accordingly, maintaining a real-time estimate of how many individuals are currently inside the space.

3) Edge Cases: We focused on addressing the two primary edge cases using both implemented logic and proposed future solutions.

Case 1: Same Door Used For Entry and Exit

- Baseline Solution: Dual IR trigger-order logic
- Proposed Future Solution: Implement a USB camera and face_recognition library to identify individuals. A local state table logs their entry status. If a person reappears while already marked as “entered”, the system cancels the count.

Case 2: Simultaneous Entry or Exit of Multiple People

- Baseline Solution: Apply a 300ms time-based filter to treat quick successive triggers as a single event. This minimizes false positives but does not solve true simultaneous movement.
- Proposed Future Solution: Use mmWave radar to track multiple moving objects. These sensors emit high-frequency signals that reflect off moving targets, producing real-time point-cloud data for number of targets, direction vectors and movement duration.

4) Occupancy-Based Control Logic: The control subsystem is designed to respond autonomously to changes in room occupancy. At its core, the system maintains a real-time internal variable representing the number of people currently in the space. Based on this value, two control behaviors are activated through GPIO interfaces on the microcontroller.

The first is a lighting control mechanism that automatically enables or disables an indicator light depending on whether the room is occupied. The second is a threshold-based crowd warning mechanism, where the system activates a buzzer and visual alert when occupancy reaches or exceeds a predefined limit. These control functions operate independently of network connectivity and are executed locally to ensure immediate response and fault tolerance.

5) Communication and Data Visualization: To enable remote monitoring and historical analysis, the system is structured to transmit occupancy data to an external cloud platform via Wi-Fi. This data pipeline is designed to operate in parallel with the core control functions, ensuring that local responsiveness is not compromised.

The transmitted dataset includes:

- Cumulative entry and exit counts
- Current occupancy value
- Timestamps corresponding to key events such as a first entry, last exit, peak occupancy, and alert activations

This information is visualized in real time through a web dashboard, providing stakeholders with continuous insight into space utilization. The modularity of the data structure allows for future integration with broader building management systems or analytics platforms.

6) Consolidated Solution Based on Edge Case Analysis: In the proposed consolidated design, each entrance and exit is equipped with two directional sensing units positioned to monitor opposing traffic flow. These sensors continuously emit and receive electromagnetic signals to identify the presence, movement direction, and quantity of individuals passing through.

As a person moves into or out of the room, their motion is captured in the form of spatial vectors and object counts. This real-time data is interpreted to classify the event as either an entry or an exit, enabling accurate, continuous updates to the occupancy state of the room.

The system architecture eliminates the need for visual imaging by relying solely on reflected signal data. This ensures operational consistency across different lighting environments and preserves user anonymity. The modular arrangement of directional sensors at each threshold allows for scalable deployment, even in high-traffic environments where group movement and unpredictable behavior are expected.

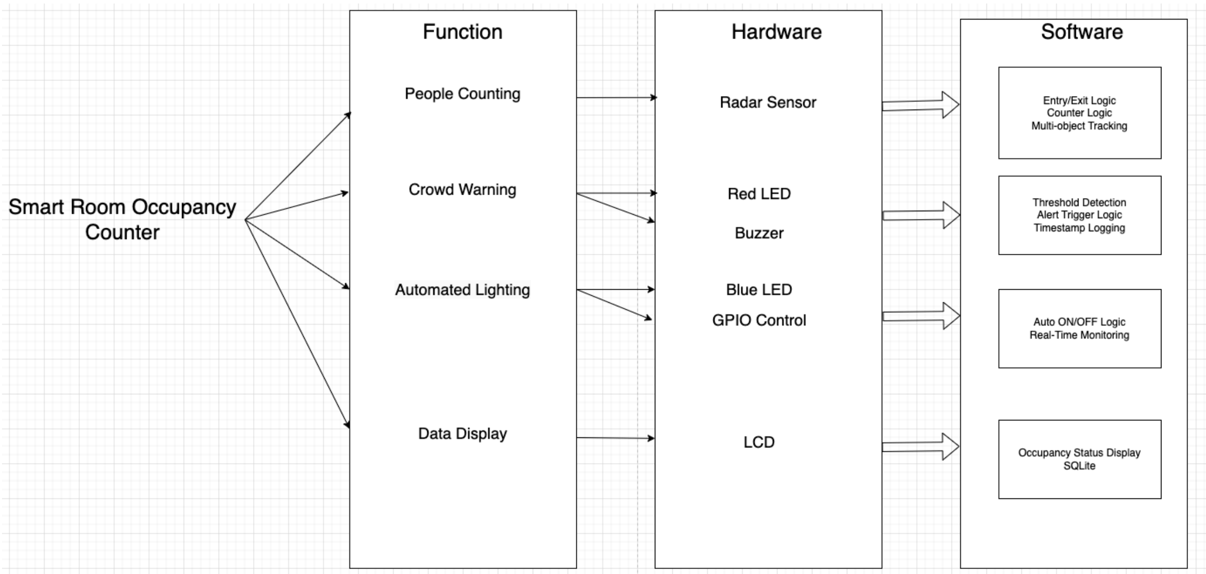


Fig. 1 Design Concept Diagram

IV. Subsystem and Functionalities

A. People Counting

Below is a representation of how the counting function operates:

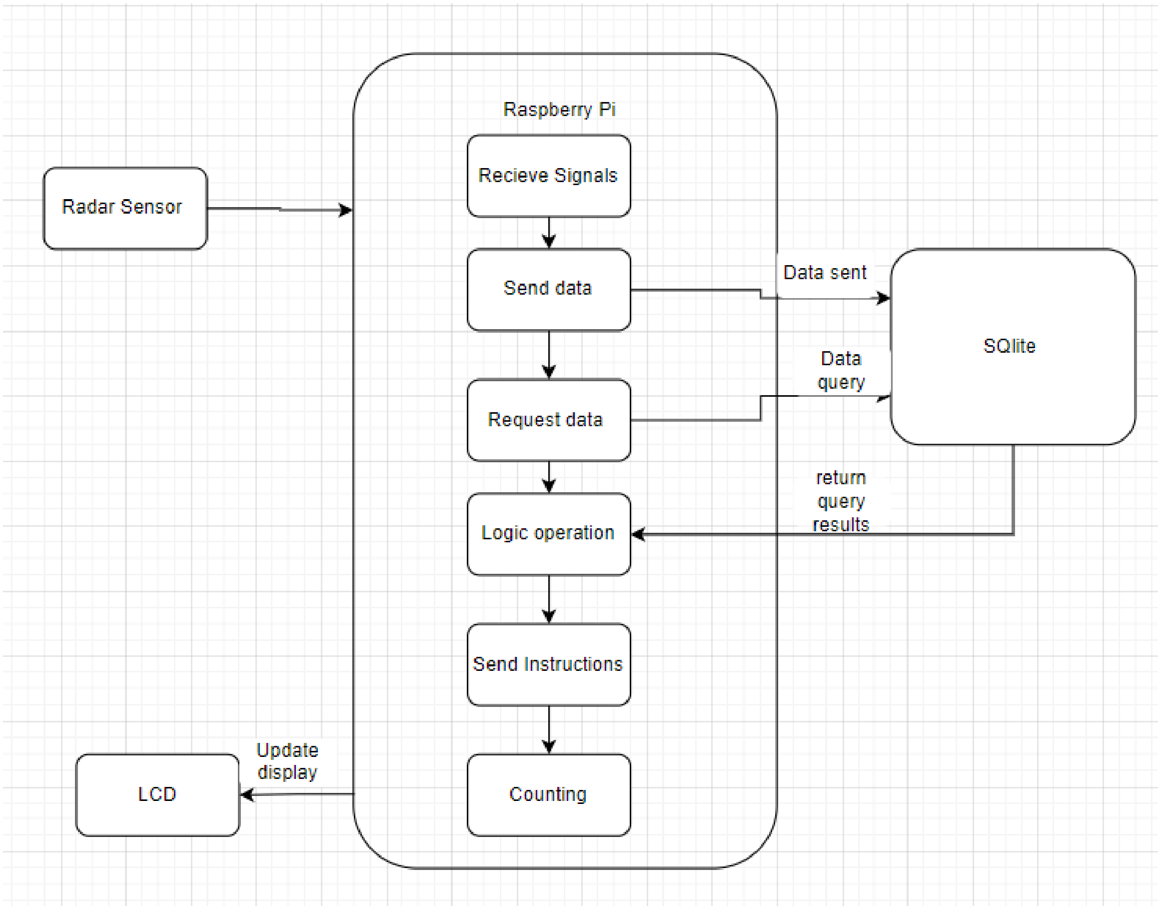


Fig. 2 Population Coun

a. The Radar Sensor placed at the side door of the classroom sends out electromagnetic radio waves to determine the passing of individuals coming in and out of the classroom.
b. The GPIO control receives the digital signals from the sensors.
c. The signal received is classified as an individual passing through the doors, the data is sent to the cloud for storage and easier access.
d. The microprocessor queries the data from the cloud to give out instructions to other devices.
e. The LCD is updated.

B. Automated Lighting

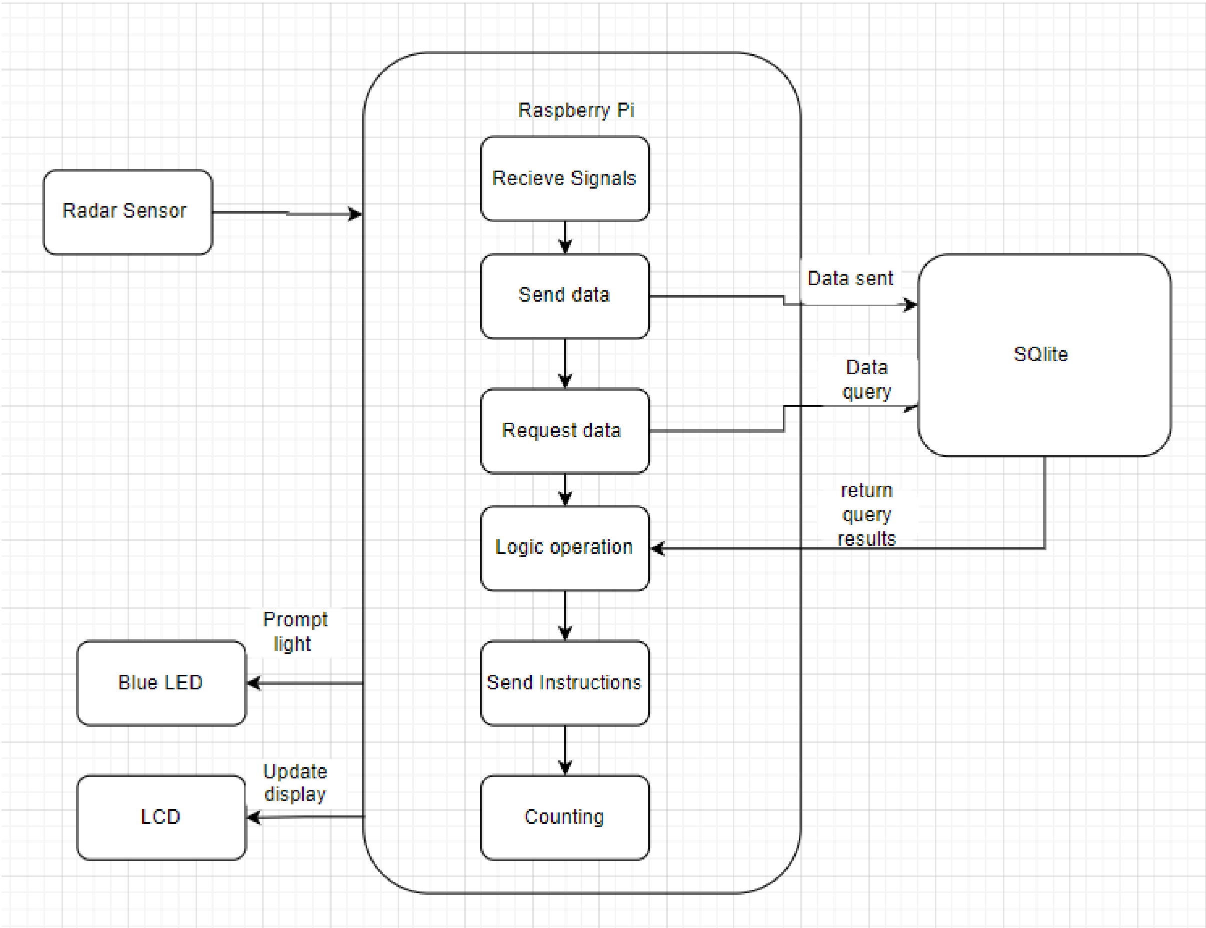


Fig. 3 Automated Lighting

a. The blue LED light is set to be turned on or off depending on the information received from the database.
b. The microprocessor reads the data received and sends instructions to the LED light to illuminate the classroom.

C. Crowd Warning and Data Display

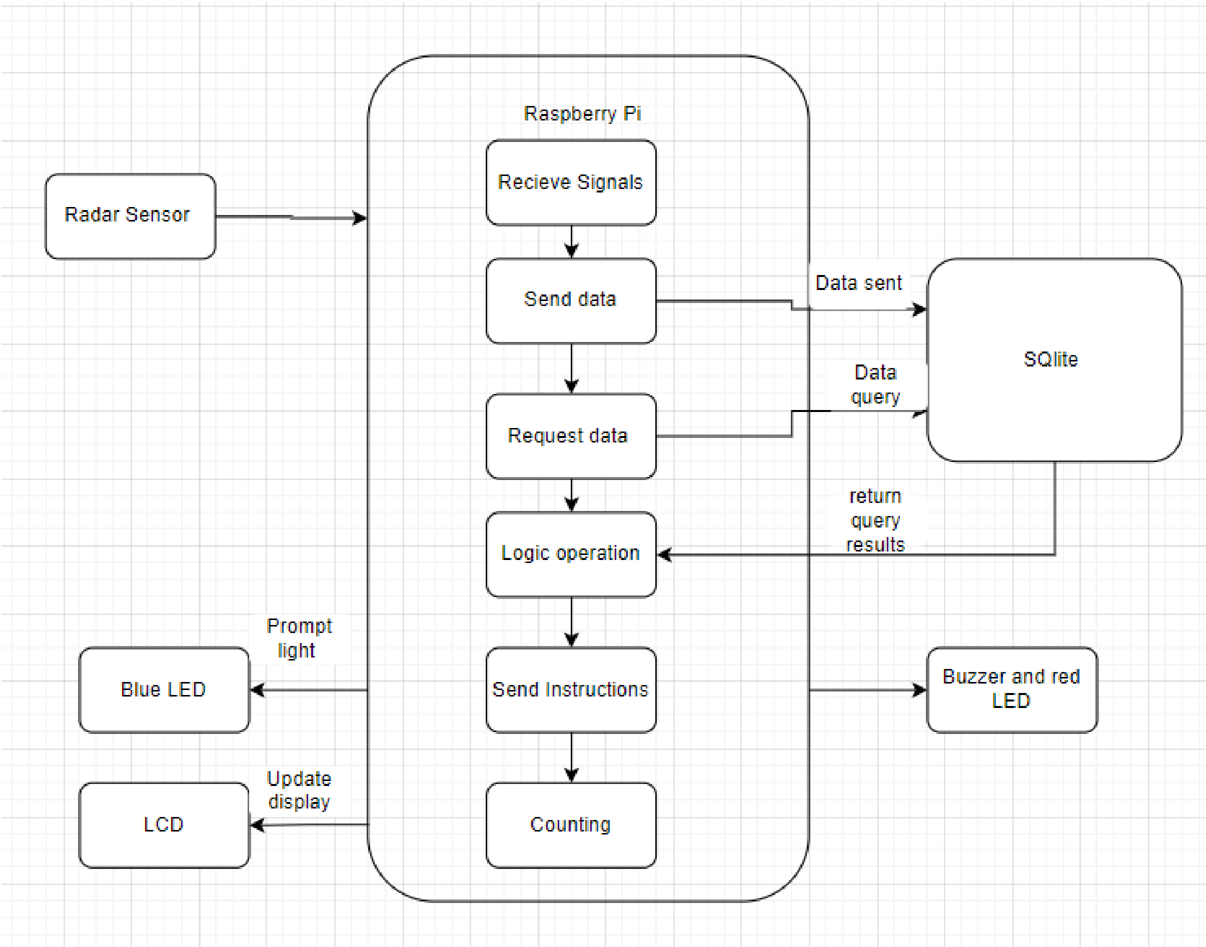


Fig. 4 Crowd Warning and Data Displayed

a. The system will have a threshold as to how many students a classroom can hold.
b. The data received is compared with the highest number the classroom can hold.
c. When the data received is higher than the limit, a buzzer will sound and the red LED lighting turns on.
d. A report is generated by the database to display the statistics of how many students came in and out of class for a week.

D. Database and Server Solution

To determine the most suitable solution for our database and server setup, we conducted a comparison between popular cloud-based platforms and local deployment options.

TABLE III

COMPARISON BETWEEN CLOUD-BASED PLATFORM AND LOCAL DEPLOYMENT

Feature	**Home Assistant + SQLite**	**AWS IoT Core**
Deployment Location	Local (Raspberry Pi)	Cloud (AWS data centers)
Internet Dependency	Fully offline capable	Requires network connection
Real-time Performance	Very low latency	Cloud round-trip latency
Data Processing	Local automation logic	Rules Engine, Lambda
Data Storage	SQLite (on-device)	S3, DynamoDB, Timestream
Visualization Tools	Lovelace Dashboard	CloudWatch, QuickSight
Scalability	Limited by local hardware	High - supports millions of devices
Ease of Setup	Simple, beginner-friendly	Moderate (requires AWS expertise)
Cost	Free (hardware only)	Pay-per-use (devices, storage, etc)

After comparing local and cloud-based IoT solutions, our team decided to adopt the **Home Assistant + SQLite** approach for this project. Given our objectives — low complexity, offline capability, minimal cost, and full control over data — the local solution proved to be the most suitable.

With the decision made, the following section outlines the functional logic of our chosen system, detailing how sensors, automation, and storage work together to track and respond to room occupancy in real time:

a. Sensors: Detect entry/exit and other behaviors using radar sensors and send signals to Home Assistant
b. Home Assistant: Receives sensor data, integrates devices, and manages system logic
c. Real-time Counter Logic: Implements occupancy counting (+1 for entry, -1 for exit) using automation and counter components
d. Status Record & Event Logging: All occupancy changes and sensor states are saved to the built-in SQLite database for historical tracking
e. Visualization: A Lovelace Dashboard displays real-time occupancy, system status, and historical trends.

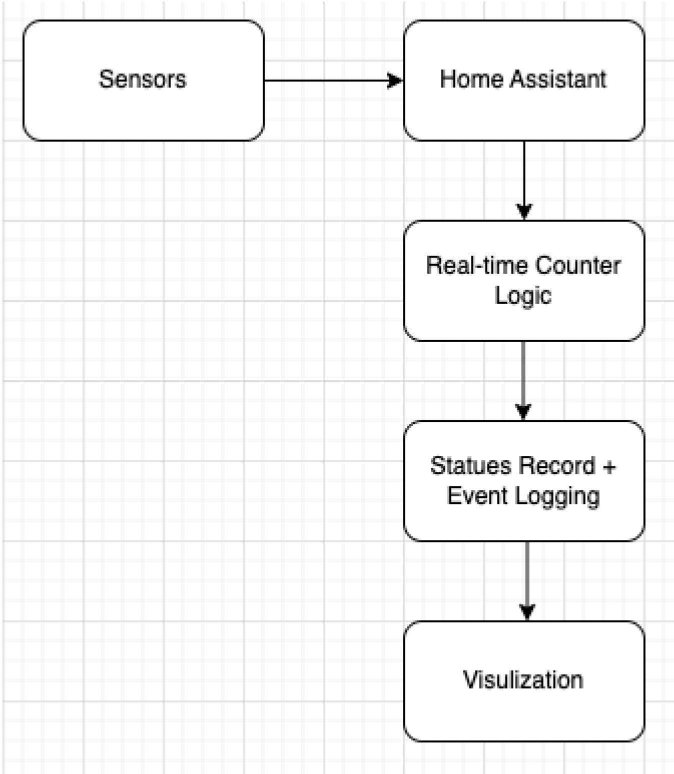


Fig. 5 Logic of Home Assistant + SQLite Workflow

V. Hardware Identified

TABLE IV

Hardware Components List

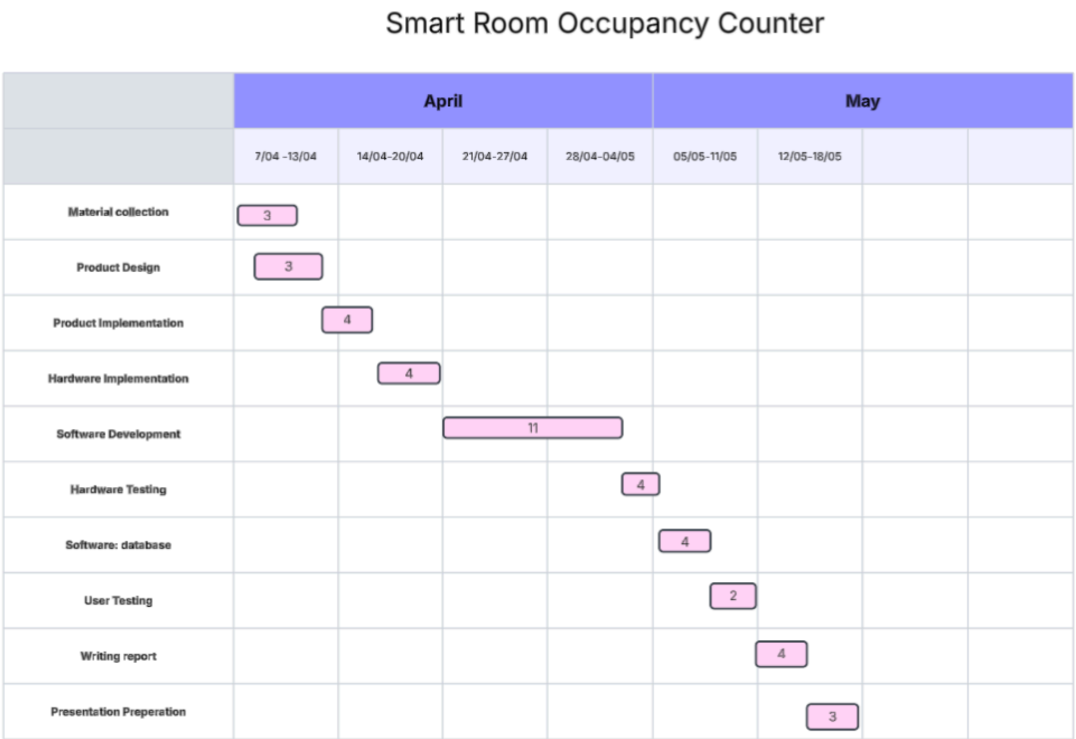
No.	Items Description	Available at UWA	Cost	Web address	Delivery Time(Days)
1	RPI 3B+	Yes	N/A	https://core-electronics.com.au/raspberry-pi-3-model-b-plus.html	N/A
2	MicroSD Memory Card - 16GB Class 10	Yes	N/A		N/A
3	Solderless Breadboard - 830 Tie Point (ZY-102)	Yes	N/A	https://core-electronics.com.au/solderless-breadboard-830-tie-point-zy-102.html	N/A
4	5MM Various Colours	Yes	N/A	https://www.ebay.com.au/b/5mm-Indi	N/A

				vidual-LEDS/181880/bn_99029403	
5	Resistor 220R	Yes	N/A	N/A	N/A
6	Assembled Standard LCD 16x2 + extras - White on Blue	Yes	N/A	https://core-electronics.com.au/assembled-standard-lcd-16x2-extras-white-on-blue.html	N/A
7	5V DC 2A Appliance Power Supply Adapter	Yes	N/A	https://www.altronics.com.au/p/m8904a-powertran-5v-dc-2a-fixed-2.1mm-tip-appliance-plugpack/	N/A
8	Gravity: mmWave C4001 24GHz Human Presence Detection Sensor (12 Meters, I2C & UART)	Yes	N/A	https://www.dfrobot.com/product-2795.html	N/A
9	Professional Female to Female Jumper Wires - 40 x 20cm	Yes	N/A	https://core-electronics.com.au/professional-female-to-female-jumper-wires-40-x-20cm.html	N/A
10	Jumper Wire 20cm Ribbon (M/F, 40pcs)	Yes	N/A	https://core-electronics.com.au/premium-female-male-extension-jumper-wires-40-x-6-150mm.html	N/A
11	Buzzer 5V - Breadboard friendly	Yes	N/A	https://core-electronics.com.au/buzzer-5v-breadboard-friendly.html	N/A
12	ModMyPi - Raspberry Pi T-Cobbler PRO Breakout	Yes	N/A	https://core-electronics.com.au/40-pin-raspberry-pi-gpio-breakout.html	N/A

VI. Timeline

TABLE V

Gantt Chart for the Project Timeline (Days)



VII. Distribution

TABLE VI

Distribution of Teammembers

Name of Student	Student Work Assigned	Reason for the Assignment
Wendy Wang	a. Web application design and development	a. Has skills in frontend development
Leon Nel	a. Database design and development	a. Experienced on software design and back-end development
Srinath Rajan	a. Distance sensor b. Hardware testing c. Hardware assembly	a. Experience with hardware sensors. b. Understanding sensor triggers and how to activate and manage them.
Yonghe Hu	a. Documentation b. Web application design and development	a. Has skills in frontend development b. Being involved in the web interface and hardware development, she is well-placed to document the aspects.

VIII. References

[1] Memoori, "Occupancy Analytics & In-Building Location Services 2023," Memoori Research, 2023. [Online]. Available: https://memoori.com/portfolio/occupancy-analytics-building-location-2023/.

[2] SmartViz Ltd, "Occupancy Monitoring and Occupancy Analytics: How Low Cost Sensors Can Help You Manage Your Space More Effectively," SmartViz, May 6, 2024. [Online]. Available: https://www.smart-viz.com/resource/occupancy-monitoring-analytics.

[3] One Sightsolutions Ltd., "People Counting & Space Occupancy," One Sightsolutions. [Online]. Available: https://onesight.solutions/people-counting-space-occupancy/.

[4] SmartViz Ltd., "Occupancy Monitoring and Occupancy Analytics: How Low Cost Sensors Can Help You Manage Your Space More Effectively," SmartViz, May 6, 2024. [Online]. Available: https://www.smart-viz.com/resource/occupancy-monitoring-analytics.

[5] Smarter Technologies, "Occupancy Monitoring System," Smarter Technologies. [Online]. Available: https://smartertechnologies.com/occupancy-monitoring/.

[6] Axis Communications, "AXIS People Counter," Axis. [Online]. Available: https://www.axis.com/products/axis-people-counter.

[7] Milesight, "People Counting Solution," Milesight. [Online]. Available: https://www.milesight.com/solution/people-counting.

[8] Hiome Inc., "Hiome - Smart Home Occupancy Detection," Hiome. [Online]. Available: https://www.hiome.com/.

[9] IPVideo Corporation, "HALO 3C-PC Product Information," Halo Detect. [Online]. Available: https://halodetect.com/product-info/halo-3c-pc/.