Smart Meeting Room Maintenance System

Meeting Room Scenario Detection: Utilizing mmWave Radar Sensing

1st Yu-Hong Chou
Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan
r12921053@ntu.edu.tw

2nd Yen-Chang Li
Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan
r13921093@ntu.edu.tw

I. Need: Problem Statement and Opportunity

In modern businesses, meeting rooms are essential spaces for collaboration, brainstorming, and decision-making. They are not only functional areas but also reflect a company's professionalism and organization. However, as companies grow and meeting demands increase, maintaining the cleanliness and functionality of multiple meeting rooms becomes a challenging and time-consuming task. Facility management teams, particularly **cleaning teams** and the **place teams**, face significant inefficiencies. Cleaning staff often waste time inspecting rooms that don't need attention or arrive at rooms only to find them in use, leading to unnecessary effort, wasted resources, and delays in addressing actual maintenance needs. This not only affects their productivity but also increases stress and frustration in their work.

Recent advancements in meeting technologies have transformed how teams collaborate. For instance, the Surface Hub 3 combines a touch-sensitive display, video conferencing tools, and collaboration software to create a seamless and productive meeting experience. Similarly, smart projectors like the BenQ LH730 offer wireless connectivity and built-in business apps, enabling efficient presentations with minimal setup. These tools help employees focus on their tasks and enhance meeting efficiency. However, while these technologies improve how meetings are conducted, they do not address the challenges faced by cleaning teams and place teams responsible for maintaining these spaces. These teams need a solution that provides real-time insights into meeting room conditions, such as occupancy, cleanliness, and equipment status. Such a system would help cleaning staff prioritize their tasks and ensure efficient use of resources, while the place team could better manage room availability and maintenance schedules. Employees also benefit from consistently clean, well-maintained spaces, fostering a comfortable and professional environment for collaboration and decision-making. By addressing these needs, businesses can enhance operational efficiency and employee satisfaction simultaneously.

II. Approach: IoT-Based Solution

To address the challenges encountered by facility management teams in maintaining meeting rooms, we proposes the development of a **Smart Meeting Room Maintenance System** powered by IoT technologies. The system employs advanced sensing and processing tools to provide real-time insights into meeting room conditions, thereby enabling efficient resource allocation and proactive maintenance strategies.

The proposed system integrates **mmWave radar**, **ultrasonic modules**, and **camera-based sensors** to monitor room conditions comprehensively. The mmWave radar generates 3D point cloud data to accurately detect the number of occupants in a room, facilitating the identification of whether the space is occupied or available for cleaning. Ultrasonic sensors measure distances to detect overflowing trash bins, ensuring timely waste management. Additionally, a camera module combined with SSIM (Structural Similarity Index Measure) algorithms evaluates changes in room tidiness by comparing images captured before and after room usage. This allows for automated alerts to be generated when disorder is detected, streamlining cleaning operations.

The system consolidates sensor data and presents it on a centralized **dashboard interface** that is accessible to facility management teams. This dashboard provides real-time updates on room occupancy, cleanliness, equipment status (e.g., whether appliances like fans are left on), and maintenance requirements. By leveraging this IoT-powered platform, facility teams can prioritize tasks effectively, reduce unnecessary inspections, and maintain meeting rooms in consistently optimal conditions.

The key advantage of this system lies in its ability to unify diverse IoT sensors into a cohesive platform that automates the collection and analysis of critical data, such as room occupancy, trash bin status, and appliance usage. This not only minimizes inefficiencies but also enables management teams to focus on addressing specific needs promptly.

Moreover, the IoT-enabled system supports long-term operational improvements by reducing manual effort, optimizing energy usage through appliance monitoring, and facilitating data-driven decision-making. These features align with modern organizational objectives, including efficiency, sustainability, and smart resource management. As a scalable and forward-thinking approach, the system offers a practical solution to existing challenges while providing the adaptability needed to meet future demands in meeting room maintenance.

III. Benefit: Advantages for Stakeholders

Our proposed Smart Meeting Room Maintenance System provides substantial benefits to a diverse set of stakeholders, including facility management teams, employees, organizations, and the broader environment.

A. Benefits for Facility Management Teams

The system empowers facility management teams by automating the monitoring of meeting room conditions. Leveraging real-time data on room occupancy, cleanliness, trash levels, and appliance usage, facility teams can prioritize tasks efficiently, reducing unnecessary inspections and optimizing resource allocation. This streamlined workflow improves productivity and alleviates the challenges of managing multiple meeting rooms, particularly in large-scale facilities. By ensuring that resources are directed to where they are most needed, the system enhances operational efficiency and reduces logistical burdens.

B. Benefits for Employees

Employees directly benefit from the consistent maintenance of clean, organized, and functional meeting rooms. With fewer interruptions caused by cleaning or equipment malfunctions, employees can work in a professional environment that fosters collaboration and productivity. Additionally, the system's real-time monitoring and notification capabilities allow issues such as untidy spaces or equipment failures to be resolved without requiring employees to leave their meeting. For instance, if maintenance is needed, the system automatically notifies relevant staff, ensuring swift intervention and minimizing disruption. This capability addresses key concerns for employees, creating a seamless and convenient meeting experience.

C. Benefits for Organizations

The Smart Meeting Room Maintenance System delivers measurable advantages to organizations by enhancing efficiency, reducing operational costs, and supporting a professional workplace image. Automation of routine monitoring and maintenance tasks ensures that both human and energy resources are utilized optimally, eliminating unnecessary expenditures such as overstaffing or excessive energy usage. Furthermore, maintaining well-functioning meeting spaces positively impacts employee satisfaction and productivity, which directly contributes to improved organizational performance. The system also aligns with organizational priorities of innovation and sustainability, enhancing reputation and stakeholder confidence.

D. Environmental and Sustainability Benefits

The system contributes to environmental sustainability by promoting responsible energy usage and waste management. By monitoring appliance usage, the system ensures that devices are turned off when not in use, reducing unnecessary energy consumption. Similarly, trash bin monitoring enables timely waste removal, preventing overflows and minimizing environmental impact. These sustainable practices support corporate environmental goals and demonstrate a commitment to reducing the organization's ecological footprint.

By addressing the needs of facility teams, employees, organizations, and the environment, our solution offers a comprehensive framework for meeting room maintenance. It bridges current gaps in operational management while paving the way for innovative, efficient, and sustainable practices in the workplace.

IV. Competition: Comparative Analysis with Supplemental Insights

Our Smart Meeting Room Maintenance System presents significant advantages over existing market solutions. By leveraging advanced IoT technologies and a comprehensive multi-sensor approach, it effectively addresses the critical limitations of competing products, offering unparalleled functionality and scalability.

A. Alternatives in the Market

Current market solutions often focus on isolated aspects of meeting room management, limiting their ability to provide a holistic and integrated approach.

1) Single-Function Systems: Many existing systems are designed to address specific capabilities, such as occupancy detection or scheduling. While these solutions meet certain needs, they fail to provide a comprehensive view of meeting room conditions and lack essential features such as tidiness monitoring and appliance usage management.

2) Distributed Microservice Architectures: Some systems utilize distributed architectures for meeting room scheduling and device coordination. While effective for basic management, these architectures often do not support real-time environmental monitoring or advanced alert systems for cleaning and maintenance.

3) Cloud-Based SaaS Platforms: Cloud-based platforms are known for their scalability and compatibility with third-party tools. However, they frequently struggle to provide real-time responsiveness or detailed local control, such as trash bin monitoring and appliance usage tracking, which are essential for effective facility management.

B. Our Competitive Edge

Our system addresses these limitations by offering an integrated, intelligent, and user-friendly solution that combines advanced IoT technologies with practical functionality:

1) Comprehensive Multi-Sensor Integration: Our system incorporates mmWave radar for accurate real-time occupancy detection, ultrasonic sensors for monitoring trash levels, and SSIM-based camera modules for assessing tidiness. This multi-sensor approach ensures comprehensive and precise monitoring of meeting room conditions, far surpassing the functionality of most competitors.

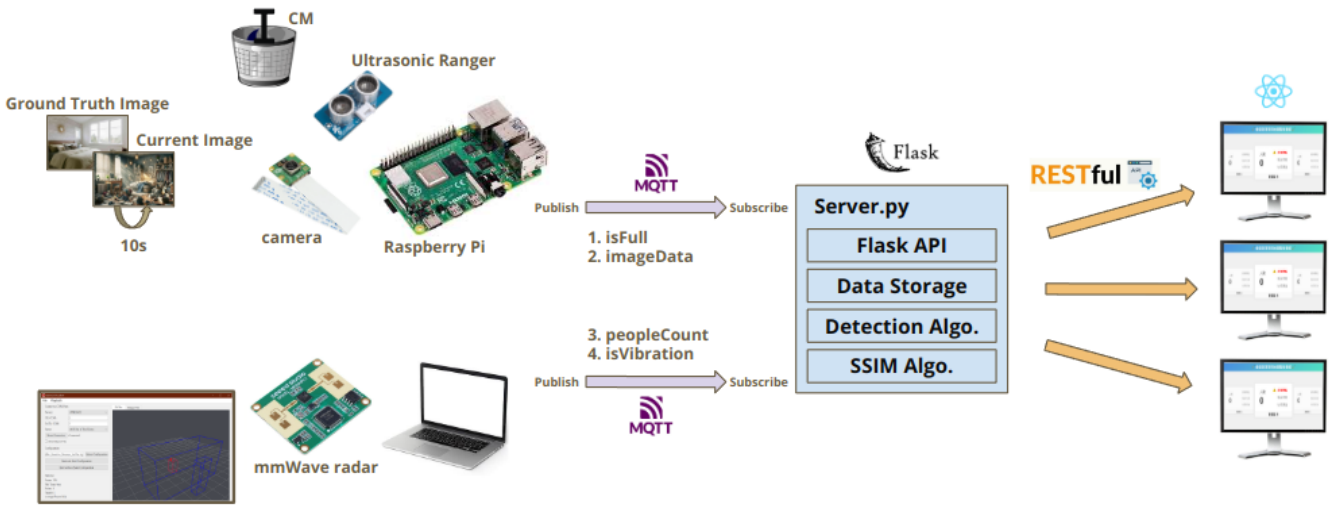

Fig. 1. The figure showcases a meeting room monitoring system where data flows from sensors to a user interface. The **sensing layer** includes a Raspberry Pi camera for capturing images every 10 seconds, an ultrasonic sensor for monitoring trash bin status every 2 seconds, and an mmWave radar for real-time detection of occupancy and appliance vibrations. Data is transmitted via MQTT to the **server layer**, which processes it using detection algorithms and hosts a RESTful API. The processed data is then displayed on the **application layer** using a React-based interface, providing real-time updates on room occupancy, cleanliness, appliance statuses, and trash bin conditions, ensuring efficient management.

2) Actionable Insights and Proactive Alerts: Unlike competing systems that only collect and present raw data, our system processes inputs to generate actionable insights and automated alerts. For instance, cleaning teams receive real-time notifications when rooms become vacant or when trash bins approach full capacity, enabling efficient resource allocation.

3) Energy Optimization: Through continuous appliance usage monitoring, our system identifies and turns off unused devices automatically, reducing energy waste. This feature directly supports sustainability initiatives and helps organizations reduce operational costs.

4) Centralized and Intuitive Dashboard: Our centralized dashboard consolidates data from all sensors into a single, intuitive interface. This allows facility teams to monitor conditions and prioritize tasks effectively without the need for manual interpretation of data, streamlining operations and improving productivity.

By addressing key limitations in existing solutions and providing integrated, intelligent, and scalable features, our system offers a new approach to meeting room management. Unlike competitors that focus on specific aspects of room management, our solution brings together multiple functionalities into a cohesive and comprehensive platform. While existing tools, such as basic occupancy detection systems, provide valuable insights, they often lack the precision and depth enabled by our advanced multi-sensor monitoring capabilities. By helping organizations improve operational efficiency, enhance sustainability, and elevate user satisfaction, our system contributes to a more productive and resource-efficient workplace, setting a promising direction for innovation in meeting room management.

Fig. 2. Our user interface shows real-time status for meeting rooms, including occupancy, table and chair tidiness, appliance status, and trash bin condition. In this example, Meeting Room B displays a warning for disorganized tables, while the features for Meeting Rooms A and C are not yet activated.

V. Design

This section provides a detailed explanation of the system design, incorporating the system architecture (Fig. 1), functionality, and the logic behind each component. The design ensures efficient data collection, processing, and visualization to achieve real-time monitoring of meeting room conditions.

A. System Architecture Overview

The system, based on IoT technology, integrates multiple sensing modules (mmWave radar, Raspberry Pi camera, ultrasonic sensor), a server for data processing, and a user interface (Fig. 2) for real-time visualization. Its functionalities include:

- **Meeting Room Occupancy Detection**
- **Environmental Disruption Detection**
- **Appliance Status Monitoring**
- **Trash Bin Overflow Detection**

The architecture is divided into three layers:

1) **Sensing Layer**: Collects raw data from sensors such as the mmWave radar, camera module, and ultrasonic sensor.
2) **Server Layer**: Handles data transmission, analysis, and storage using MQTT protocol, Flask APIs, and algorithms.
3) **Application Layer**: Displays the processed data in a user-friendly interface.

B. Sensor Modules

*1) **mmWave Radar**:* The mmWave radar module plays a vital role in detecting the number of people and monitoring activities in a meeting room. It generates 3D point cloud data to track and distinguish human targets from non-human objects. By analyzing parameters such as speed and displacement, it effectively classifies entities through its advanced tracking system. The module transmits data, including the number of people (peopleCount) and vibration status (isVibration), to a server in real time using the MQTT protocol. This ensures accurate and up-to-date monitoring of the environment for optimal management and analysis.

*2) **Raspberry Pi Camera Module**:* The Raspberry Pi camera module is designed for detecting environmental disruptions. It captures an image every 10 seconds and compares it with a ground truth image to evaluate the similarity. Using the Structural Similarity Index Measure (SSIM) algorithm, which quantifies image quality by comparing structural information, the module determines whether the similarity score meets a predefined threshold. If the score falls below this threshold, an alert is triggered to indicate a potential environmental issue. The module transmits image data to the server every 10 seconds for real-time comparison, ensuring continuous monitoring and prompt identification of disruptions.

*3) **Ultrasonic Sensor Module**:* The ultrasonic sensor module monitors the status of a trash bin by measuring the distance to the trash. It emits and receives ultrasonic signals to calculate the distance and triggers a trash overflow alert when the measured distance falls below a predefined threshold, such as 24 cm. The sensor transmits this distance data (isFull) every 2 seconds via MQTT to ensure timely updates. This mechanism facilitates dynamic monitoring of the trash bin's status, helping to ensure prompt cleaning and maintenance.

C. Server Layer

The server layer is developed using the Flask framework and incorporates multiple functionalities to manage sensor data and provide real-time monitoring. It handles MQTT communication to process incoming data from sensors using custom logic. The Flask API offers endpoints that allow the user interface to query and retrieve real-time data. Additionally, the server stores images and environmental indicators for historical analysis. It employs detection algorithms to analyze occupancy and vibration data, triggering status alerts as necessary. The SSIM algorithm is used to compare ground truth images with current images, identifying disorganized environments.

The server receives data from sensors, processes it through these algorithms, and provides updates via a RESTful API, ensuring seamless data flow. This integration facilitates efficient communication between the sensors and the server, enabling responsive and intelligent environmental monitoring.

D. Application Layer

The application layer, developed using React, serves as the user interface to display the real-time status of the meeting room. It provides key information, such as current occupancy, environmental disruption alerts (e.g., disorganized chairs or tables), appliance status (e.g., whether the fan is off), and trash bin overflow alerts. Data for these updates is retrieved dynamically from the Flask API, ensuring that the user interface reflects the latest status of the monitored environment in real time. This integration allows for efficient and user-friendly interaction with the system.

VI. Resource

Image	Name	Quantity & Price
	mmWave Radar	1 * 300 = 300 NTD
	Raspberry pi	1 * 1500 = 1500 NTD
	Camera Module	1 * 1000 = 1000 NTD
	Ultrasonic Ranger	1 * 140 = 140 NTD
	Dupont Line	20 NTD
	Skilled Labor	2 * 25000 = 50000 NTD
	Maintanance	5000 NTD / Month
	Complete TIme	2 Weeks

Fig. 3. Estimated Costs for Implementing a Smart Meeting Room System.

Fig. 3 outlines the estimated costs required to set up a smart monitoring system for a single meeting room. The system

includes essential hardware such as an mmWave radar (300 NTD), Raspberry Pi (1,500 NTD), camera module (1,000 NTD), and ultrasonic sensor (140 NTD), totaling 2,940 NTD. Additional accessories like Dupont lines may incur minimal costs. The skilled labor costs cover the development and installation efforts by two professionals over a two-week period. Additionally, server maintenance is projected at 2,000 NTD per month to ensure system functionality and updates. The total investment provides a comprehensive solution for monitoring occupancy, tidiness, appliance usage, and trash bin conditions, making it an efficient and cost-effective choice for meeting room management.

VII. Conclusion

The smart meeting room monitoring system successfully integrates mmWave radar, ultrasonic sensors, and camera modules to provide comprehensive environmental monitoring functionalities. These include occupancy detection, environmental disruption detection, appliance status monitoring, and trash overflow detection. All these features are consolidated into a centralized smart dashboard that delivers real-time information to cleaning and management teams. By implementing this system, meeting room conditions can be effectively monitored and maintained without manual intervention.

From a practical standpoint, the system significantly reduces the inefficiency of unnecessary patrols by cleaning personnel, thereby enhancing cleaning operations' productivity and precision. This provides organizations with immediate operational benefits and economic advantages in environmental management.

Looking ahead, there is great potential for future system enhancements. For instance, incorporating air quality monitoring sensors could detect PM2.5 levels or unusual odors, helping determine if a meeting room requires additional cleaning. Another valuable feature could be light usage monitoring through light sensors to identify whether lights remain on when the meeting room is unoccupied. These developments will further optimize meeting room management, ensuring sustainability and energy efficiency while addressing the dynamic needs of modern workplaces.

Acknowledgment

We would like to extend our heartfelt gratitude to our professor and teaching assistants for their invaluable guidance and support throughout the course. We are also deeply appreciative of the industry experts who attended our demo session and provided insightful feedback, which greatly enriched our work. Furthermore, we wish to express our sincere thanks to JORJIN TECHNOLOGIES INC., especially Neo, Peter, and Steven, for their generous provision of mmWave radar modules, related software, and technical assistance, which were essential to the successful implementation of this project.

References

[1] Surface Hub 3.
https://www.microsoft.com/zh-tw/surface/business/surface-hub-3

[2] How are Interactive Whiteboards Applied in Business Settings? An Analysis of Advantages, Disadvantages, Key Purchasing Considerations, and Practical Examples.
https://www.systexdc.com/2024/01/11/smart-meeting-room/

[3] chatgpt.
https://chatgpt.com/

[4] Grove – Ultrasonic Ranger Ultrasonic Distance Measurement Module Distance Detection Sensor by Seeed.
https://www.taiwaniot.com.tw/product/grove-ultrasonic-ranger

[5] Using MQTT with Raspberry Pi for Communication with Windows and Ubuntu.
https://medium.com/ching-i/

[6] [Edge] Installing and Configuring Mosquitto MQTT Message Broker on Raspberry Pi with Publish and Subscription Testing.
https://learningsky.io/install-mosquitto-mqtt-message-broker-on-raspberry-pi-and-python-publish-subscription/

[7] Motion_Presence_Detection_Demo_Tuning_Guide.
https://drive.google.com/file/d/1GxftvZT6akj2m2HVwaW4mQJBNk_f8wb5/

[8] LH730 4000lms 1080p LED Conference Room Projector.
https://www.benq.com/en-in/business/projector/lh730.html?

[9] Vector Icons and Stickers.
https://www.flaticon.com/

[10] TBB012 Male-to-Female Dupont Wire.
https://www.oursteam.com.tw/view-product.php?id=256

[11] Raspberry Pi 4 Model B 8GB Development Board - Official Product with Bonus 3-Piece Aluminum Heatsink Set.
https://www.taiwaniot.com.tw/product/raspberry-pi-4-model-b-8gb/

[12] Raspberry Pi Camera Module 3 — Official Raspberry Pi Camera Module V3.
https://piepie.com.tw/product/pi-camera-module-v3

[13] 24GHz mmWave Sensor — Human Detection Millimeter-Wave Radar Module.
https://www.icshop.com.tw/products/368030200831

[14] pixabay.
https://pixabay.com/zh/photos/notebook-laptop-computer-keyboard-1361981/

[15] MQTT.
http://mqtt.tw/mqtt-specification.html

[16] What is a RESTful API? A Guide to Semantic Design of Routes.
https://tw.alphacamp.co/blog/rest-restful-api

[17] Backend Integration of Flask, MongoDB, and Scrapy.
https://medium.com/@v0220225/backend-flask-mongodb-scrapy-5fccbdefb0ae

[18] React Native.
https://zh.wikipedia.org/zh-tw/React_Native

[19] What Is The Psychology Behind Messy Rooms?
https://www.sparklymaidmiami.com/blog/what-is-the-psychology-behind-messy-rooms

[20] How to Design a Room, in 12 Easy Steps.
https://www.thespruce.com/how-to-design-a-room-5198563