10.48047/jocaaa.2022.30.02.23

Smart Classroom Occupancy Monitoring and Automation System using Raspberry Pi Integrated Sensor Intelligence

M. Shashidhar
,Professor, Department of Electronics and Communication Engineering, Vaagdevi College of Engineering, Bollikunta, Warangal, Telangana, 506005, India. sasi47004@gmail.com
M. Sukesh
Assistant Professor, Department of Computer Science and Engineering, Vaagdevi College of Engineering, Bollikunta, Warangal, Telangana, 506005, India. sukeshcse@gmail.com
Varun Revuri
Professor & Head CSE (AI & ML), Jayamukhi Institute of Technological Sciences, Narsampet, Telangana 506332, India. revuri_varun@yahoo.co.in

Abstract

The Smart Classroom Occupancy Monitoring System utilizes a Raspberry Pi integrated with dual infrared (IR) sensors to accurately count the number of occupants entering and exiting a classroom. The system dynamically manages electrical appliances such as fans and lights by activating them based on real-time occupancy thresholds, enhancing energy efficiency and comfort. A 16x2 I2C LCD display provides instant local feedback on the occupancy count and device statuses, while the system also pushes updated data to a remote web server for continuous monitoring and analysis. The implemented algorithm uses sensor state transitions with debouncing flags to ensure precise counting without duplication. The occupancy count governs relay control for connected fans and lights, turning devices ON or OFF according to predefined thresholds, enabling responsive environment automation. This system enables better energy conservation by reducing appliance use when rooms are unoccupied, while ensuring comfort when occupied. The remote data logging permits administrative oversight and integration into larger building management or research systems. Overall, this blend of sensing, control, local display, and networked communication forms an intelligent solution for modern educational environments seeking automated control, safety, and resource optimization.

Keywords: Occupancy counting, Infrared sensors, Energy efficiency, Raspberry pi automation, Remote data logging.

1. Introduction

With the rapid development of information technology, the smart classroom, as an emerging educational model, is gradually becoming an important part of modern education. Smart classrooms are defined as technology-assisted, closed environments that enhance the teaching and learning experience [1]. The emergence of the "smart classroom" represents a paradigm shift in educational environments, merging traditional teaching and learning methods with advanced technological integration. As a model for contemporary educational settings, smart classrooms are often characterized by the use of digital tools, information and communication technologies (ICT), and interactive learning systems. Smart classrooms are designed to bridge the gap between students and teachers, to help teachers teach more effectively, and to make the environment more conducive to teaching and learning [2]. In recent years, smart sensor technologies have emerged as pivotal tools in education transformation. Sensor technology is an indispensable basic part of the application of many advanced technologies such as AI (Artificial Intelligence), intelligent learning technology, the Internet of Things, information technology, and big data in the classroom. In smart classrooms, the presence of sensors provides a way to naturally collect learning data during the learning process, forming the data foundation of intelligent systems, and providing educators with unprecedented opportunities to deepen students' learning experience and improve the teaching efficiency.

10.48047/jocaaa.2022.30.02.23

The progress of Artificial Intelligence technology in recent years has been remarkable, and the tremendous impact of this technology is undoubtedly being introduced into smart classrooms. The introduction of AI combined with emerging technologies having the form of interactive, remote, and mobile computing in physical and/or virtual environments constitutes an evident trend in the development of the concept of the smart classroom [3]. There are also integrated applications of AI technology with sensor technology, where data collected by sensors can be processed and analyzed by AI algorithms. Spikol et al. points out that computer systems have been widely used with the delivery of instructional content, which are ideal systems for assisting in teaching and learning analytics [4]. Therefore, AI technologies such as big data analytics and machine learning methods can be deployed to help understand and categorize learning outcomes. Further integration and application of artificial intelligence and sensor technologies are foreseen. The smart classroom is a research topic that extends multiple disciplines, and there is a considerable number of studies reviewing the progress of research in this area, whether from a technological dimension, pedagogical perspective, or sociological perspective.

With increasing focus on energy conservation and smart infrastructures, educational institutions face challenges in managing electrical appliances efficiently. Classrooms are often left with fans and lights turned ON even when unoccupied, resulting in unnecessarily high energy consumption and operational costs. Traditional manual control lacks responsiveness and real-time awareness of occupancy, limiting optimization potential. Advances in sensor technology and embedded systems enable automation of room environmental controls using accurate occupant detection methods. Various occupancy detection methods have evolved from simple manual switches to advanced image processing and sensor fusion techniques. Infrared (IR) sensors became popular for presence detection due to their affordability and reliability. Previous systems mostly used single-point sensors or manual controls but had limitations in accurately counting occupants entering and exiting. Raspberry Pi and other microcontroller platforms brought greater flexibility, programming ease, and network connectivity to occupancy monitoring, enabling real-time data logging and remote management. These developments set the foundation for affordable, precise smart classroom occupancy systems.

1.1 Problem Definition

The problem addressed is the lack of an automated, real-time system for accurately counting the number of occupants in a classroom to intelligently control electrical appliances. Manual control and single-point sensing can cause energy wastage and occupant discomfort due to unregulated device operation. The absence of real-time occupancy data also impedes facility management and energy optimization strategies.

1.2 Research Objectives

1. Develop a reliable occupancy counting system using dual IR sensors to detect entry and exit events accurately.
2. Implement automated control of classroom appliances (fans and lights) based on real-time occupancy thresholds to enhance energy efficiency.
3. Provide real-time local feedback through an LCD display displaying occupancy count and device statuses.
4. Enable remote data logging by transmitting occupancy and device data to a web server for monitoring, analysis, and management.
5. Design a user-friendly, cost-effective, and scalable system applicable for smart classroom environments to optimize resource use and improve comfort.

10.48047/jocaaa.2022.30.02.23

2. Literature Survey

Saini and Goel [2] described interdisciplinary research on smart classroom technologies, dividing smart classrooms into "Smart Content", "Smart Engagement", "Smart Assessment", and "Smart Physical Environment" to describe and review the technological research progress in smart classrooms. Saini and Goel also present potential challenges and future perspectives and recommendations, summarizing the technological development and applications of smart classrooms in a more comprehensive way. Alfoudari et al. [5], employing the systematic review approach, focus on the social and technological challenges faced by smart classrooms as well as future research directions at the macro level. For a more specific field of research, Wang et al. [6] presented a review of sensor technology in the classroom, focusing on devices and systems that use eye-tracking sensors to monitor student attention in smart classrooms. The advantages, characteristics and limitations of different eye-tracking devices and systems were illustrated in this review, providing a detailed introduction to the current technology of eye-tracking sensor systems. From the perspective of artificial intelligence, Zawacki-Richter et al. [7] summarized the application areas of AI technologies in academic support services, institutional services, and administrative services in higher education. In addition to a general overview of artificial intelligence in smart classrooms, Dimitriadou and Lanitis [3] conducted a comprehensive SWOT analysis of the advantages, disadvantages, opportunities, and threats of applying artificial intelligence in smart classrooms.

The climate factor refers primarily to the suitability of the air, specifically the temperature and humidity of the air and the level of pollutants in the air. The study by Chiou and Tseng [18] proposed a smart classroom management system deployed in a lab classroom environment. In this study, a Wireless Sensor Network (WSN) was created using Zigbee technology to enable the regulation of the physical environment of the classroom (temperature, humidity, lighting, etc.). A field experiment was conducted to verify the effectiveness of the proposed system. The experimental results showed that the system had good accuracy and robustness in a real-time environment. Stazi et al. [8] proposed a smart window opening and closing to improve air quality and thermal comfort in the classroom, using a PT100 thermistor sensor to measure the temperature and a CO_2 sensor to monitor the air quality. The results of a comparative study in two adjacent classrooms showed that this system provided good quality in terms of indoor air quality, thermal comfort and user satisfaction. Twumasi et al. [9] utilized a passive infrared radio sensor to automatically start and turn off the fan in the classroom. When a student enters the classroom, the infrared energy emitted activates the PIR sensor and provides it to the microcontroller, which triggers a relay to "turn on" the fan, and ten minutes later "turn off" the fan when no motion is detected. The fan will only 'turn on' when the room temperature reaches 25 degrees Celsius to 30 degrees Celsius. In the research by Pastor et al. [10], the proposed system allows simultaneous real-time monitoring of multi-dimensional indicators including CO_2, temperature, humidity, and particulate matter in shared public spaces in higher education settings. This system is able to automatically control the corresponding ventilation or air conditioner to regulate the air conditions.

To reduce the risk of infection to students, maintaining a healthy classroom environment during the COVID-19 pandemic is even more necessary. Infrared cameras are employed in [11] to monitor students for fever and can help regulate the temperature of the classroom. In addition, Deepaisarn et al. [12] proposed an end-to-end camera-based human physical distance recording system for indoor environments (especially classrooms). The recording system automatically tracks the location of students and the direction of their movement in the classroom. It also records the movement of students to and from their seats, helping to maintain physical distance between students indoors and reducing the risk of disease transmission.

10.48047/jocaaa.2022.30.02.23

3. Proposed System

The proposed smart classroom occupancy monitoring and automation system as demonstrated in Fig. 1 is based on a Raspberry Pi and IR sensors, designed to track how many people are inside a classroom and control devices like fans and lights accordingly.

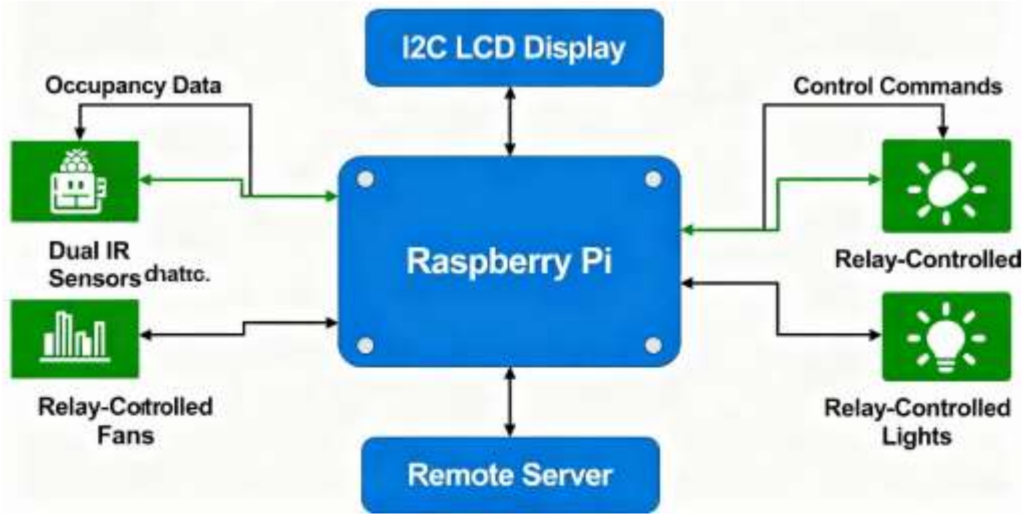

Fig. 1: Proposed architecture of smart classroom occupancy monitoring and automation system.

The detailed overview of proposed system is as follows:

- The Raspberry Pi acts as the central controller, interfacing with two infrared (IR) sensors placed at entry and exit points to count the number of people entering or leaving the classroom.
- Each IR sensor detects interruptions, and the system increases the count on entry and decreases it on exit, with safeguards to prevent counting errors or negative counts.
- The system uses GPIO outputs to control relays connected to fans and lights — turning them ON or OFF based on occupancy thresholds to optimize energy use and comfort.
- A 16x2 I2C LCD display provides real-time feedback showing current occupant count and the ON/OFF status of controlled devices for easy local monitoring.
- Occupancy counts are continuously sent to a remote web server via HTTP POST requests where SQL update queries allow remote storage and further processing or dashboarding.
- The Python program runs in a loop, periodically reading sensor values, updating device states, refreshing the LCD display, and posting data online. It includes handlers to clean up GPIO resources safely on termination.
- This project automates environmental control in classrooms, improving energy efficiency by activating devices only when needed and provides an electronic record of occupancy for admin or research purposes.

This integrated smart system combines sensing, actuator control, local display, and remote data logging to create an efficient and convenient occupancy-aware classroom environment, facilitating better energy management and monitoring.

3.1 Proposed Workflow

The workflow of proposed system details the functional sequence and decision-making process implemented in this. Understanding the workflow explains how sensor inputs are processed to update

10.48047/jocaaa.2022.30.02.23

occupancy counts, control devices, refresh the local display, and communicate data to a remote server continuously and efficiently.

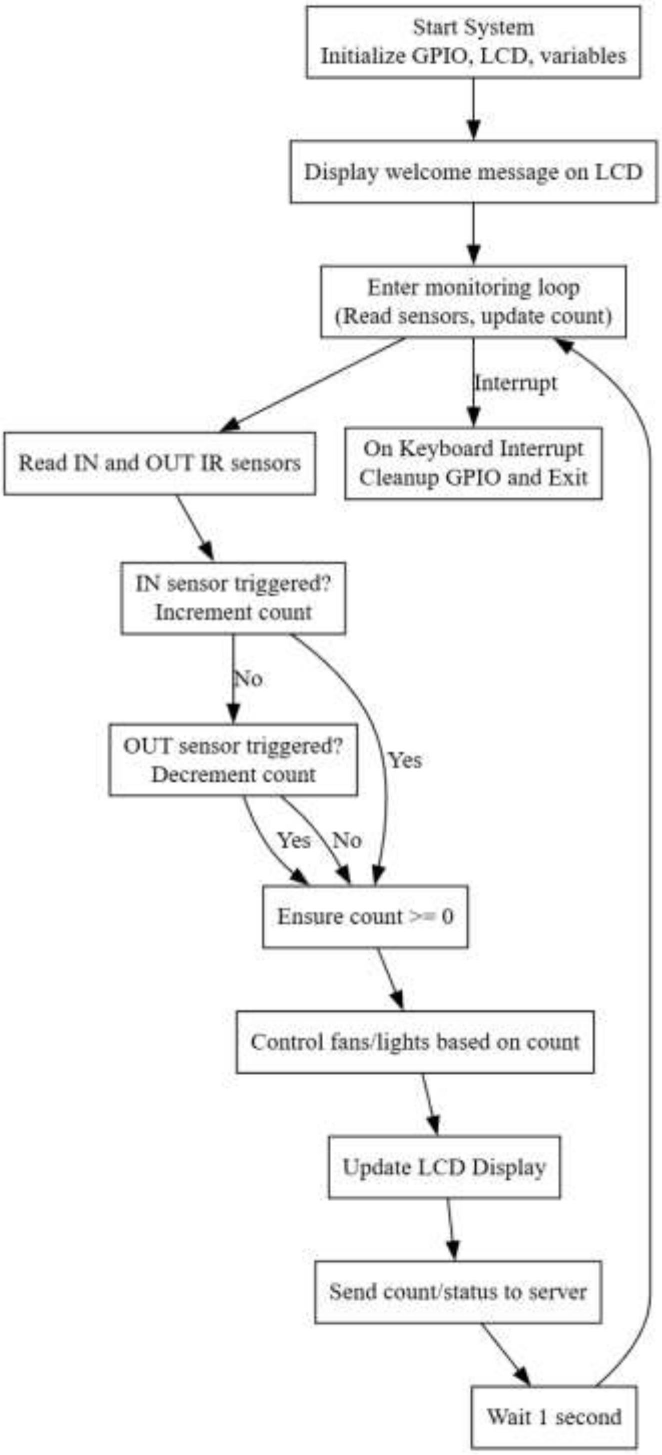

Fig. 2: Proposed workflow diagram.

Workflow:

- Start system and initialize GPIO pins, sensors, relays, LCD, and variables.
- Display the initial welcome message on the LCD.
- Enter an infinite monitoring loop:

10.48047/jocaaa.2022.30.02.23

- Read IR sensors for entry (IN) and exit (OUT) status.
- On detecting an entry, increment the occupancy count once per interruption.
- On detecting an exit, decrement the occupancy count once per interruption, ensuring it never drops below zero.
- Based on the current count, control fans and lights:
  - If count is between 1 and threshold (e.g., 5), turn ON primary devices (L1, F1).
  - If count exceeds or equals threshold, turn ON all devices (L1, L2, F1, F2).
  - If count is zero, turn OFF all devices.
- Update the LCD display to show count and device status.
- Send the updated count and statuses to a remote server via a POST request.
- Repeat with a delay (e.g., 1 second).

- On user interrupt (Ctrl+C), reset all GPIO pins safely and exit.

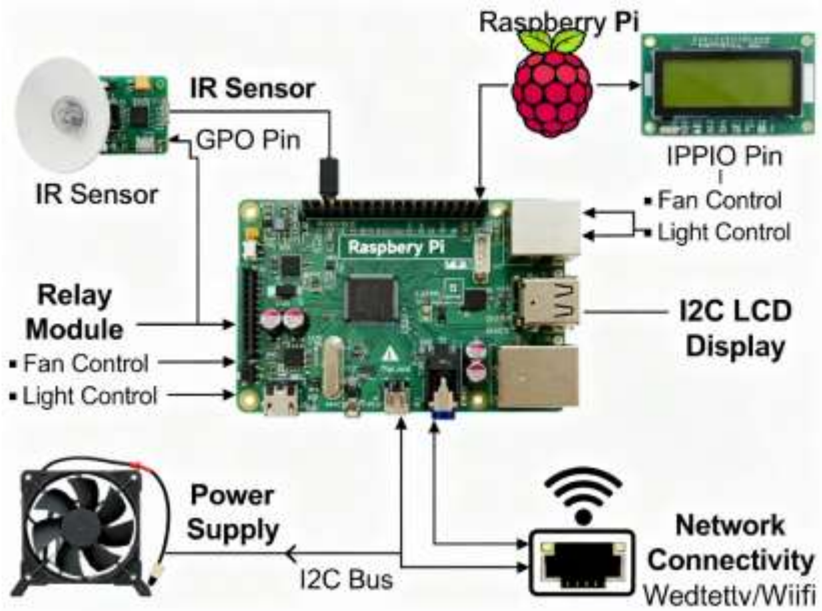

Fig. 3: Hardware integration process of proposed system.

4. Results and Discussion

The results and discussion section presents the performance evaluation and analysis of both software and hardware components of the proposed system. It encompasses how the sensor data processing algorithms accurately detect and count classroom occupants based on IR sensor inputs, ensuring minimal errors through effective flag-based debouncing. The hardware integration comprising the Raspberry Pi, dual IR sensors, relay-controlled appliances, and I2C LCD display is assessed for real-time responsiveness, reliability, and ease of control. The section evaluates the system’s ability to dynamically activate or deactivate fans and lights according to occupancy thresholds, delivering energy-efficient automation without compromising comfort. Additionally, the successful transmission of occupancy data to a remote server for continuous monitoring is discussed, highlighting the system’s potential for centralized management and further data analytics. The observed results validate the integrated design’s effectiveness in automating classroom environmental controls, improving energy conservation, and providing useful real-time feedback. Challenges such as sensor placement sensitivity

10.48047/jocaaa.2022.30.02.23

and network reliability are also addressed to inform future improvements. This comprehensive discussion demonstrates the system's practical viability and the synergistic benefits of combining intuitive software logic with robust hardware implementation for smart classroom environments.

4.1 Hardware Integration Process

The hardware integration process as depicted in Fig. 3 involves assembling and connecting various components to enable sensing, control, display, and communication functions:

1. **Raspberry Pi Setup**: Begin by preparing the Raspberry Pi board with the necessary operating system and software packages for GPIO control, I2C communication, and networking.
2. **Infrared (IR) Sensors**
    - Connect two IR sensor modules to designated GPIO pins on the Raspberry Pi (e.g., pins 20 and 16).
    - These sensors detect entrant and exit movement by sensing when the IR beam is broken.
    - Ensure proper power supply (3.3V/5V) and ground connections.
3. **Relay Modules for Fans and Lights**
    - Interface relay modules with GPIO output pins (such as 26, 19, 13, 6) to switch fans and lights ON/OFF.
    - Connect the relay input pins to Raspberry Pi GPIO output pins; relay output side connects to the appliances' power circuits with appropriate safety.
    - Confirm relay voltage compatibility and isolate Raspberry Pi from high voltages.
4. **I2C LCD Display**
    - Attach the I2C LCD to the Raspberry Pi's I2C bus pins (SDA and SCL) for real-time local display.
    - Ensure the LCD's power and ground connections are correctly made.
    - Enable I2C communication on the Raspberry Pi.
5. **Networking**: Connect the Raspberry Pi to a network (via Ethernet or Wi-Fi) to enable sending occupancy data to a remote server using HTTP requests.
6. **Testing and Calibration**
    - Power the system and verify sensor trigger signals through Raspberry Pi GPIO readings.
    - Test relay activation/deactivation for the fans and lights based on GPIO control commands.
    - Validate LCD display updates correctly.
    - Calibrate sensor placement to ensure accurate occupant counting without false triggers.

4.2 Results description

This section provides a comprehensive visualization of the hardware setup, software interface, automated control, threshold management, dynamic device response, and data reporting integral to the smart classroom occupancy monitoring project. Fig. 4 shows the physical assembly of the core

10.48047/jocaaa.2022.30.02.23

components used in the project. The Raspberry Pi serves as the central controller connected to two infrared (IR) sensors placed at the classroom entrance and exit to detect movement for occupancy counting. Relay modules linked to GPIO pins of the Raspberry Pi control electric devices such as fans and lights by switching them on or off based on occupancy. The I2C LCD displays real-time counts and device statuses for onsite monitoring. Proper wiring of power, ground, and signal pins is depicted, illustrating the hardware integration necessary for the project's functionality. Fig. 5 presents the user interface of the associated Android application that receives and displays occupancy data transmitted from the Raspberry Pi system. It demonstrates how the occupant count increases when a person crosses the entry IR sensor. The app's dynamic counter visually confirms the accurate detection of occupants entering, acting as a remote verification and monitoring tool for system users or administrators. Fig. 6 illustrates the automated control of classroom appliances within the Android application. As real-time occupancy count changes, corresponding fans and lights are activated or deactivated by the system. For instance, a low occupancy count might enable just one fan and light, while higher occupancy triggers additional device operations. This depicts effective energy management through intelligent automation tied to the counting logic.

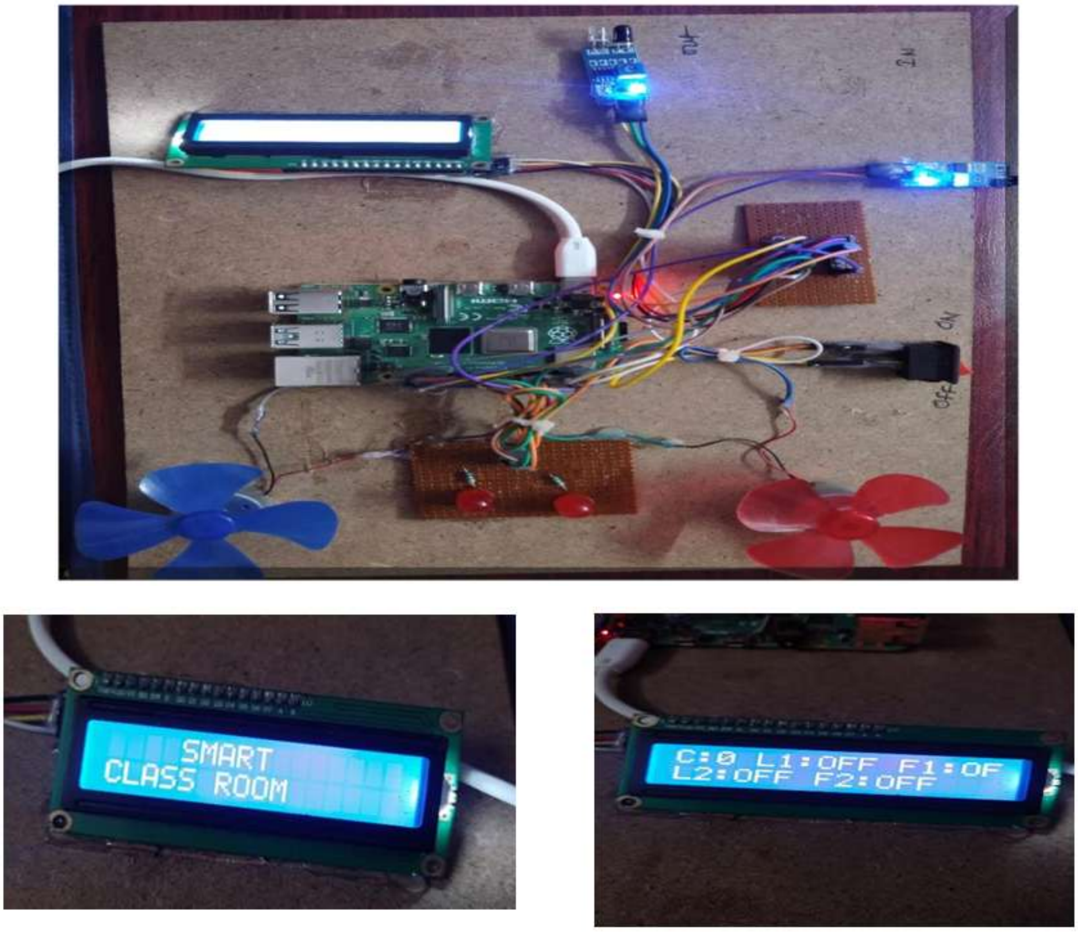

Fig. 4: Initial hardware setup of proposed system.

10.48047/jocaaa.2022.30.02.23

Fig. 5: Increment of the count in android application.

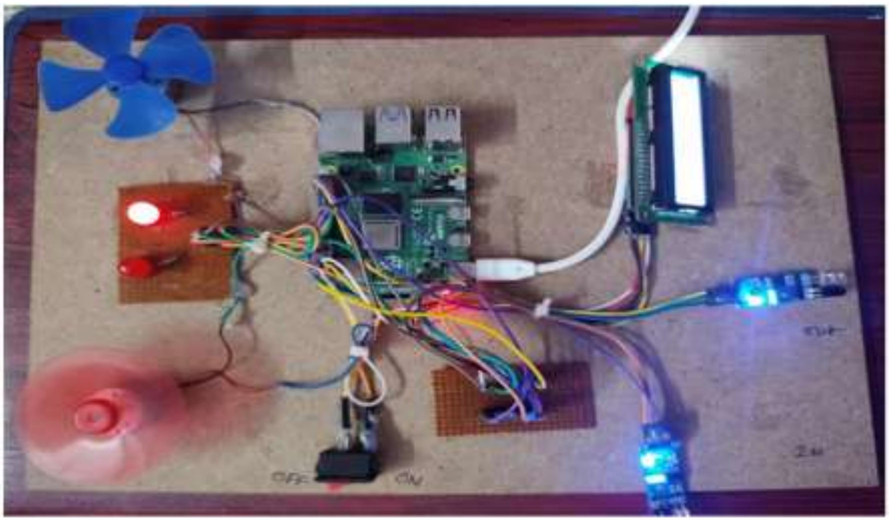

Fig. 6: Controlling of electric devices based on the count.

Fig. 7: The count value reached to 5.

10.48047/jocaaa.2022.30.02.23

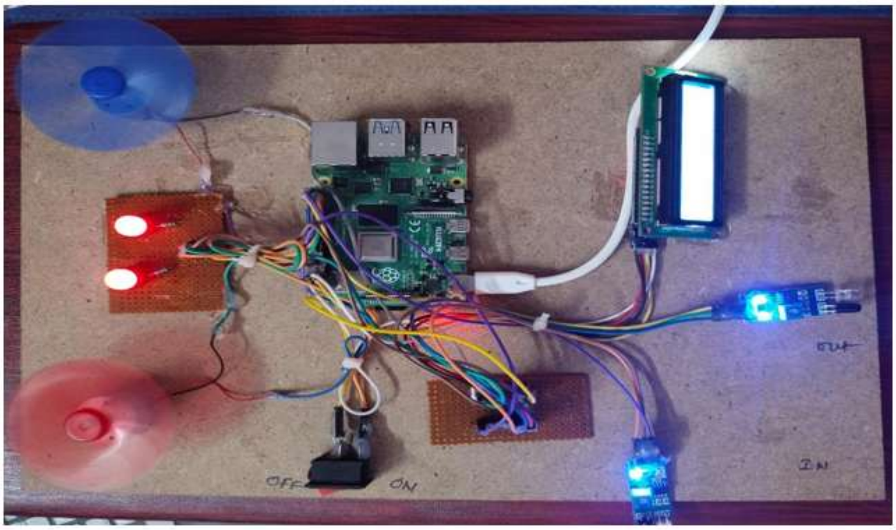

Fig. 8: As the count in the classroom increased the working of electric devices are also increased.

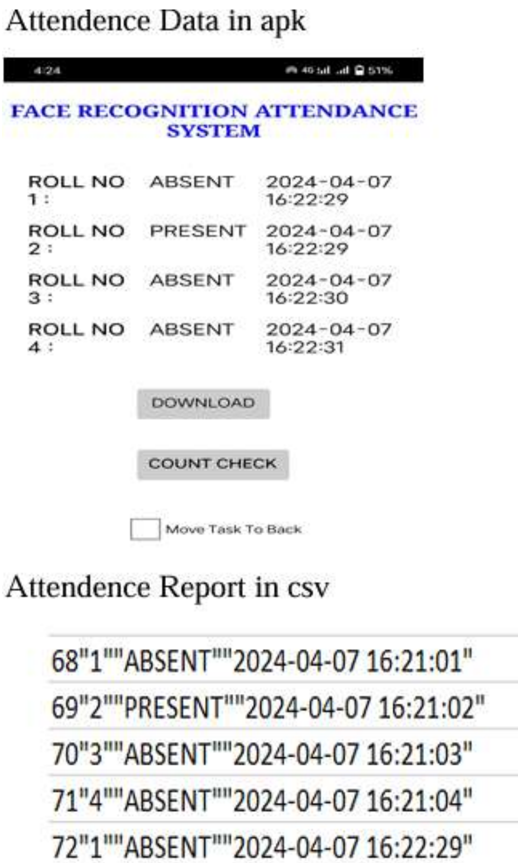

Fig. 9: Attendance report in android application and downloaded csv file.

Fig. 7 shows the Android app when the occupant count reaches a critical threshold (e.g., 5). Reaching this number triggers the system to turn ON all connected electric devices such as multiple fans and lights to ensure adequate ventilation and lighting for comfort. It validates threshold-based automated device control integrated into the entire monitoring setup. Fig. 8 demonstrates the proportional relationship between occupant count and device operation. As more people enter, the system responds by incrementally activating additional fans and lights, ensuring the classroom environment remains comfortable without wasting energy. The figure highlights the scalability and responsiveness of the system in managing multiple devices dynamically. Fig. 9 displays the administrative side of the system

10.48047/jocaaa.2022.30.02.23

showing attendance records in the Android app. It includes occupant count logs and timestamps, which can be downloaded as a CSV file for offline analysis or record-keeping. This feature extends the system's use beyond immediate control to provide valuable data for attendance tracking, security auditing, or facility utilization analysis.

5. Conclusion

The project successfully demonstrates an effective smart classroom occupancy monitoring and automation system using affordable hardware and straightforward programming. It achieves accurate occupant counting, real-time appliance control, local display feedback, and remote data management in a cohesive manner. This solution can significantly improve energy efficiency and operational convenience in educational facilities. By automating device control based on actual occupancy, it reduces unnecessary power consumption and enhances user comfort without manual intervention. The design and implementation can be expanded with additional sensors and communication features to further improve smart classroom capabilities and integration with IoT infrastructure. This system represents a practical step towards intelligent, sensor-driven classroom environments that promote sustainability and efficient resource usage.

REFERENCES

[1] Roberts, J. From know-how to show-how? Questioning the role of information and communication technologies in knowledge transfer. *Technol. Anal. Strateg. Manag.* 2000, *12*, 429–443.

[2] Saini, M.K.; Goel, N. How Smart Are Smart Classrooms? A Review of Smart Classroom Technologies. *ACM Comput. Surv.* 2020, *52*, 28.

[3] Dimitriadou, E.; Lanitis, A. A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms. *Smart Learn. Environ.* 2023, *10*, 12.

[4] Spikol, D.; Ruffaldi, E.; Dabisias, G.; Cukurova, M. Supervised machine learning in multimodal learning analytics for estimating success in project-based learning. *J. Comput. Assist. Learn.* 2018, *34*, 366–377.

[5] Alfoudari, A.M.; Durugbo, C.M.; Aldhmour, F.M. Understanding socio-technological challenges of smart classrooms using a systematic review. *Comput. Educ.* 2021, *173*, 20.

[6] Wang, Y.H.; Lu, S.L.; Harter, D. Multi-Sensor Eye-Tracking Systems and Tools for Capturing Student Attention and Understanding Engagement in Learning: A Review. *IEEE Sens. J.* 2021, *21*, 22402–22413.

[7] Zawacki-Richter, O.; Marin, V.I.; Bond, M.; Gouverneur, F. Systematic review of research on artificial intelligence applications in higher education—Where are the educators? *Int. J. Educ. Technol. High. Educ.* 2019, *16*, 39.

[8] Stazi, F.; Naspi, F.; Ulpiani, G.; Di Perna, C. Indoor air quality and thermal comfort optimization in classrooms developing an automatic system for windows opening and closing. *Energy Build.* **2017**, *139*, 732–746.

[9] Twumasi, C.; Dotche, K.A.; Banuenumah, W.; Sekyere, F. Energy Saving System using a PIR Sensor for Classroom Monitoring. In Proceedings of the IEEE PES-IAS PowerAfrica Conference, Accra, Ghana, 27–30 June 2017; pp. 347–351.

[10] Pastor, F.J.F.; Horcajadas, M.P.; Davo, J.A.L.; Iglesias, V.G. Developing Environmental Adaptative Comfort Using Internet of Things and Business Process Management: Application in a University Building. In Proceedings of the International Conference on Ubiquitous Computing & Ambient Intelligence (UCAmI), Cordoba, Spain, 29 November–2 December 2022; pp. 535–546.

10.48047/jocaaa.2022.30.02.23

[11] Alkhayat, A.H.; Bagheri, N.; Ayub, M.N.; Noor, N.F.M. Fever Detection & Classroom Temperature Adjustment Using Infrared Cameras. In Proceedings of the IEEE International Conference on Consumer Electronics—Taiwan (ICCE-TW 2015), Taipei, Taiwan, 6–8 June 2015; pp. 240–241.

[12] Deepaisarn, S.; Angkoonsawaengsuk, A.; Arunkit, C.; Srisumarnk, C.; Nimmanwatthana, K.; Linphrachaya, N.; Chiewnawintawat, N.; Tanthanathewin, R.; Seinglek, S.; Buaruk, S.; et al. Camera-Based Log System for Human Physical Distance Tracking in Classroom. In Proceedings of the 14th Annual Summit and Conference of the Asia-Pacific-Signal-and-Information-Processing-Association (APSIPA ASC), Chiang Mai, Thailand, 7–10 November 2022; pp. 1977–1983.