A Review on Bidirectional Visitor Counting Systems for Smart Energy Management

Miss .Durga Eknathrao Kadam, Mr. Ganesh Harinam Kadam, Mr. Pramit Prashant Kharjule, Mr. Sayed Shoaib Anwar

Department of Electronics & Telecommunication Engineering
MGM's College of Engineering, Nanded
s23_kadam_durga@mgmcen.ac.in, s23_kadam_ganesh@mgmcen.ac.in,
s23_kharjule_pramit@mgmcen.ac.in, sayed_shoaib_@mgmcen.ac.in

***Abstract*—Modern buildings use a growing share of global electrical energy because of rapid urbanization, higher occupancy, and steady demand for comfort-based appliances like lighting, air-conditioning, and ventilation. Studies consistently show that 25 to 45% of a building's energy consumption is wasted due to human negligence or inefficient manual control of appliances. Therefore, occupancy-based automatic control systems are becoming essential for managing energy in smart buildings. Among these systems, bidirectional visitor counting technology is key. It accurately detects when people enter and exit, keeping a real-time count of occupants in a space. This review paper provides a detailed study of bidirectional visitor counting systems, covering their technological foundations, operational methods, sensing principles, hardware, software algorithms, and performance features. It evaluates a range of technologies, including infrared (IR) beam interruption sensors, ultrasonic distance sensors, passive infrared (PIR) motion sensors, thermal imaging, radio frequency identification (RFID), camera-based systems, artificial intelligence (AI)-based computer vision, LiDAR sensors, and IoT-based hybrid systems. The paper also discusses design challenges such as environmental interference, difficulties in detecting multiple people, line-of-sight issues, multi-door synchronization, privacy concerns, and computing demands.**

***Index Terms*—Visitor counter, bidirectional counting, IR beam interruption, ultrasonic sensors, computer vision, AI-based people counting, smart building energy management, IoT automation, occupancy detection, sensor fusion, predictive analytics.**

I. Introduction

I notice the demand for energy building systems has gone up a lot because electricity costs are rising, infrastructure is expanding and people worry about the environment worldwide. Buildings today use a share of the electricity produced worldwide. The share of electricity used by buildings keeps growing as cities expand and technology is used more. Research from energy bodies shows that lighting, fans, computers, HVAC units and other electrical appliances are responsible for a part of the energy used inside buildings. Energy is wasted when appliances stay on after the room is empty. Human negligence causes energy waste. Unpredictable behavior causes energy waste. The absence of automated control mechanisms causes energy waste.

To solve the problem intelligent occupancy monitoring is now a part of automation systems. In my work I have seen visitor counting systems used to track the number of people inside a room or any enclosed space. Simple motion detectors only sense movement but bidirectional visitor counters keep a count of people by detecting both entry and exit events. Because bidirectional visitor counters know when the first person enters bidirectional visitor counters can turn appliances on. When the last person leaves bidirectional visitor counters turn appliances off automatically. I have seen automation remove the need for a person to step in to cut energy waste and improve the building's efficiency. The growing need for infrastructure also raises interest in occupancy systems. Advanced occupancy systems integrate sensors, machine learning models, IoT platforms and cloud‑based analytics. Cloud‑based analytics give insights into space utilization.

Bidirectional visitor counters form the foundation of these systems by providing the most critical variable: the number of people present in a room at any given time. Their widespread applicability in homes, offices, schools, laboratories, malls, hospitals, libraries, and public facilities makes them a versatile solution for energy conservation. This review paper offers an in-depth discussion of various technologies used in bidirectional counting, their working mechanisms, and the challenges and opportunities associated with implementing them in real-world environments.opinion mining, examines the opinions, sentiments, attitudes, and emotions conveyed in text' As big data grows and artificial intelligence advances, machine learning has become a key technology for automating sentiment analysis. Unlike traditional rule-based or lexicon-based methods, machine learning algorithms can learn intricate language patterns and subtle contextual hints from data, improving accuracy and scalability. The ability to assess social media sentiment in real time is particularly advantageous for marketing, politics, disaster response, and mental health monitoring. This paper reviews the recent progress of machine learning techniques in sentiment analysis of social media data.

II. LITERATURE REVIEW

Earlier studies on visitor counting mainly focused on using infrared sensors. Sharma and Kulkarni (2018) in "Infrared Based Bidirectional Visitor Counter" showed that dual IR beams can detect entry and exit but have accuracy problems under strong light. Patel and Deshmukh (2019) in "Microcontroller-Based Occupancy Counter for Classroom Automation" demonstrated that IR-based systems can effectively reduce electricity waste.

Other researchers looked for better alternatives. Gupta et al. (2020) found in "Ultrasonic Sensors for Indoor Movement Tracking" that ultrasonic modules perform better in changing light conditions but struggle with echo noise. Rahman and Joseph (2021) in "PIR Motion Detection for Smart Buildings" highlighted that PIR sensors detect motion well but cannot identify direction or count people.

Current issues like sarcasm detection, code-mixing, and data bias continue to be important research topics, but recent studies show the increasing use of hybrid and multimodal models that integrate textual, visual, and audio data to improve sentiment detection.

More modern methods used cameras and AI. Mehta anSahu (2020) in "Deep Learning Based People Counting Using YOLO" achieved high accuracy in crowded areas but noted privacy and processing challenges. Recent research by Kaur and Bhattacharya (2022) in "IoT Enabled Multi-Sensor Occupancy Monitoring" shows that combining IR, PIR, and ultrasonic sensors with IoT platforms boosts overall accuracy and reliability. These studies show a trend toward hybrid and smart occupancy systems for managing energy efficiently.Forest (RF) increased classification accuracy (Rifa'i et al., 2023). More accurate sentiment classification is now possible thanks to deep learning advancements that have allowed models such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) to capture semantic and sequential dependencies in text. By offering contextual embeddings that perform better than previous models, transformer architectures—specifically BERT and its variations, RoBERTa and DistilBERT—revolutionized the field (Vaswani et al., 2017; Gunasekaran, 2023).

Automation" demonstrated that IR-based systems can effectively reduce electricity waste.

III. Need for Automated Visitor Counting in Energy Management

The growing focus on sustainable energy use has shown the need for automated systems that reduce dependence on human action. Manual switching is not reliable because people often forget to turn off lights, fans, or air conditioners when leaving a room. This oversight leads to unnecessary energy waste, especially in places like classrooms, laboratories, shopping malls, hotels, and offices, where people are constantly moving in and out. For example, in schools, equipment frequently stays on between classes or during long breaks, causing significant energy loss. Similar issues occur in offices where meeting rooms and workspaces are used irregularly and left on even when empty.

Occupancy-based control systems help solve this problem by allowing appliances to run only when people are present. A bidirectional visitor counter offers a smart way to monitor occupancy by keeping an accurate count of individuals entering and exiting a room. When connected to relay modules, microcontrollers, or smart IoT switches, this system can automatically turn appliances on when someone enters and switch them off only after the last person leaves. This approach ensures efficient operation without sacrificing user comfort. Additionally, the occupancy data gathered from visitor counters can help facility managers spot trends, identify peak usage times, optimize room schedules, and plan future needs based on actual use. Thus, bidirectional visitor counting is crucial for saving energy and forms the foundation for data-driven smart building management.

IV. Technologies Used in Bidirectional Visitor Counting

Different technologies have been developed and improved over time to implement visitor counting systems, each relying on different sensing principles and hardware setups. One of the most common methods is the infrared (IR) beam interruption. In this method, a transmitter sends out an infrared beam that is detected by a photodiode or phototransistor placed directly across from it. When someone crosses the beam, the signal to the sensor changes. This change allows the system to detect movement. In bidirectional counters, two IR pairs are set up in sequence at the entrance. If the outer sensor is interrupted first, the system registers the movement as entry; if the inner one is interrupted first, it counts as an exit. This simple yet effective method makes IR systems popular due to their low cost, quick response, and easy integration with microcontrollers like Arduino. However, IR systems can be affected by environmental factors such as sunlight, reflective surfaces, dust, and multiple people moving at once, which can lead to inaccurate counts.

Ultrasonic sensors operate on a different principle based on the time it takes for sound waves to travel. These sensors emit ultrasonic pulses that bounce off obstacles. By measuring how long it takes for the echo to return, the system can tell if something is moving toward or away from the sensor. Ultrasonic sensors perform well in bright environments, but they have drawbacks, such as reflections from walls, challenges with detecting multiple people moving at once, and inaccurate readings caused by air currents from fans or air conditioners.

Another common technology for detecting presence is the passive infrared (PIR) sensor, which reacts to changes in the infrared radiation emitted by human bodies. PIR sensors are cheap and widely used in simple automation systems, like corridor lights or public restroom detection. However, they cannot distinguish between individuals entering or exiting and do not keep a count, making them unsuitable for accurate visitor counting.

Advancements in computing have led to more advanced solutions like camera-based counting using computer vision. Deep learning algorithms, including convolutional neural networks (CNNs), optical flow methods, and modern object detection systems like YOLO and MobileNet, can accurately identify and track individuals, even in crowded spaces. These systems can handle multiple-person tracking, create heat maps, and analyze dwell time. Despite their high accuracy, camera systems need powerful processors, stable lighting, specific installation angles, and raise privacy issues, especially in sensitive areas.

Thermal imaging sensors offer another effective method by detecting the heat signatures emitted by humans. These sensors work well in low light or darkness, making them suitable for places like museums, hospitals, and nighttime public installations. However, they can be costly and may struggle to differentiate between heat sources at similar temperatures.
Each of these technologies has its own advantages and limitations. The choice of technology largely depends on the environment, budget, accuracy needs, and the anticipated density of human movement.

Table 1. comparison of technologies

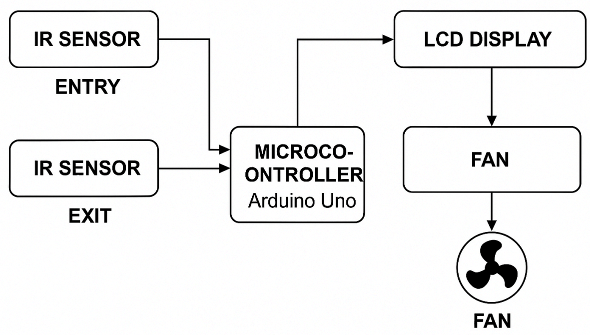
Technology	**Accuracy**	**Cost**	**Multi-Person Detection**	**Privacy Concern**	**Best Use Case**
IR Sensors	70–85%	Very Low	No	No	Small rooms, labs
Ultrasonic	80–90%	Low	Partial	No	Offices, corridors
PIR	40–60%	Very Low	No	No	Simple automation
AI Cameras	95–99%	High	Yes	High	Large buildings, malls
Thermal Imaging	85–95%	High	Yes	Low	Museums, hospitals
6RFID Tags	98–100%	Medium	Yes	Medium	Offices, labs

The above table shows the comparison between the technologies used for this project .this comparison includes various parameters such as cost efficiency accuracy etc.

Fig. 1. Prototype model of the Bidirectional Visitor Counting System showing entry and exit doors with LCD display

V. WORKING PRINCIPLE

The bidirectional visitor counting system detects human movement through two sensors at a room's entrance. When someone walks through the doorway, the first sensor activates, followed by the second, marking an entry. If the order is reversed, the system registers the movement as an exit. The microcontroller processes these signals and updates the occupancy count. Each time the count goes from zero to one, the controller turns on connected devices like lights or fans. When the count drops back to zero, the system recognizes that the room is empty and automatically turns off the electrical load. This setup ensures that devices only run when people are present, which helps lower unnecessary power use. The working principle can differ based on the sensing technology. For instance, IR sensors function by interrupting beams, ultrasonic sensors notice changes in distance by reflecting sound waves, PIR sensors detect the infrared radiation from human bodies, and camera a-based systems follow human shapes using image-processing methods. No matter the sensing approach, the main idea stays the same: detect entry, detect exit, update the count, and use that count to manage power-hungry devices.



VI. METHODOLOGY

The method for designing the bidirectional visitor counting system starts with selecting and installing sensors at the room entrance. The sensors must be aligned properly to ensure reliable detection of beam interruptions. After installation, the microcontroller is programmed to read and interpret the sensor outputs continuously using time-based logic. The system uses software algorithms to tell the difference between entry and exit events by comparing which sensor triggers first. During operation, the algorithm updates the occupancy count and makes sure it does not go below zero, even if false triggers happen. The updated count is shown on the LCD for user reference. The control logic then checks if the room is occupied. If the count is above zero, the system automatically turns on the electrical appliances connected to the relay module. If the count returns to zero, the system waits for a brief delay to prevent flickering from quick movements, and then it disconnects the load to avoid wasting energy. The method also includes periodic sensor calibration. This ensures stable detection under different environmental conditions and keeps the system reliable through noise filtering, signal debouncing, and error-handling routines. This is structured.

VII. Applications of Bidirectional Visitor Counting Systems

Bidirectional visitor counters have a wide range of uses across different sectors. In commercial buildings, they allow for smart control of lighting and HVAC in meeting rooms, conference halls, workspaces, and recreation areas. By turning on appliances only when a space is in use, companies can greatly lower their electricity bills. Monitoring is not allowed. For RFID-based systems, needing tags makes the technology unsuitable for open public areas. visitor counting systems. Waiting rooms, outpatient departments, and diagnostic centers often see varying levels of foot traffic throughout the day. Automated occupancy monitoring makes sure that lights and ventilation systems work efficiently while keeping patients and visitors comfortable. Hotels and hospitality venues can use visitor counters to manage banquet halls, dining areas, and conference rooms more effectively, adjusting conditions based on current occupancy.

In retail spaces like malls and shopping centers, visitor counters not only help with energy management but also offer valuable insights into customer habits, peak visiting times, and staff scheduling. Residential buildings can use visitor counting systems for smart home automation, allowing automatic control of lights, fans, and air conditioners in living rooms, studies, and bedrooms. This technology is also beneficial in public buildings, museums, and government facilities, where efficient space management and energy savings are important.
work efficiently while keeping patients and visitors comfortable. Hotels and hospitality venues can use visitor counters to manage banquet halls, dining areas, and conference rooms more effectively, adjusting conditions based on current occupancy.

Hospitals and healthcare facilities also gain a lot from visitor counting systems. Waiting rooms, outpatient departments, and diagnostic centers often see varying levels of foot traffic throughout the day. Automated occupancy monitoring makes sure that lights and ventilation systems work efficiently while keeping patients and visitors comfortable. Hotels and hospitality venues can use visitor counters to manage banquet halls, dining areas, and conference rooms more effectively, adjusting conditions based on current occupancy.

. One major challenge is detecting multiple individuals moving at the same time or close to each other. Infrared systems, in particular, can record incorrect sequences when two or more people cross the sensors almost simultaneously, leading to errors in the count. Environmental conditions add another significant difficulty. IR sensors may fail in bright sunlight, in dusty areas, or when placed near reflective surfaces like glass or polished floors. Ultrasonic sensors sometimes produce false readings due to airflow disturbances or reflections from walls and narrow corridors.

Installation-related challenges also affect system accuracy. Even slight misalignment of the IR transmitter and receiver can disrupt beam detection. PIR sensors do not capture stationary individuals and cannot tell direction. Camera-based systems need stable lighting, proper positioning, and high computing power, making them unsuitable for low-budget setups. They also raise privacy concerns, especially in places like restrooms or changing rooms where video.
Multi-door environments create another challenge because combining occupancy data from multiple entrances needs complex synchronization algorithms. A person may enter through one door and exit through another, causing inconsistencies if both entrances are not monitored accurately. This requires centralized processing and communication between sensor nodes, often needing advanced microcontrollers, IoT connectivity, and strong algorithms. Finally, maintenance issues such as dust buildup, physical wear, or power fluctuations can affect sensor accuracy and system reliability.

VIII. Recent Research Trends in People Counting and Energy Management

Recent research has focused on improving the precision, trustworthiness, and intelligence of visitor counting systems. Multi-sensor fusion is a growing approach that combines various sensing technologies to offset each other's weaknesses. For instance, IR sensors can be paired with ultrasonic sensors to reduce false positives. At the same time, PIR sensors can be combined with camera modules to create a mixed detection system. Advances in machine learning have also played a big role in developing predictive models that can forecast occupancy based on past data. These systems help buildings adjust their HVAC and lighting settings before occupants arrive, improving energy efficiency and comfort.

As the Internet of Things continues to grow, cloud-based occupancy management is becoming more common. Sensors connected through Wi-Fi, LoRaWAN, or Zigbee send real-time data to cloud platforms, where analytics and visualization tools provide insights into building usage patterns. Edge computing devices like the ESP32-CAM or Raspberry Pi now enable image processing directly on the device without sending data to external servers, reducing delays and improving privacy.

Computer vision has made impressive strides thanks to deep learning architectures, allowing for accurate detection even in crowded situations. Modern systems can create heat maps, density estimates, and track the movements of multiple individuals in real time. Research has also looked into using LiDAR sensors for highly accurate occupancy detection, particularly in industrial or high-traffic areas. These technologies represent the next generation of smart building monitoring systems that do more than just count people; they enhance overall building automation.

IX. Future Scope of Visitor Counting Technologies

The future of bidirectional visitor counting involves integrating artificial intelligence, smart sensor technologies, and renewable energy sources. Upcoming systems may feature self-calibrating mechanisms that automatically adjust sensor alignment and sensitivity to maintain accuracy over time. Machine learning models can analyze human movement patterns, improving direction detection and minimizing counting errors in crowded areas. Predictive occupancy algorithms will help buildings forecast usage and manage cooling or lighting systems proactively.

There is also growing interest in developing self-powered visitor counting systems that use solar cells or energy harvesting technologies. This approach reduces reliance on external power sources and enhances sustainability. Future smart buildings will likely adopt centralized monitoring platforms that integrate data from various sensors, including visitor counters, temperature sensors, CO_2 sensors, and humidity sensors, to create an intelligent environmental control system. As smart city initiatives expand worldwide, visitor counting technology can be integrated into urban monitoring systems for public transportation hubs, government buildings, parks, and other public spaces.

X. Conclusion

Bidirectional visitor counting systems have become an important part of modern smart building automation because they can track occupancy and optimize energy use. These systems cut down on power waste, improve user convenience, and boost the operational efficiency of homes, businesses, and institutions. The wide range of sensing technologies available, from infrared beam interruption to AI-powered vision models, allows for flexible use in different settings and budgets. However, challenges like environmental interference, multi-door synchronization, privacy concerns, and multi-person occlusion still exist. Ongoing research and technological progress are expected to tackle these issues. Future advancements involving sensor fusion, IoT integration, machine learning, and predictive analytics will change visitor counters into smart systems that can support fully automated, energy-efficient, and sustainable building infrastructures.

References

[1] J. Kumar and A. Sharma, “Design of infrared based bidirectional visitor counter,” International Journal of Advanced Research in Electronics and Communication Engineering, vol. 6, no. 4, pp. 412–416, 2017.

[2] N. Patel and S. Deshmukh, “Microcontroller-based occupancy counter for energy-efficient classrooms,” International Journal of Engineering Research, vol. 8, pp. 101–105, 2019.

[3] V. Gupta, R. Singh, and M. Tiwari, “Ultrasonic sensor based human detection and tracking system,” Sensors and Actuators A: Physical, vol. 305, pp. 111920, Elsevier, 2020.

[4] A. Rahman and D. Joseph, “PIR motion detection system for smart building automation,” IEEE Sensors Journal, vol. 21, no. 9, pp. 11245–11252, 2021.

[5] P. Mehta and R. Sahu, "People counting using YOLO and convolutional neural networks," IEEE Access, vol. 8, pp. 108200–108210, 2020.

[6] C. Lin and H. Wu, "Thermal imaging based occupancy detection under low-light environments," Infrared Physics & Technology, vol. 112, pp. 103590, 2021.

[7] G. Kaur and P. Bhattacharya, "IoT enabled multi-sensor fusion model for occupancy monitoring," International Journal of Computer Applications, vol. 183, no. 25, pp. 15–22, 2022.

[8] R. Singh, A. Verma, and K. Nanda, "Predictive occupancy analytics for smart building energy optimization," Energy and Buildings, Elsevier, vol. 256, pp. 111767, 2023.

[9] U. Satapathy, A. Panda, and M. Routray, "Design and implementation of Arduino-based visitor counter," International Journal of Electronics and Communication Technology, vol. 10, no. 1, pp. 58–63, 2019.

[10] S. Yadav and R. Chauhan, "Smart energy management using IoT: A survey," IEEE Internet of Things Journal, vol. 6, no. 5, pp. 8094–8105, 2019.