JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

PREDICTIVE CROWD MANAGEMENT SYSTEM

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Abstract **-** Effective crowd regulation is essential in indoor environments to maintain safety, ensure comfort, and prevent congestion. Conventional monitoring methods depend heavily on human supervision, which can be unreliable and inefficient during high-traffic periods. This project introduces a smart and affordable Predictive Crowd Management System built around the ESP32-CAM module. The system performs automatic entry counting using camera-based motion detection, while an IR sensor positioned at the exit accurately records outgoing individuals. The live occupancy count is continuously updated and shown on an I2C LCD display. A predefined maximum capacity is programmed into the controller, and when this limit is exceeded, the system triggers a warning through an LED and buzzer, while a servo motor automatically closes the entry gate to prevent additional inflow. In addition, the ESP32-CAM hosts a web interface that provides real-time video streaming and status updates, enabling remote observation.
Compact, low-cost, and easy to install, the system is suitable for applications in schools, retail stores, offices, libraries, and public event venues

IndexTerms: **ESP32-CAM, Crowd Management, IoT Monitoring, Human Detection, Automated Gate Control.**

1. INTRODUCTION

Managing the movement of people within indoor areas is crucial for maintaining safety, comfort and efficient use of available space. Places such as classrooms, retail outlets, auditoriums and offices often experience fluctuating crowd levels, and excessive occupancy can create safety risks and disrupt normal operations. Although many facilities already use CCTV systems, these setups only provide video surveillance and do not support automated crowd control or real-time decision-making.

With the growing capabilities of IoT (Internet of Things) devices, it has become possible to automate monitoring processes and reduce the dependence on manual supervision. The ESP32-CAM, a compact microcontroller equipped with a camera, Wi-Fi connectivity and onboard processing, offers a low-cost platform for implementing such intelligent systems.
This project focuses on developing an automated crowd management solution that tracks the number of people entering and leaving a space. The ESP32-CAM captures and analyses entry movement, while a reliable IR sensor placed at the exit counts outgoing individuals. The live occupancy is shown on an LCD display as well as on a web dashboard accessible over Wi-Fi.

When the number of occupants crosses the safe limit, the system instantly issues an alert and automatically restricts additional entry by operating a servo-controlled gate. By integrating sensing, automation and remote monitoring, the system reduces human effort and enhances the accuracy and efficiency of crowd control in real time.

2.RESEARCH OBJECTIVES

The objective of this project is to develop an intelligent crowd management system that can automatically track the number of people entering and leaving a room, show the live count on an LCD display, and manage access using a servo-controlled door. The system also aims to enhance safety by turning on an LED and buzzer when the preset occupancy limit is crossed. Overall, the goal is to create a fully automated and user-friendly solution that minimizes human supervision and ensures smooth and safe movement of

people within the monitored area. To create a portable, reliable and easy-to-deploy crowd management solution for classrooms, offices and public spaces. To evaluate the system's performance in real-time conditions and ensure stable operation during continuous monitoring.

2.1 Operational Modes

1.Entry Detection
In this mode, the ESP32-CAM monitors the entrance and increases the count whenever a person enters.
2. Exit Detection
The IR sensor installed at the exit detects outgoing individuals and reduces the count accordingly.
3. Normal Operation
When occupancy is within the safe limit, the LCD displays live count, the servo keeps the door open, and all alerts remain off.
4. Limit Reached
If the number of people exceeds the preset limit, the system activates the buzzer and LED, displays a warning message on the LCD, and closes the door using the servo motor.
5. Web Monitoring
The ESP32-CAM streams live video and displays the real-time count on a webpage, allowing remote monitoring through an IP address

3.SYSTEM ARCHITECTURE AND METHODOLOGY

The implemented system employs a modular architecture comprising sensing, processing, communication, and actuation components. This hierarchical design ensures robust operation while maintaining flexibility for future enhancements and modifications.

3.1 Hardware Configuration

The major components used in the system are listed below:

Component	Description
ESP32-CAM	Serves as the main controller; captures video, performs motion-based entry detection and hosts the web interface
IR Sensor	Detects entry and exit events by sensing beam interruptions and provides accurate decrement signals.
SG90 Servo Motor	Operates the entry gate by opening or closing it based on occupancy status.
16×2 I2C LCD	Displays real-time information such as current count and system status.
Buzzer	Emits an audible alert during over-capacity conditions.
ESP32-CAM MB	Used for uploading code and providing regulated power to the ESP32-CAM module.
5V Power Supply	Ensures reliable and stable power for all connected components.

3.2 Operational Principles

- Entrance Detection Using ESP32-CAM
  At the entrance, the ESP32-CAM continuously captures video frames and analyzes them using a basic motion-based detection method. When movement crosses a predefined virtual line, the system identifies it as an entry event and increments the crowd count.
  In addition to counting, the camera provides a live video stream on the webpage so the operator can monitor real-time activity
- Exit Detection Using IR Sensor
  A reflective IR sensor is installed at the exit point.

When a person passes through and breaks the IR beam, the sensor generates a digital pulse. This signal is used by the controller to reduce the count.
Using an IR sensor for exits avoids false triggers that might occur with camera detection, such as hand gestures or partial body visibility.

- Real-Time Count Display

The current occupancy and system status are displayed on the LCD module.
Example: Count: 12
Status: Normal
If the predefined limit is crossed, the display changes automatically:
Count: 30
Status: LIMIT REACHED

- Automatic Gate Control

A servo motor is used to control the entry gate. It operates at two key positions:
0° – Gate Open: Visitors are allowed to enter.
90° – Gate Closed: Entry is restricted.
This mechanism offers semi-automated crowd regulation by physically blocking entry when capacity is reached.

- Alert System
  - Upon reaching the maximum allowed limit:
  - The LED remains ON as a visual alert.
  - The buzzer emits a continuous sound until the count falls below the limit.
  - The LCD shows a warning message indicating that the threshold has been exceeded.
  - The webpage also updates the alert status, allowing remote supervision.

- Webpage Monitoring

The system hosts a webpage that continuously updates the live count, status, alerts, and camera feed.
This allows monitoring from a distance, reducing the need for operators to be physically present near the device.

3.3 Software Implementation

The software for this system is developed using the Arduino IDE. The program initializes the ESP32-CAM for live video streaming, reads entry and exit signals, and updates the people count in real time. The LCD is controlled through I2C commands to display the current occupancy, while the servo motor, LED and buzzer are triggered based on the preset limit. The code also runs a built-in web server, allowing users to view the live camera feed and count through the device's IP address. Overall, the software ensures smooth coordination between sensors, camera, alerts and door control.

BLOCK DIAGRAM

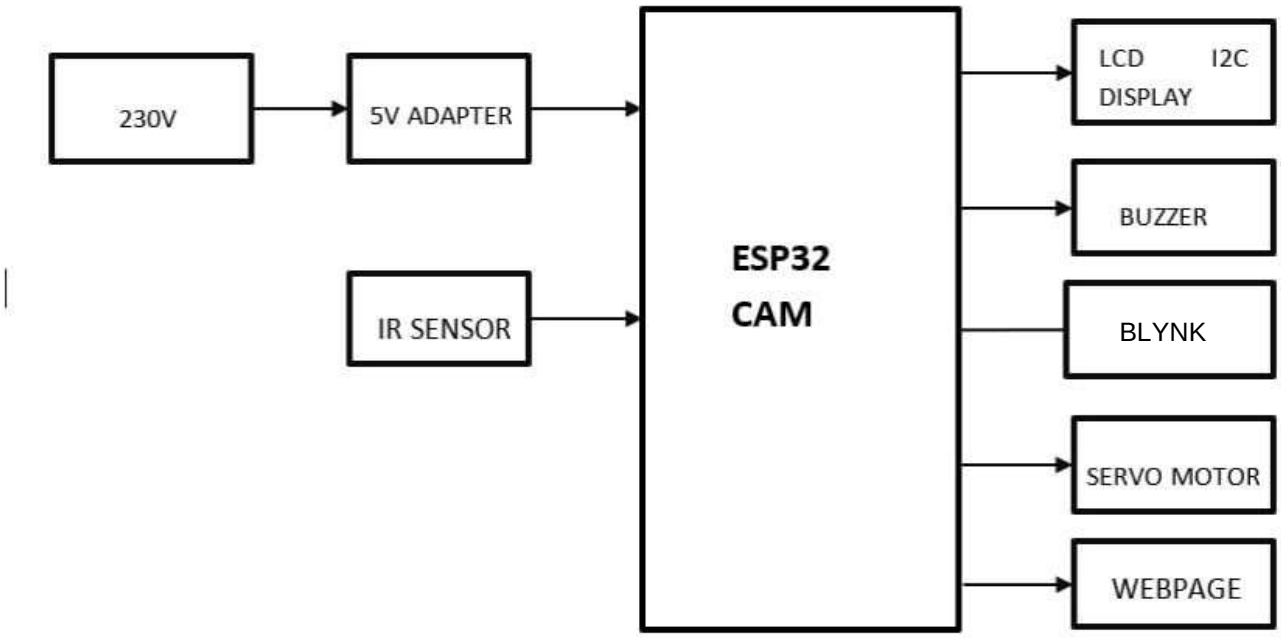

Fig -1: block diagram

CIRCUIT DIAGRAM

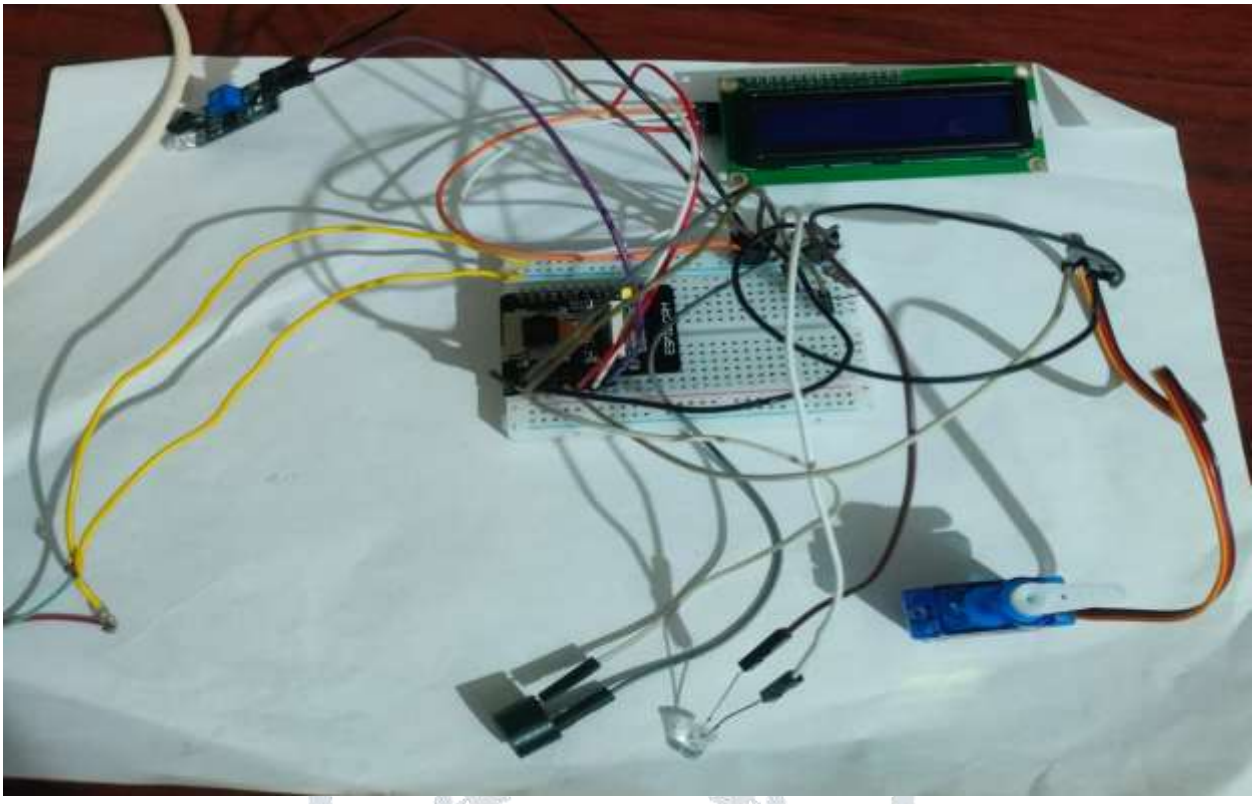

Fig. -2: Circuit architecture

4.RESULTS AND PERFORMANCE ANALYSIS

The prototype system underwent comprehensive testing in a controlled laboratory environment and simulated residential settings to evaluate performance characteristics under varied conditions.

4.1 SENSOR RESPONSE CHARACTERISTICS

The sensor response characteristics describe how quickly and accurately the sensors in the system detect and react to human movement. In this project, two types of sensors are used: the ESP32-CAM for entry detection and the IR sensor for exit detection.

1. ESP32-CAM Response
- The ESP32-CAM responds based on changes detected in video frames.
- It reacts to movement almost instantly (within a fraction of a second).
- The accuracy depends on lighting conditions and the clarity of the frame.

The camera may detect large hand movements or shadows, so the response is optimized using threshold values to reduce false counts.

2. IR Sensor Response
- The IR sensor has a fast and stable response:
- It detects beam interruption within a few milliseconds.
- It provides a clean digital signal, making exit detection more reliable.
- Its response is not affected by lighting, shadows or partial movement, which helps improve overall counting accuracy.

3. Overall System Response
- Both sensors work together to give real-time updates.
- The LCD and web interface reflect the count immediately after the sensor triggers.
- Fast sensor response helps the system maintain accuracy even during continuous or rapid movement of people.

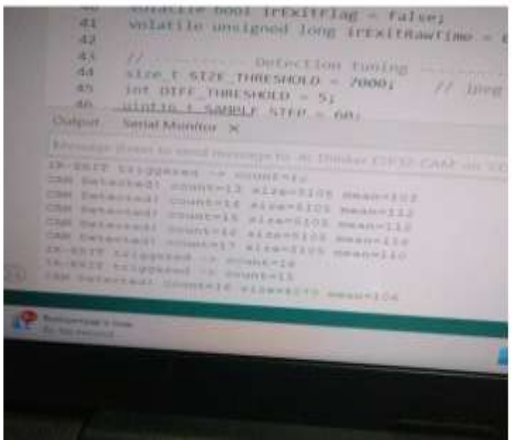

Fig. -3: Sensor response

4.2 CONTROL SYSTEM PERFORMANCE

The control system in this project manages the automatic responses of the LCD, servo motor, LED and buzzer based on the real-time occupancy count. The system continuously monitors the entry and exit sensors and updates the outputs without noticeable delay. When the count remains within the safe limit, the servo keeps the door open and all alerts stay off. As soon as the limit is crossed, the controller immediately activates the LED and buzzer and closes the door using the servo motor. This quick response ensures that no additional person can enter after the limit is reached.

The system performs consistently during continuous operation and shows stable behavior even when multiple people move simultaneously. The coordination between the sensors, camera and output devices remains smooth due to efficient code execution and fast microcontroller processing. Overall, the control system demonstrates reliable and timely performance, maintaining accuracy and ensuring effective crowd regulation

Fig. -4:

Fig. -5: Control system

5. CONCLUSIONS

The project successfully demonstrates a functional real-time Predictive Crowd Management System built around the ESP32-CAM platform. The system automates crowd monitoring by integrating camera-based entry detection, IR-based exit sensing and servo-controlled gate management, significantly reducing the need for manual supervision. The LCD display and web interface provide continuous visibility of occupancy levels, enabling quick decision-making and improved safety.

With its compact design, low cost and ease of installation, the system can be implemented in a wide range of environments such as schools, retail outlets, offices and public facilities. Overall, the developed prototype offers a practical and efficient approach to managing indoor crowd flow**.**

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