International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802364

Real-Time Crowd Density Estimation using Artificial Intelligence for Smart City Surveillance

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Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

ABSTRACT: Rapid urbanization and population growth have significantly increased crowd density in public places such as transportation hubs, shopping malls, and large event venues. Monitoring and controlling such crowd environments is critical to ensure public safety and prevent disasters such as stampedes and overcrowding incidents.

This paper presents a Real-Time Crowd Density Estimation System using Artificial Intelligence (AI) and Internet of Things (IoT) technologies for smart city surveillance applications. The system utilizes Infrared (IR) sensors to detect and count people entering and exiting a monitored area. An ESP8266 microcontroller processes the sensor data and maintains an accurate real-time occupancy count.

Artificial Intelligence techniques, specifically Long Short-Term Memory (LSTM) networks, are employed to analyze historical data and predict future crowd density trends. The system also integrates anomaly detection to identify unusual crowd behavior. When the occupancy exceeds predefined thresholds, audio-visual alerts are triggered to notify authorities.

Additionally, the system uses the ThingSpeak cloud platform for real-time data visualization, storage, and remote monitoring. The proposed solution is cost-effective, scalable, and privacy-preserving, making it highly suitable for smart city infrastructure and public safety systems.

KEYWORDS: Artificial Intelligence, Crowd Monitoring, IoT, ESP8266, Infrared Sensors, ThingSpeak, Smart City, Overcrowding Alert, LSTM, Embedded Systems.

I. INTRODUCTION

In modern urban environments, crowd management has become a critical challenge due to increasing population density and frequent large-scale gatherings. Public places such as railway stations, shopping complexes, and event venues often experience overcrowding, which can lead to severe safety risks including stampedes, congestion, and delayed emergency responses.

Traditional crowd monitoring techniques, such as manual counting and CCTV surveillance, have significant limitations. Manual counting is time-consuming and prone to human error, while CCTV-based systems require continuous monitoring, high computational resources, and raise privacy concerns.

The emergence of IoT and AI technologies has opened new possibilities for intelligent crowd monitoring systems. IoT devices enable real-time data collection using sensors, while AI algorithms provide predictive capabilities and intelligent decision-making.

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This project aims to develop a smart crowd monitoring system that combines IR sensor-based people counting, AI-driven prediction, and cloud-based monitoring. The system not only provides real-time occupancy tracking but also predicts future crowd conditions and generates alerts to prevent overcrowding situations.

The proposed system contributes to improving safety, efficiency, and automation in smart city applications.

II. LITERATURE REVIEW

Crowd monitoring has been extensively studied using various approaches, including computer vision, wireless sensing, and IoT-based methods.

Computer vision techniques using deep learning models such as CNNs and transformers have achieved high accuracy in crowd counting. However, these systems require high computational power, expensive hardware, and raise privacy concerns due to the use of cameras.

Wireless sensing methods, such as Wi-Fi and RF-based crowd estimation, provide privacy-preserving solutions. These methods estimate crowd density based on signal strength and device connectivity. However, they lack precision and are affected by environmental factors.

IoT-based crowd monitoring systems using sensors such as infrared sensors have gained attention due to their simplicity, low cost, and reliability. These systems can accurately count people without capturing visual data, thereby preserving privacy.

Recent research focuses on integrating AI with IoT systems to enhance prediction and anomaly detection. However, many existing solutions lack real-time alert mechanisms and cloud-based monitoring capabilities.

The proposed system addresses these gaps by combining sensor-based counting, AI-driven prediction, and cloud integration into a unified and efficient system.

III. RESEARCH METHODOLOGY

The proposed system consists of multiple modules working together to achieve real-time crowd monitoring and prediction.

A. People Counting Mechanism

Infrared (IR) sensors are installed at entry and exit points to detect people movement. The system uses a bidirectional counting algorithm to determine whether a person is entering or exiting based on the sequence of sensor activation.

B. Microcontroller Processing

The ESP8266 microcontroller acts as the central unit, collecting data from sensors and processing the counting logic. It continuously updates the occupancy count and ensures accurate tracking.

C. Density Classification

The system classifies crowd density into three levels:

- Low (0–6 persons)
- Medium (7–13 persons)
- High (14–20 persons)

This classification helps in easy visualization and decision-making.

D. AI-Based Prediction

An LSTM-based model is used to analyze historical occupancy data and predict future crowd density. This helps in identifying peak crowd periods and taking preventive measures in advance.

E. Alert System

When the occupancy exceeds the predefined limit, the system triggers alerts using:

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- Buzzer (audio alert)
- LED indicators (visual alert)

F. Cloud Integration

The system sends real-time data to the ThingSpeak cloud platform. Users can monitor occupancy, density levels, and alerts remotely.

IV. RESULTS AND DISCUSSION

The system was tested under various real-time scenarios to evaluate its performance.

The IR sensor-based counting system achieved an accuracy of approximately **97%**, demonstrating reliable performance. Errors were minimal and mainly occurred when multiple individuals crossed the sensors simultaneously.

The density classification module effectively categorized crowd levels into low, medium, and high with high accuracy. The LED indicators provided clear visual feedback.

The alert system responded quickly when overcrowding occurred, ensuring timely warnings. The average response time was observed to be less than 500 milliseconds.

The AI-based prediction model provided accurate short-term predictions, helping in proactive crowd management. However, prediction accuracy decreased slightly for long-term forecasts, which is expected in time-series models.

The ThingSpeak cloud platform successfully displayed real-time data and historical trends, enabling remote monitoring and analysis.

Overall, the system demonstrated efficient performance, reliability, and practical applicability in real-world environments.

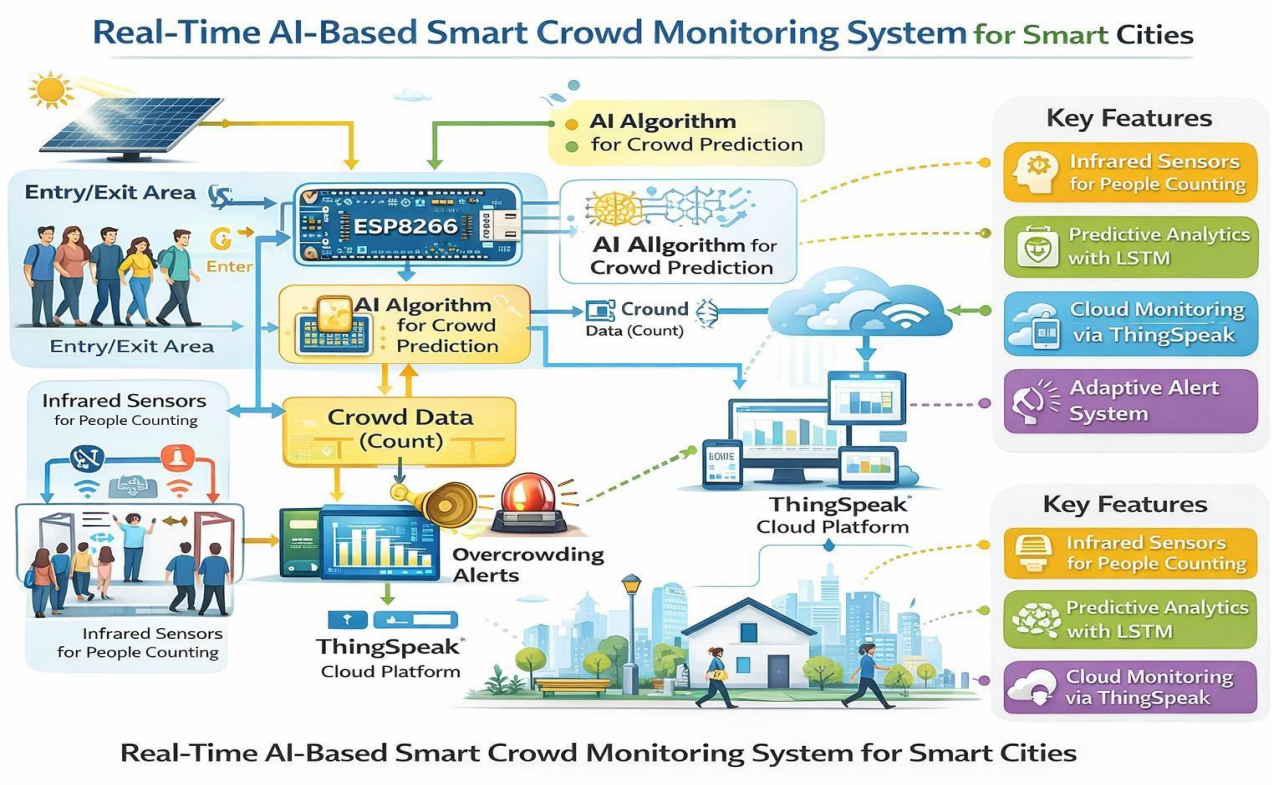

FIG: 1

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V. CONCLUSION

This paper presented a Real-Time Crowd Density Estimation System using IoT and Artificial Intelligence technologies. The system effectively monitors crowd density, predicts future trends, and generates alerts during overcrowding conditions.

The use of IR sensors ensures privacy-preserving data collection, while the ESP8266 microcontroller enables efficient processing. The integration of AI enhances prediction capabilities, and cloud platforms provide remote monitoring features.

The proposed system is cost-effective, scalable, and easy to implement, making it suitable for various smart city applications. It significantly improves crowd management and public safety by providing real-time insights and early warning mechanisms.

VI. FUTURE WORK

Future improvements can enhance the system's performance and scalability:

1. Implementation of advanced deep learning models for higher prediction accuracy
2. Integration of mobile applications for real-time notifications and alerts
3. Deployment of multiple sensor nodes for large-scale monitoring
4. Integration with CCTV systems for hybrid monitoring
5. Development of edge AI models for faster local processing
6. Improved security mechanisms for IoT communication
7. Integration with emergency response systems for automatic action

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