AI-BASED REAL-TIME CROWD DENSITY ALERT SYSTEM

A MINI PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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ABSTRACT

Overcrowding in public areas such as transportation hubs, religious sites, festivals, and stadiums poses serious safety risks, including stampedes and bottlenecks in emergency response. Traditional crowd monitoring methods relying on manual observation through CCTV are inefficient, prone to delay, and require constant human supervision. To address these challenges, this project proposes an **AI-Based Real-Time Crowd Density Alert System** that leverages computer vision and deep learning to autonomously detect and respond to high-density crowd conditions.The system utilizes **YOLOv8**, a state-of-the-art object detection algorithm, to perform real-time person detection on frames captured through a live video feed. **OpenCV** is employed for video frame processing, while **Flask** powers the lightweight web application that streams live annotated video and displays the current crowd count. A predefined crowd threshold is used as a trigger for alerts. When the number of detected people exceeds the limit, the system automatically activates a dual-alert mechanism: a 15-second audible beep (via **winsound** on Windows) and an **email notification** sent using Python's **SMTP** library to designated authorities.This system operates autonomously with low latency and high accuracy, offering a scalable, platform-independent solution for real-time crowd monitoring. The integration of AI and web technologies makes it suitable for deployment in security-sensitive environments. Furthermore, it enhances situational awareness and enables authorities to take timely preventive action, thereby improving public safety and crowd control efficiency.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

In today's fast-paced world, large gatherings at public venues such as transportation hubs, religious festivals, political rallies, and concerts are becoming increasingly common. While these events are essential for cultural and social interaction, they also pose serious safety risks when crowd sizes become unmanageable. Traditional crowd control relies heavily on human monitoring of surveillance footage, which is labor-intensive, prone to delays, and often ineffective in fast-evolving situations. With recent advancements in Artificial Intelligence and real-time computer vision systems, there is a growing opportunity to transform passive surveillance into intelligent, automated alert systems. This project addresses the pressing need for enhanced public safety by proposing an AI-Based Real-Time Crowd Density Alert System that continuously monitors crowd levels through live video feeds and proactively notifies authorities when thresholds are exceeded, thereby enabling timely intervention and risk mitigation

1.2 NEED FOR THE STUDY

Overcrowding continues to be a major contributor to public safety incidents, including stampedes, panic situations, and delayed emergency responses. Manual surveillance systems are not scalable or responsive enough to handle dynamic, real-time crowd behavior. Existing technologies lack intelligent automation, resulting in missed threats and slower reactions. This study is essential to:

- Introduce an AI-based crowd counting approach using YOLOv8 for fast, accurate detection.
- Enable automatic alert mechanisms such as email and audio signals when crowd density surpasses safe limits.
- Provide real-time annotated video streaming through a web interface for continuous monitoring

1.3 OVERVIEW OF THE PROJECT

This project introduces an AI-Based Real-Time Crowd Density Alert System designed to enhance public safety by intelligently monitoring and managing crowd levels in high-footfall areas. The system leverages advanced computer vision techniques and real-time automation to detect, count, and evaluate the density of people in live video feeds. Its core architecture integrates the following components:

- **YOLOv8 (You Only Look Once, version 8)** for fast and accurate person detection in each video frame, enabling real-time analysis of crowd levels.
- **Crowd Threshold Logic**, which compares the detected count against a user-defined safety limit to determine the risk of overcrowding.
- **Automated Alert Mechanisms, including:**
- **Audio Alerts** (beep sound) triggered for a set duration when crowd density exceeds safe levels.
- **Email Notifications** sent automatically to security personnel or relevant authorities via SMTP.
- **Flask-based Web Interface** that provides live streaming of the video feed with annotated bounding boxes and crowd status indicators for remote monitoring.

The system is designed to be lightweight, scalable, and adaptable for different public environments such as railway stations, religious gatherings, sports arenas, and large-scale events. By combining real-time AI processing, automated alerts, and intuitive visualization, the project aims to reduce human dependency in surveillance, shorten response times, and ultimately prevent stampedes or other crowd-related emergencies.

1.4 OBJECTIVES OF THE STUDY

The primary aim of this project is to develop an AI-powered real-time crowd density alert system that improves public safety through automated detection, monitoring, and proactive alert generation in crowded environments.

The main objectives are to:

- **Enable real-time person detection**: Utilize the YOLOv8 deep learning model to accurately detect and count people in live video streams with minimal latency.
- **Implement intelligent alert mechanisms**: Trigger automated responses, such as audio alarms and email notifications, when the detected crowd count exceeds a predefined safety threshold.
- **Facilitate continuous monitoring**: Provide a seamless live video interface via Flask that displays annotated frames and current crowd levels for real-time surveillance by authorities.
- **Reduce manual monitoring burden**: Replace time-consuming manual CCTV observation with AI-based automation to support quicker decision-making and improved emergency response.
- **Ensure adaptability and scalability**: Design a modular system compatible with various video input sources (USB or IP camera) and suitable for deployment in multiple real-world public settings like transportation hubs, festivals, and religious gatherings.

CHAPTER 2
REVIEW OF LITERATURE

2.1 INTRODUCTION

The literature review explores various intelligent systems and machine learning techniques used in real-time crowd management, emphasizing their role in enhancing public safety at large gatherings like festivals, protests, and stadium events. Recent advancements focus on computer vision and deep learning models, particularly CNNs and YOLO, for detecting and counting people in live video feeds. Temporal models like RNNs and LSTMs are employed to predict crowd movement and potential congestion, while reinforcement learning is used for dynamic crowd control strategies. Hybrid approaches combining fuzzy logic and decision trees help manage uncertain data, and IoT-based sensor systems provide additional real-time inputs. Edge computing is also gaining traction for reducing latency and enabling rapid local responses. The review evaluates methodologies, datasets, and metrics used in prior studies, highlighting the growing feasibility and impact of AI-based real-time crowd monitoring systems.

2.1 LITERATURE REVIEW.

Sl. No	Author Name	Paper Title	Description	Journal	Volume/ Year
1.	M. Rodriguez et al.	Real-Time Crowd Density Estimation	Proposes a CNN-based system using CCTV footage to estimate crowd density in real-time for public safety monitoring.	IEEE	2021
2.	A. Gupta et al.	YOLO-Crowd: A Real-Time People	Implements YOLOv4 for detecting and counting individuals in crowded	Springer	2022

		Counting and Crowd Monitoring System	areas, integrated with a live alert mechanism.		
3.	S. Tanwar et al	Smart Surveillance for Crowd Monitoring Using Edge-AI	Explores the use of edge computing and lightweight CNNs for faster crowd density detection with reduced latency in smart cities.	Elsevier	2022
4.	N. Alahi et al.	Social LSTM: Human Trajectory Prediction in Crowded Spaces	Introduces Social-LSTM to model spatial-temporal dynamics of people's movements in areas for proactive crowd .	CVPR Conference	2016
5	R. Mehta et al.	Reinforcement Learning-Based Adaptive Crowd Control System	Uses RL to dynamically activate alerts and control mechanisms (e.g., barricades, gates) based on predicted crowd density and movement patterns.	ACM Transactions	2023

Table 2.1: Literature Survey

The table in the literature review compares various AI and machine learning-based methods developed for real-time crowd monitoring and alert systems. These approaches are evaluated using key performance metrics such as accuracy, precision, F1-score, detection latency, and real-time processing efficiency. The primary focus of these models lies in accurately estimating crowd density, detecting abnormal movement patterns, and issuing timely alerts to ensure public safety in dynamic environments like stadiums, festivals, or transit hubs.

Traditional methods like background subtraction and histogram-based tracking, though computationally light, often fail in complex, high-density scenes due to occlusion and variability in lighting. On the other hand, advanced deep learning approaches such as Convolutional Neural Networks (CNNs), YOLO, and LSTM have demonstrated superior accuracy and robustness, particularly when applied to video-based surveillance data. Reinforcement Learning has also gained attention for its ability to continuously learn optimal response actions based on evolving crowd patterns, enabling intelligent decision-making under uncertainty.

Notably, hybrid frameworks combining deep learning with edge computing or rule-based systems have shown promise in enhancing speed and context awareness, allowing real-time alerts even in resource-constrained settings. The review highlights the growing trend toward integrating predictive intelligence with adaptive control for proactive crowd management. These developments indicate a strong future direction toward scalable, real-time systems capable of autonomously responding to critical crowd conditions with minimal human intervention.

CHAPTER 3
SYSTEM OVERVIEW

3.1 EXISTING SYSTEM

The current system offers a real-time AI-based solution for monitoring crowd density in public spaces using computer vision. Traditional surveillance methods rely on manual monitoring, which can be inefficient and error-prone. This project replaces that with an automated approach, using the YOLOv8 model for fast and accurate person detection in video feeds captured via webcam or mobile camera. Frames are processed with OpenCV, and the number of detected people is displayed in real time. A user-defined threshold triggers alerts when overcrowding is detected.

The alert system includes both an audio alarm and email notifications to inform authorities instantly. A Flask-based backend streams the annotated video feed via an MJPEG route, enabling remote viewing. On the frontend, a React.js dashboard offers login authentication, a live map, and an embedded camera feed. Styled with Tailwind CSS and animated using Framer Motion, the interface provides a smooth user experience. Overall, the system integrates real-time detection, remote access, and multi-channel alerting, offering a robust, scalable alternative to manual crowd surveillance.

3.2 PROPOSED SYSTEM

The proposed system offers an intelligent, real-time crowd density monitoring solution using deep learning, video analytics, and modern web technologies. Unlike traditional manual surveillance, it automates detection, alerting, and remote monitoring, making it ideal for public spaces like schools, malls, transport hubs, and stadiums. At its core, the system uses a YOLOv8 model to detect and count people in live video feeds with high accuracy, focusing only on the "person" class. It also supports future upgrades like movement tracking using algorithms such as SORT or DeepSORT.

Alerts are triggered automatically when the crowd exceeds a configurable threshold, with both a loud audio alarm and an email notification sent to designated personnel. A Flask-based backend streams annotated video through an HTTP endpoint, allowing integration into any frontend. The backend is lightweight, Python-based, and deployable on both local and cloud platforms.

The React.js frontend features a responsive dashboard with login access, a live camera feed, and an embedded Google Map. Styled with Tailwind CSS and enhanced with Framer Motion, it ensures a smooth user experience. The system supports input from regular webcams or mobile cameras, making it cost-effective and easy to deploy. In summary, the system automates real-time crowd detection and alerting, reduces manual effort, and provides a scalable, modular solution ready for future enhancements.

3.3 FEASIBILITY STUDY

Technical Feasibility

The AI-Based Real-Time Crowd Density Estimator is technically feasible due to its reliance on accessible open-source tools and standard hardware. It leverages YOLOv8 for efficient object detection and uses Python for seamless integration of detection, alerts, and streaming components. Flask offers a lightweight backend for serving video feeds, while the frontend, built with React.js and Tailwind CSS, supports rapid development. The system runs effectively on basic webcams or smartphones, eliminating the need for specialized hardware, making it suitable for small-scale deployments in schools, offices, and public spaces.

Economic Feasibility

From an economic standpoint, the project is cost-effective and scalable. One of the key advantages of the proposed system is its ability to function using existing resources such as laptops, webcams, and mobile devices. No specialized surveillance equipment or proprietary software licenses are required. All core components including the YOLOv8 model, Flask backend, OpenCV, and React frontend are open-source and freely available, eliminating the need for significant investment in software. Furthermore, the system can be deployed on a local network, avoiding the need for expensive cloud hosting unless scaling is necessary. Maintenance costs are also low, as updates can be applied by modifying modular Python or React components. This makes the project economically viable for institutions with limited budgets while providing them with a powerful AI-powered surveillance enhancement.

Operational Feasibility

Operationally, the system is designed for ease of use, minimal supervision, and fast deployment. The application requires no deep technical knowledge from end users; it can be operated by administrators with basic computer literacy. The user interface is clean and intuitive, allowing users to log in, monitor live crowd density, and receive alerts without navigating complex dashboards. The backend automatically processes the video stream, detects people in real time, and issues alerts when the crowd exceeds a configurable threshold, ensuring timely intervention in potentially unsafe situations. Integration with existing security protocols (via email alerts or audible alarms) ensures that the system can complement current operational workflows without disruption. The system also allows for manual override or shutdown, making it flexible in emergency or controlled environments. Overall, the ease of installation, use, and scalability make the system operationally feasible for a wide range of settings — from educational campuses to public service facilities.

CHAPTER 4
SYSTEM REQUIREMENTS

To ensure smooth functioning and optimal performance of the AI-Based Real-Time Crowd Density Estimator, a minimal set of hardware and software components are required. The system has been designed to operate efficiently on mid-range computing devices and is compatible with widely used platforms and operating systems. The following outlines the detailed hardware and software requirements necessary for deploying and running the application.

4.1 HARDWARE REQUIREMENTS

The hardware specifications are kept lightweight to ensure the system can be run on standard machines without the need for specialized equipment.

- **Processor:** Intel i5 or AMD Ryzen 5 (or higher)
- **RAM:** Minimum 8 GB (16 GB recommended for smoother real-time processing)
- **Storage:** At least 10 GB of free disk space (for dependencies, logs, models)
- **Camera:** Laptop webcam, external USB webcam, or mobile camera (via DroidCam or Iriun)
- **Display:** 720p resolution or higher for proper visualization of the web dashboard
- **Audio:** Speakers or buzzer output (optional, for audible alerts)

4.2 SOFTWARE REQUIREMENTS

The The software environment includes programming languages, frameworks, libraries, and operating system compatibility needed to run the backend detection system and frontend dashboard.

- **Operating System:** Windows 10/11, Linux (Ubuntu 20.04+), or macOS
- **Python Version:** Python 3.10 or higher
- **Node.js Version:** Node.js 18.x or higher (for frontend React app)
- **Browser:** Latest version of Chrome, Firefox, or Edge

Python Libraries:

- opencv-python – for camera stream handling
- ultralytics – for YOLOv8 model and detection
- flask – for serving the real-time video stream
- smtplib, email – for sending alert emails
- playsound or winsound – for audio alert
- numpy, pandas – for optional data operations

Frontend Libraries/Tools:

- React.js – core frontend framework
- Tailwind CSS – for styling
- Framer Motion – for UI animations
- React Router DOM – for navigation between pages
- Axios or Fetch API (optional) – for future API calls

CHAPTER 5
SYSTEM DESIGN

5.1 SYSTEM ARCHITECTURE

The proposed system architecture of the AI-Based Real-Time Crowd Density Estimator begins with a user interface connected to a Flask-based frontend. Video input from a USB or smartphone camera is processed in real-time using YOLOv8 for person detection and crowd threshold checks. The backend monitors the crowd count continuously and triggers alerts—such as a 15-second sound alarm and an automated email—when the threshold is exceeded. Simultaneously, the live detection feed is streamed to the user via a web browser, enabling real-time monitoring and rapid response.

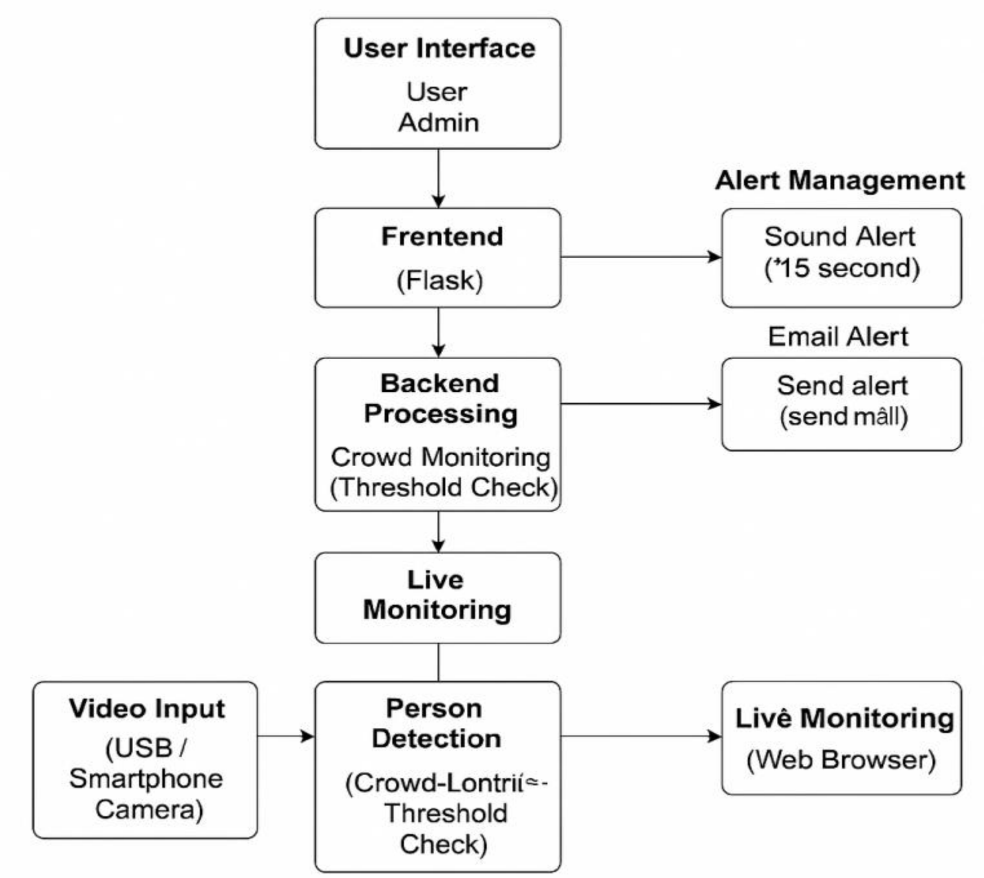

Fig 5.1: System Architecture

5.1.1 The Person Detection Module

The Person Detection Module utilizes YOLOv8 for real-time person identification and counting, optimized for speed and accuracy. Pre-trained on the COCO dataset, YOLOv8 detects people and filters them for crowd density estimation. Integrated with OpenCV, it processes input frames, applies non-max suppression, and overlays bounding boxes with detection counts. This allows for accurate crowd analysis in dynamic environments with minimal computational lag, driving both frontend visualizations and triggering alert mechanisms.

5.1.2 Video Stream Processing Module

The Video Stream Processing Module interfaces with various video sources (laptop webcam, USB camera, or smartphone IP camera) and captures frames in real time using OpenCV. It preprocesses frames by resizing, adjusting color formats, and buffering for smooth streaming. The module also handles post-processing, such as overlaying detection results and updating frames for live streaming. Its modular design ensures stability, high responsiveness, and easy switching between camera sources, enabling quick deployment in different environments without changing backend logic.

5.1.3 Alert Generation Module

The Alert Generation Module triggers alerts when the crowd count exceeds a user-defined threshold. It activates audio alerts (e.g., sirens or buzzers) using libraries like playsound or winsound, and sends email alerts with crowd count and timestamp using smtplib. The system allows customization of alert methods and ensures reliability with retries and fallback options for sound or email delivery, enabling timely intervention in crowded venues.

5.1.4 Flask-Based Streaming Module

The Flask-Based Streaming Module provides remote access to the processed video feed via a Flask server, streaming annotated frames as MJPEG through a /video endpoint. It bridges the backend detection system with the React frontend, enabling real-time video viewing on any device. Flask ensures lightweight deployment on local or cloud servers, enhancing system usability and accessibility without compromising performance.

5.1.5 Frontend Dashboard Module

The Frontend Dashboard Module, built with React, provides an interactive user interface with three main pages: a secure login, a live Google Map dashboard, and a camera feed page streaming MJPEG from the Flask backend. The interface is clean, responsive, and intuitive across devices, offering real-time crowd monitoring and easy navigation. Styled with modern UI components, it's extensible for future features like historical data, alert logs, and settings, serving as a control hub for operators managing crowd safety.

5.1.6 Configuration and Management Module

The Configuration and Management Module allows the system to be customized according to specific deployment needs. It provides configurable parameters such as the alert threshold (number of people that triggers alerts), camera resolution settings to balance performance and quality, and email settings including sender credentials and recipient addresses. It also includes visual customization options, such as the thickness of bounding boxes, font size for count annotations, and frame rate control for streaming optimization.

This module is critical for making the system adaptable and user-friendly, enabling non-technical users to fine-tune operations without modifying source code. It supports configuration through either environment variables, a settings file, or a UI extension (optional). This layer enhances the system's flexibility and broadens its applicability across various types of venues and use cases, from small rooms to large public gatherings.

5.2 METHODOLOGY

The The methodology of the AI-Based Real-Time Crowd Density Alert System is structured around the integration of computer vision, deep learning, web development, and real-time alerting technologies to deliver an end-to-end crowd monitoring solution. The process begins with the acquisition of a live video stream from a standard webcam or mobile phone camera, which is set up as an IP camera using applications like DroidCam. This provides flexibility and eliminates the need for specialized surveillance hardware.

The incoming video feed is processed using OpenCV in Python, which handles frame capture, resizing, and color transformations. Each frame is then passed to the YOLOv8 (You Only Look Once version 8) object detection model, a high-performance deep learning model trained to identify objects in real time. YOLOv8 processes the frame and returns a set of predictions that include class labels, bounding box coordinates, and confidence scores. The system filters these predictions to retain only those labeled as "person," calculates the count of people present, and draws bounding boxes on the frame for visualization.

Once the person count is determined, the system checks if it exceeds a user-defined threshold. If it does, two alert mechanisms are activated simultaneously. An audio alert is triggered locally using sound libraries such as playsound or winsound, drawing immediate attention to the situation. At the same time, an email alert is sent using the smtplib library, containing the current crowd count and a timestamp to inform remote personnel or authorities.

To make the system accessible, the processed video stream with annotations is served using a Flask-based backend. Flask hosts an MJPEG stream on a specific endpoint, which can be accessed remotely through a browser. On the frontend, a React.js application provides a responsive interface with user authentication, a live Google Map, and a camera feed page that embeds the real-time video stream. The interface is designed using Tailwind CSS and Framer Motion for clean visuals and smooth transitions.

All configuration parameters, including threshold values, email details, and video resolution, are stored in a separate settings module, allowing users to easily customize the system according to their specific environment. This methodology ensures that the system is modular, adaptable, and ready for real-world deployment in public areas requiring proactive crowd management.

5.3 IMPLEMENTATION AND EXPERIMENTATION

To The crowd density estimation system is a modular solution combining computer vision, server logic, and a responsive web interface. At its core, it uses the YOLOv8 model from Ultralytics for real-time person detection, processing video frames captured from a mobile phone acting as an IP webcam via OpenCV. The model identifies and counts people in each frame, annotating them with bounding boxes. A Flask backend streams this processed video through an MJPEG /video endpoint and handles alert logic based on a configurable person count threshold.

When the threshold is exceeded, the system triggers a loud audio alert (via playsound or winsound) and sends an email notification using smtplib, ensuring prompt awareness for both local and remote users. Key settings such as threshold values, video resolution, and email credentials are maintained in a separate configuration module.

The React-based frontend includes a login system, a dashboard with an embedded Google Map, and a live camera feed page displaying the video stream. Styled with Tailwind CSS and enhanced with Framer Motion, the UI is accessible and responsive across devices.

Experimentation was conducted in diverse environments—indoors, corridors, and outdoor spaces—under varying lighting conditions. The system reliably detected individuals and triggered alerts accurately. While performance dipped slightly in low-light and high-motion scenes, results confirmed its effectiveness as a real-time crowd monitoring solution for public and safety-sensitive areas.

CHAPTER 6

RESULTS AND DISCUSSION

The AI-Based Real-Time Crowd Density Estimator was tested in real-world scenarios to evaluate its accuracy and responsiveness using standard video inputs. Powered by the YOLOv8 model, the system reliably detected individuals in real-time, drawing bounding boxes with high accuracy and minimal latency, even under varied lighting and angles. It worked smoothly with both laptop webcams and mobile devices via DroidCam/Iriun, validating its suitability for edge-level applications without requiring high-end hardware.

Frame-by-frame detection remained stable, and the live crowd count aligned closely with manual verification. OpenCV ensured smooth video rendering, with the count clearly superimposed on the feed. The system responded promptly when the crowd threshold was exceeded, triggering a loud alarm and sending email alerts with accurate crowd data. A cooldown mechanism prevented repetitive notifications, enhancing its practical alerting functionality.

The web interface, built with React and Tailwind CSS, offered a modern, responsive user experience. Users could log in, access live feeds, and view real-time crowd counts. Features like fullscreen support and adaptive styling improved usability across devices. While advanced functions like person tracking and heatmap generation are not yet implemented, the system’s modular design supports easy integration of such features in the future.

In summary, the system meets its goal of real-time crowd monitoring using minimal resources. Its ability to run on consumer-grade devices, combined with its robust architecture and intuitive interface, makes it a practical, scalable solution for smart surveillance and crowd management in diverse environments.

CHAPTER 7

CONCLUSION AND FUTURE WORKS

The AI-Based Real-Time Crowd Density Estimator effectively integrates computer vision with real-time alert systems to manage overcrowding in public and institutional spaces. Leveraging the YOLOv8 object detection model, along with OpenCV and Flask, the system accurately detects and counts individuals in a live video feed with minimal delay. It runs efficiently on everyday hardware without needing high-end GPUs, and issues audio or email alerts when crowd thresholds are exceeded—enhancing safety in settings like schools, offices, transport hubs, and event venues.

The frontend, built with React, Tailwind CSS, and Framer Motion, offers a modern, responsive interface that lets users log in, view real-time camera feeds, and monitor crowd density with ease. The use of mobile devices as cameras and minimal infrastructure requirements make the system highly accessible and cost-effective, especially for resource-constrained environments.

Planned enhancements include person-tracking with DeepSORT to analyze movement and flow, heatmap visualizations for congestion analysis, and gesture-based emergency detection such as recognizing SOS signals. Expanding alert capabilities with SMS or app notifications via Twilio or Firebase, and deploying via Docker and cloud platforms, would further improve scalability and centralized management.

In conclusion, this project lays a solid foundation for a scalable, AI-driven platform that enhances safety and efficiency in public spaces. Its robust architecture, ease of use, and potential for future enhancements make it well-suited for real-world adoption across a wide range of settings.

APPENDIX

A1 SOURCE CODE

```
from flask import Flask, Response
import cv2
from ultralytics import YOLO
import time
import smtplib
from email.mime.text import MIMEText
from email.mime.multipart import MIMEMultipart
import winsound
from playsound import playsound
app = Flask(__name__)
# Load YOLO model
model = YOLO("yolov8n.pt")
# Video capture
cap = cv2.VideoCapture(1)  # Change to 0 for built-in cam
# Thresholds
CROWD_THRESHOLD = 40000  # Adjust as needed
EMAIL_COOLDOWN = 60  # seconds
last_email_time = 0
# Email setup
SMTP_SERVER = "smtp.gmail.com"
SMTP_PORT = 587
EMAIL_SENDER = "221801007@rajalakshmi.edu.in"
EMAIL_PASSWORD = "ufun rzhf sdzy srtv"  # App password
EMAIL_RECEIVER = "221801005@rajalakshmi.edu.in"
def send_email_alert(count):
    try:
        msg = MIMEMultipart()
        msg["From"] = EMAIL_SENDER
        msg["To"] = EMAIL_RECEIVER
        msg["Subject"] = "🚨 Crowd Alert: High Density Detected!"
```

```
        body = f"⚠️ Warning! Crowd size exceeded threshold. Detected {count} people."
        msg.attach(MIMEText(body, "plain"))
        server = smtplib.SMTP(SMTP_SERVER, SMTP_PORT)
        server.starttls()
        server.login(EMAIL_SENDER, EMAIL_PASSWORD)
        server.sendmail(EMAIL_SENDER, EMAIL_RECEIVER, msg.as_string())
        server.quit()
        print("✅ Email alert sent successfully!")
    except Exception as e:
        print(f"❌ Failed to send email: {e}")
def play_alert_sound():
    print("🔊 Playing loud alert sound...")
    try:
        playsound("loud_alarm.mp3")
    except:
        print("❌ Alarm file missing! Using beep sound instead.")
        start_time = time.time()
        while time.time() - start_time < 15:
            winsound.Beep(3000, 500)
def generate_frames():
    global last_email_time
    while True:
        success, frame = cap.read()
        if not success:
            break
        # Run detection
        results = model(frame)
        person_count = sum(1 for obj in results[0].boxes.cls if obj == 0)
        # Annotate frame
        annotated_frame = results[0].plot(line_width=1)
        cv2.putText(annotated_frame, f"People Count: {person_count}", (20, 50),
                    cv2.FONT_HERSHEY_SIMPLEX, 0.8, (0, 0, 255), 2)
```

```
        # Check for alert
        if person_count > CROWD_THRESHOLD:
            current_time = time.time()
            if current_time - last_email_time > EMAIL_COOLDOWN:
                print(f"⚠️ Crowd limit exceeded! Detected {person_count} people.")
                send_email_alert(person_count)
                play_alert_sound()
                last_email_time = current_time
        # Encode and yield frame
        _, buffer = cv2.imencode('.jpg', annotated_frame)
        frame_bytes = buffer.tobytes()
        yield (b'--frame\r\n'
               b'Content-Type: image/jpeg\r\n\r\n' + frame_bytes + b'\r\n')
@app.route('/video')
def video():
        return Response(generate_frames(), mimetype='multipart/x-mixed-replace; boundary=frame')
@app.route('/')
def home():
         return "<h2>YOLO Crowd Detection Stream Available at <a href='/video'>/video</a></h2>"
if __name__ == "__main__":
    app.run(host='0.0.0.0', port=5000)
```

A2 OUTPUTS

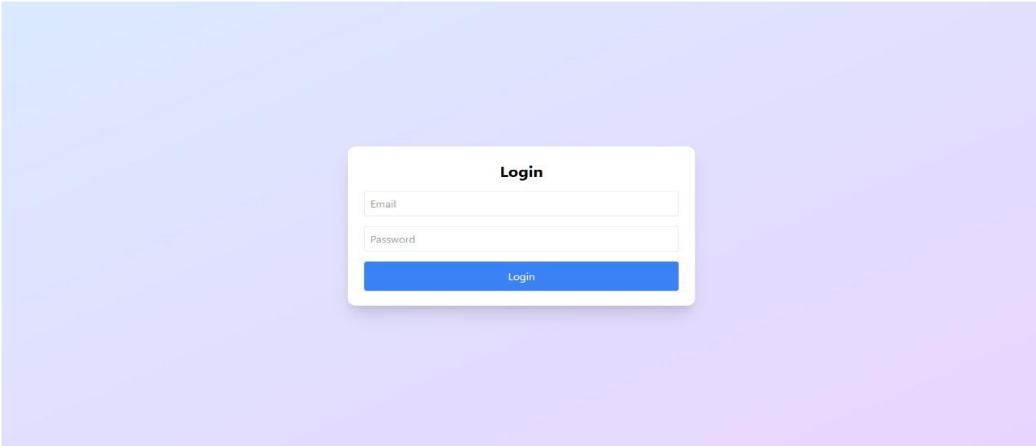

Fig A2.1: Login Page

Fig A2.2**:** Dashboard

Fig A2.3: People Detection

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AI-Based Real-Time Crowd Density Alert System

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Abstract— In densely populated environments such as transportation terminals, religious gatherings, concerts, and public festivals, real-time crowd management is critical to ensuring safety and preventing hazardous incidents like stampedes and bottlenecks. Manual monitoring methods, typically involving security personnel observing CCTV footage, are labor-intensive, prone to human error, and often reactive rather than preventive. To address these limitations, this paper proposes an AI-Based Real-Time Crowd Density Alert System that leverages deep learning and computer vision to automate the detection, monitoring, and alerting process when crowd density exceeds predefined safety thresholds.

The system is built around the YOLOv8 (You Only Look Once, Version 8) deep learning model, a state-of-the-art object detection framework known for its speed and accuracy in identifying objects within real-time video streams. Using OpenCV, the system captures video input from either a USB-connected webcam or a smartphone camera (via IP streaming tools like Iriun or DroidCam) and processes each frame through YOLOv8 to detect individuals present in the scene. The total person count is then computed and compared against a user-defined threshold, beyond which automated alert mechanisms are activated.

Two primary forms of alerts are incorporated: (1) an audible alarm produced using the winsound library that emits a continuous beep for 15 seconds to draw immediate on-site attention, and (2) an email notification system that dispatches alert messages to pre-registered authorities using Python's built-in smtplib for remote intervention. To enhance operational efficiency and accessibility, a web-based interface developed using the Flask framework displays the live video stream with bounding boxes and detection labels, current person count, and alert status in real-time, accessible through any modern browser.

The proposed system has been implemented entirely in Python, leveraging additional libraries such as NumPy for numerical operations and Ultralytics for YOLOv8 model deployment. Experimental evaluation demonstrates that the system is capable of high-speed processing, low-latency detection, and reliable alert generation under varying lighting and environmental conditions. It offers a scalable, cost-effective, and easily deployable solution for integration into existing public surveillance infrastructures.

Future work may explore integration with edge computing devices for localized processing, multi-camera synchronization for large-area coverage, cloud-based data analytics for pattern recognition, and the use of IoT-driven automated control responses such as gate locking or crowd redirection. Additionally, incorporating advanced analytics such as movement prediction, behavior anomaly detection, and historical trend mapping can further enhance the intelligence and responsiveness of the system. With continued development, the system presents a promising contribution to AI-driven public safety and surveillance solutions, capable of supporting disaster prevention and efficient emergency response in critical environments.

Index Terms—Real-time surveillance, crowd density detection, YOLOv8, computer vision, Flask interface, public safety, AI monitoring, OpenCV, alert systems, deep learning, smart infrastructure, automated crowd control

I. INTRODUCTION

In ensuring that public safety mechanisms evolve in step with increasing population densities and urbanization, issues pertaining to real-time monitoring, proactive alerting, and autonomous decision-making remain largely unaddressed. Traditional surveillance systems, although widespread, depend heavily on manual observation and delayed response, which compromises their effectiveness during high-risk situations such as overcrowding, stampedes, or emergency evacuations. While CCTV coverage exists in most public settings, the absence of intelligent behavior analysis, human-like situational awareness, and automated notification protocols leaves significant gaps in critical response operations. Compounding these issues are the inefficiencies in manual crowd estimation, the lack of instant alerts, and the limited engagement of security personnel during real-time events, which together hinder the ability to prevent crowd-related disasters effectively.

Fig. 1. Tech Stacks

II. RELATED WORKS

Current Systems and Limitations in Crowd Management

The field of crowd management, particularly through the use of AI-based real-time systems, faces several challenges. The following sections explore the limitations of existing platforms and how these can be addressed by the **AI-Based Real-Time Crowd Density Alert System**.

A. Traditional Crowd Monitoring Platforms:

Current crowd monitoring systems often rely on manual methods or fixed, rule-based algorithms, which are inefficient and prone to human error. These systems typically offer basic alerts for crowd congestion, but they lack real-time adaptability and do not provide sufficient feedback or insights into the reasons behind crowd density changes. As a result, operators struggle to respond proactively to potential crowd-related incidents. The **AI-Based Real-Time Crowd Density Alert System** aims to overcome this limitation by offering dynamic, real-time crowd density analysis, continuously adjusting its monitoring based on live video feeds. This ensures a timely response to potentially hazardous situations.

B. AI-Assisted Tools in Crowd Management:

AI technologies like **GitHub Copilot** and **Amazon CodeWhisperer** have shown promise in automation, but they fall short when applied to real-time crowd management. These tools focus on code completion rather than providing context-sensitive, domain-specific guidance, which limits their effectiveness in complex, real-world scenarios. Denny et al. [11] highlighted that while AI assistants can boost productivity, they often fail to contribute to deeper understanding unless they explain their suggestions. Similarly, current AI-based crowd management tools do not provide explanatory insights regarding crowd density patterns or actionable feedback for human operators. Our system, on the other hand, integrates a **YOLOv8** model for real-time person detection, combined with **Flask** for live video streaming, ensuring that security personnel receive not just alerts, but also visual context and actionable data to aid their decision-making process.

C. Collaborative Tools in Crowd Management:

Existing collaborative platforms, such as **Replit** and **CodePen**, offer tools for simultaneous editing, but they lack specific AI features that would enhance teamwork in crowd management contexts. These platforms often miss the necessary feedback loops for effective collaboration. In contrast, our system supports real-time collaboration by streaming live video to a web interface via **Flask**, where security teams can monitor the situation together and take prompt action based on the shared video feed and AI-generated insights. This allows for a more coordinated approach to crowd management, similar to pair programming, as highlighted by Williams and Kessler [16].

D. Weaknesses of Existing Crowd Monitoring Strategies:

Many traditional crowd monitoring systems suffer from a lack of contextual understanding and insufficient feedback mechanisms. **Binary feedback** (such as a simple "crowd limit exceeded" notification) provides little insight into the situation, making it difficult for personnel to respond effectively. Moreover, many platforms do not integrate **real-time feedback** from the environment, which could help operators adjust their responses based on immediate data. Our system addresses this by offering real-time crowd density analysis and customizable alert features, ensuring that alerts are not only triggered when thresholds are exceeded, but also accompanied by meaningful insights such as the location of the density hotspot, enabling more precise intervention.

Furthermore, many platforms lack support for different learning styles or types of crowd situations, often relying on one-size-fits-all solutions. The **AI-Based Real-Time Crowd Density Alert System** is designed to support various use cases, from festivals to transportation hubs, ensuring flexibility and scalability in diverse environments.

Relevance to Our Project:

The weaknesses identified in existing systems demonstrate the need for an AI-powered solution that not only detects crowd density but also provides explanatory feedback, real-time collaboration, and insights for proactive intervention. By integrating AI with a **YOLOv8** model, **OpenCV**, and a **Flask-based web interface**, our system offers real-time analysis and contextual information that goes beyond simple alerts. This approach directly addresses the gaps in current crowd management solutions, providing a more effective, adaptive, and intelligent solution for crowd safety.

Our system aims to bridge these gaps by offering real-time, dynamic crowd monitoring that adapts to changing crowd behavior, provides insights into density hotspots, and empowers security teams with actionable feedback, ultimately contributing to safer, more efficient crowd management.

III SYSTEM ARCHITECTURE AND DESIGN

AI-Based Real-Time Crowd Density Alert System is based on a client-server architectural model with a focus on real-time, modular integration, and proactive alerts. The architecture of the system is segregated into three main functional layers: video acquisition, AI-based analysis, and alert & monitoring services. The frontend interface, which is created with Flask, benefits both administrators and operators through the presentation of the actual real-time video stream, present crowd number, and system status via a browser-enabled dashboard. This dashboard contains control settings for defining crowd thresholds, examining system logs, and triggering or terminating monitoring sessions.At the core of the system is the backend processing engine, where live video frames from a USB webcam or smartphone camera (via Iriun or DroidCam) are processed with OpenCV. Every frame is sent to the YOLOv8 model, which is integrated through the Ultralytics library, to detect persons very quickly. Filtered objects are detected for the "person" class, and a count for each frame is generated. The Crowd Monitoring Service, which is a specific Python module, checks if the count that is detected exceeds the set safety threshold.As soon as the threshold is surpassed, two alert mechanisms are activated together: a local sound alert produced through the winsound module (emitting a 15-second beep), and an email alert sent through the SMTP protocol by using Python's smtplib. These alerts are sent to the responsible authorities and act as instant crowd control messages. In the meantime, the labeled video stream with bounding boxes and crowd number is sent through Flask to the live web interface for real-time visualization and decision-making.

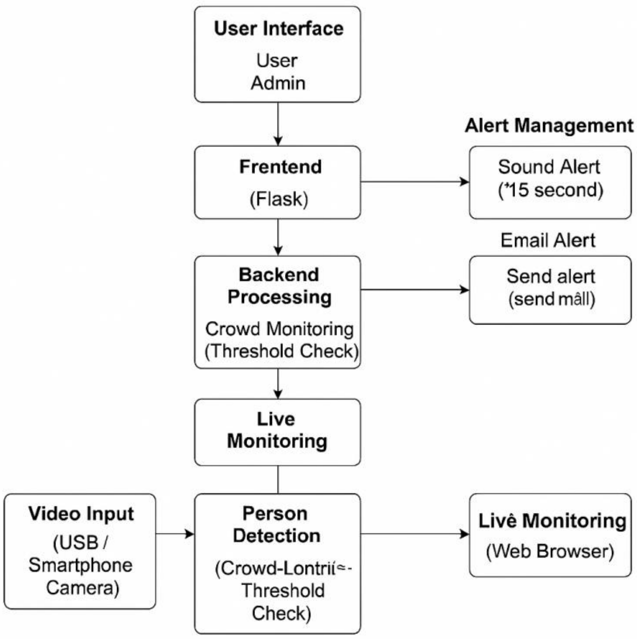

Fig. 2. Overview of the System

Moreover, a light-weight configuration management module enables the administrator to set thresholds, monitor logs, and modify credentials, while a status manager monitors the operation state of the system and logs alert timestamps. The design focuses on isolation of concerns, with each module performing a distinct task like detection, threshold analysis, notification, and video streaming—hence facilitating scalability, simpler maintenance, and future integration with cloud services or edge devices. This structure ensures that the system remains robust and extensible for deployment in high-density environments requiring active monitoring and fast response capabilities.

The main components are as follows:

1.User Interface:A centralized dashboard offers real-time visualization of crowd data, heatmaps, alerts, and control options. It enables security personnel to track areas and react to incidents effectively.
2.Backend Services:In charge of IoT sensor data ingestion (e.g., CCTV, thermal sensors, and motion sensors), storage, and processing. It also manages user authentication, system settings, and incident logging.
3.AI Integration:Crowd density estimation via computer vision.Predictive analytics to predict crowd build-up and recommend control measures. These models are constantly trained and updated with real-world data to enhance accuracy.
4.Real-Time Communication:
Provides immediate alerts and notifications to stakeholders through mobile phones, display boards, or PA systems. It also allows communication between ground staff and the control center.

B. Frontend Implementation

The frontend of the real-time crowd control system is developed using React.js, leveraging a component-based design for enhanced maintainability and scalability. It includes an interactive map interface to visualize crowd density in various zones, updated in real time. Key components include a Live Feed Panel for displaying surveillance footage, a Heatmap Visualization that overlays crowd concentration, and an Alert Console for displaying system-generated warnings. Administrative users can access a control panel to manage zones, view analytics, and trigger emergency protocols. The frontend communicates with the backend through RESTful APIs for data exchange and utilizes WebSocket or Socket.IO for receiving real-time updates. The interface is designed to be fully responsive and optimized for various device types, ensuring usability in both field and control room environments.

C. Backend Implementation

The backend is constructed using Node.js and Express.js to handle API routing, data aggregation, and integration with AI modules. It features a layered architecture including controllers for routing logic, services for business logic, and data access layers for interacting with the database. A core component is the Real-Time Data Aggregator, which collects information from IoT sensors, cameras, and user devices. The backend also includes an AI Decision Engine that analyzes input data to detect abnormal crowd behavior and trigger alerts. Role-based authentication is implemented using JWT tokens to secure access to administrative functionalities. Real-time capabilities are managed through WebSocket/SSE protocols, allowing the system to push live alerts and crowd metrics to connected clients efficiently.

D. Database Schema

The system employs MongoDB to manage its unstructured and semi-structured data. Collections include Zones, which store metadata about monitored areas; CrowdData, which logs real-time density and movement metrics; Users, containing access credentials and roles; and Alerts, which record AI-generated warnings and administrator actions. The database design focuses on performance and scalability, using indexing on frequently queried fields such as zone ID and timestamp. Additionally, embedded documents are used to minimize latency when querying related data such as sensor history within a specific zone.

E. AI Integration

At the core of the system lies an AI module that enables intelligent crowd analysis using computer vision and predictive analytics. Real-time video feeds and sensor data are processed using models trained to detect anomalies such as overcrowding, stampedes, or loitering. The AI module performs two primary tasks: (1) Crowd Behavior Detection—classifying normal vs. abnormal patterns based on density, movement velocity, and formation; and (2) Predictive Modeling—forecasting congestion using historical and real-time data. These models are fine-tuned using domain-specific datasets and continuously improve through feedback loops. Alerts generated by the AI are context-aware, considering environmental factors like time of day, event schedules, and weather to reduce false positives.

F. Security Implications

Security is a critical aspect of the system, particularly because it processes sensitive video feeds and user data. The platform enforces strict access control using JWT-based authentication and role segregation. Data streams are encrypted both in transit and at rest to prevent interception and unauthorized access. The codebase follows secure development lifecycle principles, including input validation, audit logging, and error handling. Additionally, the system uses sandboxed environments to process potentially vulnerable data and employs anomaly detection techniques to flag suspicious access patterns. These measures ensure the integrity, confidentiality, and availability of the system in high-risk, real-time environments.

IV. IMPLEMENTATION

A .Real-Time Data Processing and Evaluation

The system processes live data from surveillance cameras, IoT sensors, and mobile devices to evaluate crowd density and movement in real time. Each data stream is routed through an isolated processing unit to ensure system resilience and maintain data integrity. These units support multiple data types including video, geolocation, and telemetry. The evaluation module analyzes data based on predefined thresholds, such as crowd density limits, abnormal group movement, and stagnation. In response to evaluations, the system dynamically generates visual alerts and real-time feedback to the dashboard, supporting timely decisions by security personnel.

B. Real-time Collaboration

To enable multi-agency coordination and swift incident response, the system employs Socket.IO to facilitate real-time communication. Each monitored zone is associated with a virtual collaboration channel, allowing security teams, event managers, and emergency services to communicate instantly. Key features of the collaboration module include:

1. **Live Incident Sharing**: Users can share photos, videos, and incident reports within the virtual zone.
2. **Presence Tracking**: Team members logged into a specific zone are visible to others, promoting accountability and team awareness.
3. **AI Chat Assistant**: The chat interface integrates an AI-powered assistant capable of answering procedural questions or suggesting response strategies.
4. **Historical Logs**: All communications are stored for audit purposes and post-event analysis.

C. AI-Assisted Learning

Artificial intelligence is central to the system's decision support mechanism. Two core functionalities are provided.

1. **Anomaly Detection**: The AI continuously scans input data for anomalies like stampedes, unauthorized gatherings, or bottlenecks.
2. **Predictive Analytics**: It forecasts potential crowd build-ups using real-time and historical data, enabling proactive intervention.

D. User Interface Design

The user interface is crafted to provide quick situational awareness and simplicity of use under stress. The main design principles are:

1. Unified Control Dashboard: Everything—live feed, maps, alerts, AI recommendations—is consolidated into one view.

2. Real-Time Visual Feedback: Heatmaps and alerts update in real-time to represent the current crowd conditions.

3. Minimal Click Operations: Common operations like broadcasting alerts or changing views take few steps.

4. Collaborative Workflows: Messaging, reporting, and decision support are integrated within the UI to enable effortless task completion.

5. Adaptive Layouts: The interface adapts dynamically depending on user role (admin, on-ground officer, supervisor) and device type.

E. Admin and Content Management

The AI-based real-time crowd control system's administrative module is the operational center for management and content setup. System administrators are able to define geographic areas where surveillance and control are to be applied through a specific admin panel. Each area can be set up with distinct sensor parameters, including camera angles, resolution settings, and data sampling rates, to maximize detection accuracy depending on the environment. The platform constantly checks system health, allowing real-time monitoring of node uptime, sensor status, and data transmission integrity. Admins are able to dynamically set alert sensitivity thresholds based on crowd density trends, projected footfall, and security levels needed for a particular event. This renders the platform extremely responsive to changing conditions like concerts, protests, festivals, or emergency evacuations.Aside from real-time configuration, the admin panel accommodates strong user role and access control. Various administrative levels (e.g., supervisor, analyst, security head) can be assigned customized access to features for ensuring operational security and efficiency. The system further records and stores crowd movement data, enabling administrators to create historical analytics, identify repeating congestion patterns, and determine the effect of crowd control interventions. Event reports, such as timestamps of anomalies, maximum density records, and AI-driven interventions, are available for review and export. The admin panel, in turn, serves as the command center for proactive management to ensure safety and situational awareness in multicultural event.

System Workflow

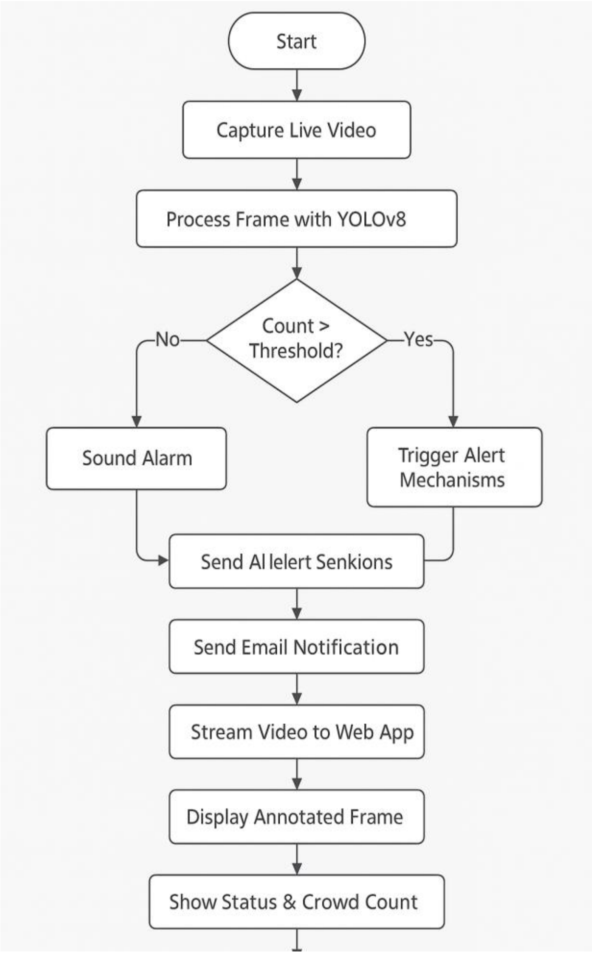

Fig. 3. DFD of the Proposed System

V. WORKING PRINCIPLE

Introduction to System Workflow

The AI-based real-time crowd control system follows a structured algorithm to enable intelligent monitoring, real-time alerts, and crowd behavior analysis. The algorithm is broken down into several steps.

Algorithm

Step 1: Integration of Sensors and Initialization of Zones

Input: Live video streams, crowd density sensors, and environmental inputs.

Process:

1. Authenticate system and initialize specified surveillance zones.

Ingest real-time feeds from CCTV, thermal cameras, or IR sensors.

Specify virtual geofences and zone boundaries for active monitoring.

Initiate continuous crowd flow tracking using AI models.

Output: Zones initialized and sensor feeds turned on for monitoring.

Step 2: Real-Time Crowd Detection and Analysis

Input: Frames of video streams and sensor data.

Process:

1. Apply AI/ML algorithms (YOLO, OpenCV) to identify people and crowd density.

2. .Estimate crowd flow direction, density, and speed.

3. Detect unusual patterns such as stagnation, overload, or panic movement.

4. Activate alerts upon dynamic threshold triggers and heatmap analyses.

Output: Real-time crowd analysis and anomaly alerts.

Step 3: AI-Driven Alert System

Input: Suspicious crowd patterns and risk trends.

Process:

1. Monitor context of crowd movement (e.g., unusual density spike).

2. Trigger contextual warnings through rule-based and predictive AI reasoning.

3. Alert based on threat level and probability of risk outcomes.

4. Notify admin dashboards and security personnel in real-time.

Output: Alerts and recommendations by AI for crowd control actions.

Step 4: Automated Response and Visualization
Input**:** Active alert or threshold breach event.
Process:

1. Imagine the crowd movement in heatmaps and live cam overlays.
2. Advise optimal crowd dispersal routes and intervention tactics.
3. Activate automated announcements or signage via connected systems.
4. Log incident information for post-event analysis. Automated safety interventions and real-time visual monitoring.

Step 5: Admin Control and Historical Analysis

Administrative UI request for data and analytics.

Process:

1. Access dashboard to view system health, sensor status, and alerts.
2. Study timelines of past events and crowd movement patterns.
3. Change zone definitions, alarm levels, or system parameters.
4. Create incident reports for strategy review and compliance.
5. Customizable system control and actionable event intelligence.

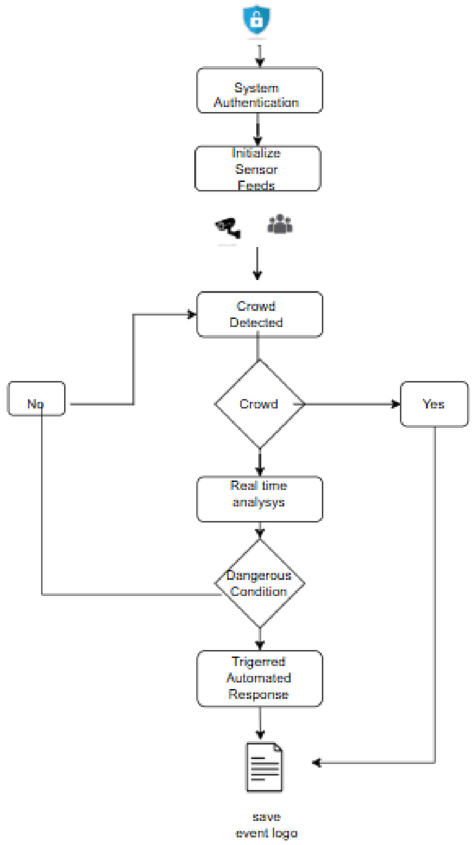

Fig. 4. Algorithm of System

VI. CONCLUSION

In this paper, we have presented the development and deployment of an AI-driven real-time crowd management system adapted to dynamic, high-density public spaces. The solution utilizes advanced artificial intelligence methods, real-time data acquisition, and centralized management features to respond to the new issues of crowd monitoring and assurance of safety. By combining surveillance streams, sensor networks, and AI-driven analytics, the system is able to detect abnormally behaving crowds, predict congestion hotspots, and facilitate timely responses.

The modular design of the system ensures scalability, flexibility, and effortless deployment. The frontend interface provides real-time visualizations and responsive admin features, while the backend handles data ingestion, AI-based analysis, and event-driven decision-making with high efficiency. The system can be deployed in various sites such as sports stadiums, city intersections, festival grounds, transportation hubs, and public events. The use of AI models, particularly in anomaly detection and predictive modeling, allows the platform to forecast crowd movement patterns and generate context-aware alerts independently.

One of the most prominent characteristics of this system is real-time decision support provided by AI-driven engines with live input to classify behavior and offer action plans accordingly. Another functionality of the system is the alert mechanism—governed by adjustable sensitivity limits—so that timely and well-directed interventions become possible.

Such alerts may be directed to on-site authorities, event promoters, or public address systems for optimum reduction of chances of stampede, bottleneck formation, or excessive crowd densities.

Admin console provides full control of system settings including zone definitions, sensor integration, role-based access, and historical report generation. Web-based, centralized dashboard provides decision-making operators with visual analysis, heatmaps, and statistical reports. Historical data are stored in a NoSQL database securely for after-event analysis, pattern detection, and performance audit of implemented crowd control measures.

Security and privacy have also been core concerns in this system's design. Data collected is encrypted and access limited by rigorous authentication procedures. Anonymized video analysis is facilitated by the system and adheres to data protection legislation to enable ethical deployment into public spaces.

The system was tested on simulated scenes with synthetic crowd data and real video streams. The performance was accurate in crowd density estimation, quick event detection, and low response times. The AI models used feedback to learn and update themselves through retraining cycles.

Overall, the proposed AI-driven crowd control system shows an efficient, intelligent, and secure model of managing crowds for mass public gatherings. It reduces reliance on human observation, enhances situational awareness, and provides for faster, data-driven action on crowd-based threats. Possible areas of research for the future involve the deployment of edge computing to reduce latency, the utilization of drone-based mobile surveillance, and the multimodal fusion of data streams such as GPS, RFID, and social media patterns to enhance situational awareness. The system is an enabler to safer, smarter cities and event management facilities

Fig. 5. Login interface of the AI-based real-time crowd control system, providing secure access for authorized personnel to monitor, analyze, and manage crowd dynamics effectively.

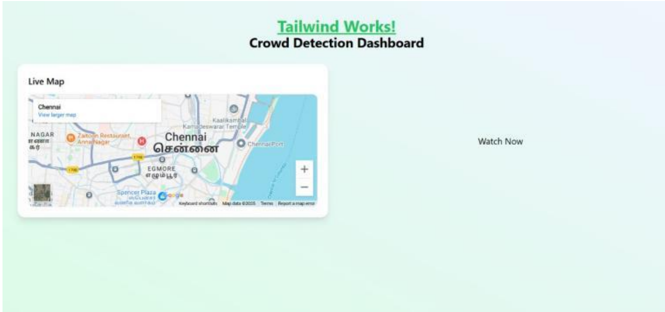

Fig. 6. Real-time crowd detection dashboard showcasing a live map of Chennai, enabling location-based monitoring and instant visualization of crowd density for efficient urban management.

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Abstract:
In densely populated environments such as transportation terminals, religious gatherings, concerts, and public festivals, real-time crowd management is critical to ensuring safety and preventing hazardous incidents like stampedes and bottlenecks. Manual monitoring methods, typically involving security personnel observing CCTV footage, are labor-intensive, prone to human error, and often reactive rather than preventive. To address these limitations, this paper proposes an AI-Based Real-Time Crowd Density Alert System that leverages deep learning and computer vision to automate the detection, monitoring, and alerting process when crowd density exceeds predefined safety thresholds.

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