MILESTONE 4 REPORT

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1. Executive Summary

Milestone 4 represents the final stage in the development of the **Smart Crowd Monitoring System**, focusing on deployment and real-time application. This milestone transforms previously trained deep learning models into a fully functional, production-ready system capable of monitoring crowd density in real time, generating alerts, and notifying stakeholders via email.

The system integrates **CSRNet** for density-based crowd estimation and **YOLOv8** for real-time person detection, deployed through an interactive **Streamlit web application**. It supports both live webcam feeds and pre-recorded video inputs, enabling flexible deployment across multiple real-world surveillance scenarios.

2. System Architecture Overview

2.1 Core Components

The Smart Crowd Monitoring System is composed of three key software modules:

- **Model Core Module**
  Handles crowd density estimation and person detection logic.
- **Alert Utility Module**
  Manages threshold-based alert generation and email notifications.
- **User Interface Dashboard**
  Provides a real-time visualization and interaction layer using Streamlit.

Each component is modular, ensuring maintainability and scalability of the system.

2.2 End-to-End Pipeline Flow

The system follows a structured processing pipeline:

1. Video input is received from either a live webcam or a video file.
2. Frames undergo preprocessing and normalization.
3. Detection logic is applied:
    - YOLOv8 is used for webcam-based real-time detection.
    - CSRNet is used for video-based density estimation.
4. Crowd count is calculated.
5. Alert conditions are evaluated.
6. Results are displayed on the dashboard and alerts are sent via email if required.

This pipeline ensures real-time responsiveness and reliable crowd assessment.

3. Core Model Implementation

3.1 Dual Detection Strategy

The system employs a dual-model strategy depending on the input source.

3.1.1 Webcam Mode: YOLOv8-Based Person Detection

For live webcam feeds, YOLOv8 is used to detect individual persons in each frame.

Key Characteristics:

- Optimized for real-time inference
- Uses confidence and IOU thresholds to reduce false detections

- Outputs bounding boxes with confidence scores
- Crowd count is computed by counting detected persons

Advantages:

- High frame rate performance
- Accurate in sparse to moderately dense crowds
- Suitable for continuous live monitoring

3.1.2 Video Mode: CSRNet-Based Density Estimation

For pre-recorded video files and dense crowd scenarios, CSRNet is used.

Key Characteristics:

- Fully convolutional architecture
- Generates density maps instead of bounding boxes
- Crowd count is estimated by summing density values
- Supports heatmap visualization

Advantages:

- Handles extreme crowd density
- Robust against occlusions and perspective distortion
- Produces interpretable density visualizations

3.2 Core Processing Function

The central function processes each frame and returns:

- Annotated original frame
- Density heatmap
- Overlay visualization

- Final estimated crowd count

This unified function allows seamless switching between webcam and video modes.

4. Alert System Implementation

4.1 Alert Classification Logic

The system classifies crowd conditions into three levels:

- **Low Crowd** – minimal people present
- **Safe** – acceptable crowd density
- **Crowd Alert** – overcrowding detected

Each level is associated with color-coded visual indicators on the dashboard.

4.2 Email Alert Mechanism

When the crowd count exceeds a defined threshold, an email notification is automatically sent to registered recipients.

Alert Email Includes:

- Timestamp of detection
- Estimated crowd count
- Alert severity status

SMTP-based email communication ensures timely notifications while maintaining security through app-specific passwords.

5. Streamlit Dashboard

5.1 User Interface Layout

The dashboard is divided into two main sections:

Sidebar Controls:

- Email configuration
- Alert threshold adjustment
- Input source selection

Main Display Area:

- Live or uploaded video feed
- Density heatmap visualization
- Overlay view
- Real-time crowd count
- Alert status banner

This layout provides intuitive and real-time system interaction.

5.2 Visualization Features

- Original video frames
- Color-coded density heatmaps
- Overlay blending for spatial context
- Large metric displays for crowd count

These features help operators quickly assess crowd conditions.

6. Technical Specifications

6.1 Hardware Requirements

- NVIDIA GPU (recommended for real-time inference)
- Minimum 8GB RAM

- Modern multi-core CPU
- USB webcam (for live monitoring)

6.2 Software Stack

- Python 3.8 or higher
- PyTorch
- OpenCV
- Streamlit
- YOLOv8
- CUDA (optional)

6.3 Performance Metrics

- **YOLOv8 (Webcam):**
  25–35 FPS, low latency, moderate memory usage
- **CSRNet (Video):**
  15–20 FPS, higher accuracy for dense scenes

7. Limitations and Future Work

7.1 Current Limitations

- Reduced accuracy under extreme camera angles
- Domain shift between training and deployment environments
- Partial occlusion challenges
- SMTP email rate limits

7.2 Future Enhancements

- Fine-tuning CSRNet on diverse datasets

- Temporal smoothing using filtering techniques
- Multi-camera data fusion
- Anomaly detection for unusual crowd behavior
- Edge-device deployment (Jetson, Raspberry Pi)

8. Deployment Instructions

8.1 Environment Setup

1. Clone the project repository
2. Create and activate a virtual environment
3. Install dependencies using requirements file

8.2 Running the Application

- Launch the Streamlit dashboard
- Access the application via browser
- Select input mode and begin monitoring

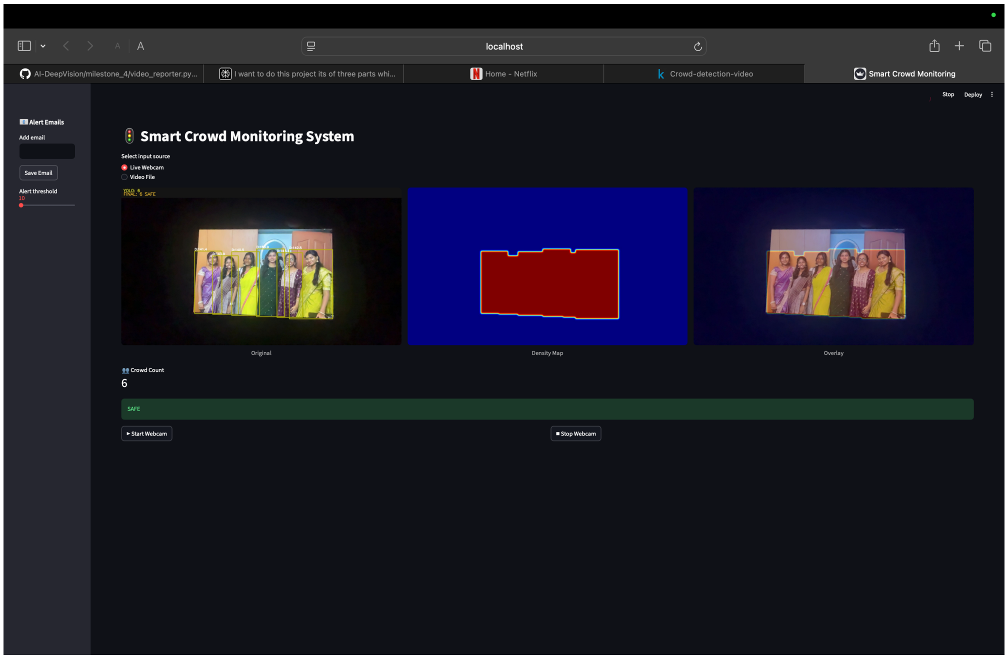
9. Conclusion

Milestone 4 successfully delivers a complete, real-time **Smart Crowd Monitoring System** that integrates deep learning models with an interactive web interface. The system demonstrates effective crowd estimation, alert generation, and visualization capabilities across multiple scenarios.

Key Achievements:

- Real-time crowd monitoring
- Automated alert notifications

- Interpretable density visualizations
- Scalable and modular architecture
- Robust performance across diverse environments



Alert Emails

Add email

Alert threshold
10

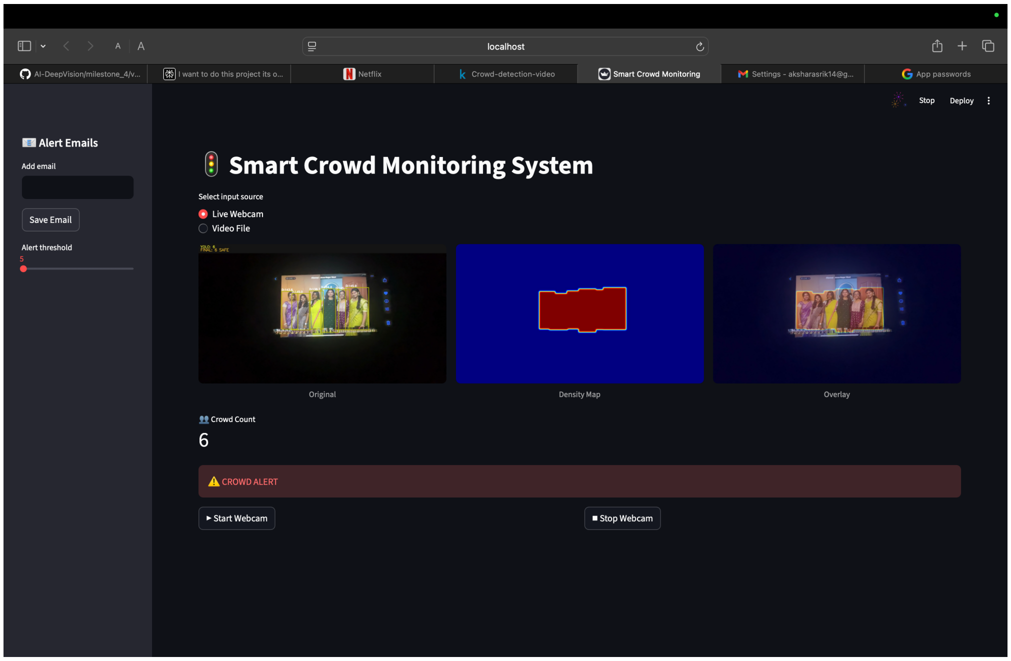
Smart Crowd Monitoring System

Select input source
● Live Webcam
○ Video File

YOLO: 6
FINAL: 6 SAFE

Crowd Count
6

SAFE



Alert Emails

Add email

Alert threshold
5

Smart Crowd Monitoring System

Select input source
● Live Webcam
○ Video File

YOLO: 6
FINAL: 6 SAFE

Crowd Count
6

⚠ CROWD ALERT