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AI DeepVision – Crowd Monitoring Project

1. Introduction

Crowd monitoring is an important task for public safety in areas such as malls, stadiums, festivals, and public transport. Manual monitoring is slow and inaccurate. Modern computer vision enables automated crowd density estimation using deep learning.

This project builds an AI-based system that:

- Estimates number of people in an image
- Generates density heatmaps showing crowd distribution
- Detects overcrowding levels

2. Dataset Description

We use the ShanghaiTech Crowd Counting Dataset and it has two parts:

part	characteristics	difficulty
Part-A	Highly crowded scenes, dense crowds	Hard
Part-B	Outdoor scenes, fewer people	Easier

Each sample contains:

- RGB Image
- Ground truth (.mat file) containing (x, y) head locations

The folder structure looks like:

```
- ShanghaiTech
  |- part-A
    |- test_data
      |- ground-truth/
      |- images/
    |- train_data
      |- ground-truth/
      |- images/
```

```

|- part-B
  |- test_data
    |- ground-truth/
    |- images/
  |- train_data
    |- ground-truth/
    |- images/

```

3. Problem With Raw Ground Truth

Ground-truth gives points only => not suitable for training CNN directly.

So, we convert points => **density maps**

Each head point contributes to a **Gaussian peak** => sum of density = **count of people**

4. Preprocessing Pipeline

Performed on both Part-A and Part-B data using the following steps:

Step	Purpose
Convert BGR – RGB	Standard colour format for deep learning
Resize Images (512×512)	Uniform input size
Create Impulse Map (zeros + head locations=1)	Binary head map
Gaussian Blur ($\sigma=1.5\text{--}4$)	Converts impulses → density distribution
Downsample to 1/8 resolution	To match CSRNet output
Save as .npy	Efficient numeric storage

Sum of density map = number of people in image

5. Density Map Visualization

We displayed:

- Image with head annotations
- Impulse map (binary points)
- Density map (heat style)
- Heatmap overlay on original image

This helps verify dataset correctness.

6. Why Downsample Density Map?

CSRNet has pooling layers → output is **1/8 size** of input.

Input: 512×512

Output: 64×64

So, GT density must be downsampled to same size.

To preserve crowd count, multiply by 64 (8×8).

7. Dataset Splitting

For training the model, split the training data to 80% for training and 20% for testing

And Testing data keeps separate.

8. Model Architecture – CSRNet

CSRNet = **Convolutional Neural Network** for crowd counting.

Component	Description
Frontend	VGG-16 style feature extractor
Backend	Dilated CNN to enlarge receptive field
Output Layer	1-channel density map

CSRNet is used because It

- Works for both dense & sparse crowds
- No detection required → faster
- Accurate counting from density estimation

9. Training Setup

Feature	Value
Loss Function	MSE Loss (pixel-wise density difference)
Optimizer	Adam
Learning Rate	1e-5
Batch Size	4
Epochs	100

Monitoring Metrics

- Train Loss
- Validation Loss
- Train MAE
- Validation MAE

MAE → Measures counting accuracy:

$$\text{MAE} = |\text{Predicted Count} - \text{Actual Count}|$$

For part-A, the test results are

MAE : 98.13

MSE : 19226.94

RMSE : 138.66

For part-B, the test results are

MAE : 22.83

MSE : 1190.72

RMSE : 34.51

10. CSRNet Crowd Counting — Model Loading, Image Testing, Video Processing & Webcam Inference

a. Loading the CSRNet Model & Trained Weights

After training CSRNet on ShanghaiTech Part-A/Part-B datasets, the trained .pth model files are loaded into the system.

This allows the model to perform inference without retraining.

Steps:

1. Import CSRNet model architecture.
2. Move the model to CPU device.

3. Load the trained weights (CSRNet_best.pth or CSRNet_best_2.pth).
4. Set model to evaluation mode.

Purpose:

- ✓ Load the trained model
- ✓ Avoid backpropagation
- ✓ Enable prediction on new images/videos

b. Testing Prediction on a Single Image

To verify that the model works correctly after loading, a simple image is tested.

Steps:

1. Read image using OpenCV.
2. Convert BGR → RGB (CSRNet expects RGB).
3. Normalize using ImageNet mean and std.
4. Convert image into PyTorch tensor.
5. Feed the tensor into CSRNet.
6. Get the density map and compute total count.
7. Overlay heatmap on original image for visualization.

Purpose:

- ✓ Confirm the model predicts count properly
- ✓ Understand density map behavior
- ✓ Visualize crowd intensity on image

c. Video Processing (Frame-by-Frame Crowd Counting)

CSRNet is applied on each frame of a video to generate real-time predictions.

Steps:

1. Open a video file using cv2.VideoCapture()
2. Loop through video frame-by-frame
3. Preprocess each frame
4. Predict density map
5. Sum density values to get person count
6. Generate heatmap and overlay on frame
7. Display frame inside notebook
8. Continue until video ends

Purpose:

- ✓ Handle dynamic scenes
- ✓ Demonstrate CSRNet on real video
- ✓ Produce visual heatmaps for each frame

d. Real-Time Crowd Counting with Live Webcam

After video prediction works, the next step is live webcam inference.

Steps:

1. Open webcam feed (VideoCapture(0))
2. Read frames continuously
3. Resize frame to match CSRNet crowd scale

4. Preprocess frame
5. Predict density map
6. Clip negative density values (avoid negative counts)
7. Compute final count
8. Overlay heatmap + display live
9. Exit when user presses q

Purpose:

- ✓ Create a real-time crowd monitoring system
- ✓ Display real-time heatmap and person count
- ✓ Demonstrate final working model in practical use

11. Fine-Tuning

a. Why Fine-Tuning Is Required

Pre-trained CSRNet models are trained on datasets like ShanghaiTech, which differ from:

- Real-time CCTV footage
- Camera angle
- Lighting conditions
- Crowd distribution

So, directly applying a pre-trained model gives **poor accuracy**.

Fine-tuning adapts the model to our real-world data.

b. Overall Workflow (High-Level)

Video => Frames => Pseudo Head Points

- Gaussian Density Maps
- Dataset Preparation
- CSRNet Fine-Tuning
- Real-Time Inference

c. Dataset Preparation

Video to Frames

- Real-time or recorded crowd videos were collected.
- Videos were converted into individual frames.
- These frames represent real-world crowd scenes.

Purpose:

CSRNet is trained on images, not directly on videos.

d. Pseudo Head Annotation (No Manual Labeling)

Manual annotation of head points is time-consuming and impractical.

Instead, we used:

- A pre-trained CSRNet model
- Generated pseudo head annotations automatically

Steps:

1. Each frame is passed through pre-trained CSRNet
2. A density map is obtained
3. Local peaks in density correspond to head locations

This method is:

- Research-accepted
- Scalable
- Similar to ShanghaiTech labelling

e. Density Map Generation

CSRNet does not train on head points, it trains on density maps.

f. Gaussian Density Map

For each head point:

- A **Gaussian kernel** is placed
- All kernels are summed to form a density map

Properties:

- Integral of density map \approx crowd count
- Smooth spatial representation
- Stable training

g. Downsampling Density Maps

CSRNet architecture downsamples input images due to pooling layers.

Therefore:

- Ground truth density maps must match model output resolution

Rule:

If input image is $H \times W$

CSRNet output is $(H/8) \times (W/8)$

So:

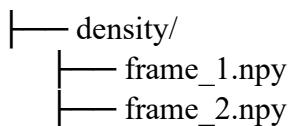
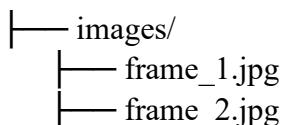
1. Density map is created at original resolution
2. Then downsampled by factor 8
3. Density values are scaled to preserve count

This step is critical for correct training.

h. Dataset Structure

The final dataset is organized as:

dataset/



- Each image has a corresponding density map
- Density maps are 2D arrays
- Shapes match CSRNet output

i. CSRNet Model Architecture

CSRNet consists of:

Frontend

- Based on VGG-16
- Extracts low-level and mid-level features

Backend

- Dilated convolutions
- Enlarged receptive field
- Preserves spatial resolution

Output Layer

- Single-channel density map

Output:

Density Map => Sum => Crowd Count

j. Training Configuration

8.1 Loss Function

- Mean Squared Error (MSE)
- Measures difference between predicted and ground-truth density maps

Why MSE?

- Standard loss used in CSRNet
- Stable for density regression

k. Optimizer

- Adam Optimizer
- Very low learning rate

Reason:

We are fine-tuning, not training from scratch.

l. Fine-Tuning Strategy

Fine-tuning is done in two phases.

(i) Phase-1: Backend-Only Training

- Frontend (VGG) layers are frozen
- Only backend layers are trained

Purpose:

- Adapt density estimation to new crowd patterns
- Avoid destroying pre-trained features

Duration:

- Few epochs (5–10)

Expected behavior:

- Loss decreases steadily
- Counts become reasonable

(j) Phase-2: Full Network Fine-Tuning

- Frontend layers are unfrozen
- Entire network is trained

Purpose:

- Adapt model to camera angle, lighting, and perspective
- Improve accuracy further

Duration:

- More epochs (20–40)

m. Training Validation

During training, we verified:

- Loss decreases across epochs
- No shape mismatch errors
- Predicted count ~ Ground truth count
- Density blobs align with heads

This confirms correct fine-tuning.

n. Final Model Output

The fine-tuned CSRNet produces:

- A density map
- Crowd count = sum of density
- Works well on real-world scenes

12. Dashboard

The Crowd Monitoring Dashboard is a web-based application designed to analyze crowd density using a fine-tuned CSRNet deep learning model.

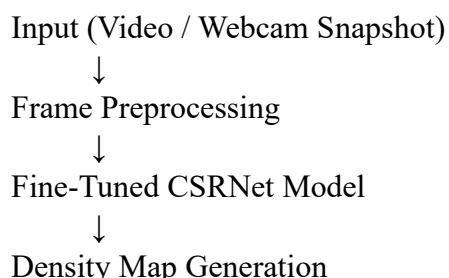
The system processes uploaded videos and webcam snapshots to estimate crowd count, visualize density maps, and generate automated alerts when overcrowding is detected.

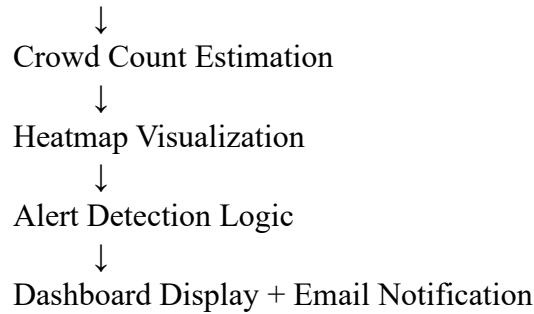
The dashboard is built using Streamlit, enabling an interactive and user-friendly interface suitable for real-time monitoring, demonstrations, and academic projects.

Objectives

- To visualize crowd density heatmaps
- To estimate accurate crowd count in dense scenes
- To detect overcrowding situations
- To provide email alerts using SMTP
- To support video input and webcam snapshots
- To deploy the system as a local web dashboard

System Architecture





Dashboard Overview

The dashboard provides:

- Live visualization of crowd density
- Numerical crowd count
- Overcrowding alert status
- Email notification on alert
- User-controlled alert threshold

Model Loading Module

- Loads the fine-tuned CSRNet model
- Automatically selects **GPU if available**, otherwise CPU
- Uses **cached loading** for efficiency
- Downloads the model from Google Drive if not found locally

Advantages:

- Reduces load time
- Ensures portability across systems

Input Modes

Video Upload Mode

- User uploads a crowd video (.mp4, .avi)
- Frames are extracted sequentially
- Each frame is processed through CSRNet
- Density map and crowd count are updated continuously

Webcam Snapshot Mode

- Uses browser-based webcam (`st.camera_input`)
- Each captured image is processed like a video frame
- Density map, count, and alert are generated for every snapshot

Frame Preprocessing

Each frame undergoes:

- BGR → RGB conversion
- Normalization using ImageNet statistics
- Conversion to PyTorch tensor
- Transfer to computation device (CPU/GPU)

This ensures compatibility with CSRNet training conditions.

Density Map & Heatmap Visualization

- CSRNet outputs a density map
- Density map is resized to frame resolution
- A color heatmap (JET) is applied
- Heatmap is overlaid on the original frame

Purpose:

- Visual understanding of crowd concentration
- Identification of high-density regions

Crowd Counting

Crowd count is computed as:

$$\text{Crowd Count} = \text{Sum of Density Map Values}$$

To reduce fluctuations:

- A sliding window smoothing method is applied
- Average of last N frames is displayed

Alert Detection Logic

- User sets alert threshold via slider
- Alert is triggered when smoothed count exceeds threshold
- Visual alert is shown on dashboard
- Email alert is sent once per alert event

This avoids false positives and email spamming.

Email Alert System (SMTP)

Functionality:

- Sends automated email alerts during overcrowding
- Includes crowd count and timestamp

Security:

- Uses Gmail App Password
- Avoids exposing real email credentials

Dashboard Output

The dashboard displays:

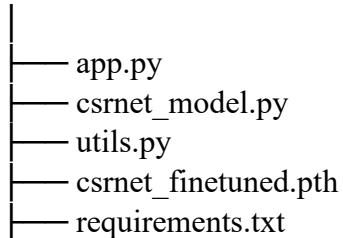
- Heatmap-overlaid frames
- Crowd count
- Alert status (NORMAL / OVERCROWDING)
- Email notification on alert

Deployment

The system is deployed as a local Streamlit web application

Project Directory Structure

AI-DeepVision/dashboards/dashboard_1 & dashboard_2



Running the Application

streamlit run app.py

Application opens at:

<http://localhost:8501>

Conclusion

The Crowd Monitoring Dashboard successfully integrates deep learning, computer vision, and web technologies to provide an intelligent crowd analysis system.

By combining a fine-tuned CSRNet model with Streamlit visualization and SMTP alerts, the system offers a practical, scalable, and real-world-ready solution for crowd safety and monitoring.