TRINETRA

28.05.2025

Harsh Vardhan , Sujal Chondhekar , Piyush Jain , Rakshit Mondanwal , Sumit Kumar
IIIT Nagpur

⭐Project Title

❖ **TRINETRA**

➢Targeted Retail Insights via NETworked Real-time Analytics

"Smart Surveillance and Customer Behavior Analytics System Using Multi-Camera Computer Vision"

⭐Project Objectives

- Track customer footfall and movement inside a shop or cafe using CCTV feeds.
- Recognize repeat customers and personalize experiences through facial recognition.
- Extract behavioral and transactional insights such as waiting time, purchase habits, and service quality.
- Monitor staff performance and recommend operational improvements.
- Associate external vehicle data with customer identity for extended profiling.

System Architecture Overview

```
Camera Feeds → Central Server → Processing Modules:
- Entrance Count Module
- Face Recognition Module
- Object & Clothing Descriptor
- Billing Camera Analysis
- Vehicle Recognition Module
↓
Unified Customer Profile Database + Staff Performance Dashboard
```

⭐Core Modules and Functions

1. Entrance Count Module

- **Purpose**: Count number of people entering and exiting.
- **Tech**: Background subtraction or YOLO/Detectron2 + tracking (Deep SORT or ByteTrack).

2. Face Recognition & Identification

- **Purpose**: Match faces to existing database.
- **Tech**: FaceNet / Dlib / DeepFace for embedding; cosine similarity for matching.

3. Customer Journey Tracker

- **Purpose**: Track movements across different cameras.
- **Tech**: Multi-camera person re-identification using appearance and trajectory cues.

4. Billing Counter Matcher

- **Purpose**: Match customer with bill data using face detection and timestamp correlation.
- **Tech**: OCR for bill details + face alignment.

5. Object & Attire Description

- **Purpose**: Describe what the customer is wearing or carrying.
- **Tech**: CLIP or BLIP models + object detection and captioning.

6. Behavioral Insights Engine

- **Features**:
    - Waiting time (arrival to bill time)
    - Repeat orders/favorite items
    - Companion identification
    - Staff member interaction
    - Avg. order value per visit

7. Vehicle Monitoring Module

- **Purpose**: Extract and match vehicle numbers to customers.
- **Tech**: License Plate Recognition (LPR) models like OpenALPR or PaddleOCR.

📊 Output & Applications

For Management:

- Staff analytics and performance dashboard
- Heatmaps of customer flow and service time
- VIP or high-value customer alerts

For Staff:

- Notification of regular or VIP customers
- Behavioral tips based on previous history
- Smart recommendations on service approach

🔐 Ethical Considerations

- **Privacy**: Ensure data encryption, consent notices, and opt-out options.
- **Bias Mitigation**: Use diverse datasets for training facial recognition and re-identification models.
- **Compliance**: Align with GDPR or local data protection laws.

🧾 Possible Tech Stack

Component	Suggested Tools
Face Recognition	DeepFace, Dlib, FaceNet
Object Detection	YOLOv8, Detectron2
Tracking	Deep SORT, ByteTrack
OCR	Tesseract, PaddleOCR
Captioning	BLIP, CLIP, ImageBind
Backend	Flask/FastAPI, PostgreSQL
Frontend Dashboard	React.js + D3.js or Streamlit
Camera Feed	RTSP ingestion via OpenCV or FFmpeg

⭐Research Papers

➤Here are some research papers closely aligned with your project on customer tracking and behavioral analytics in retail using computer vision:

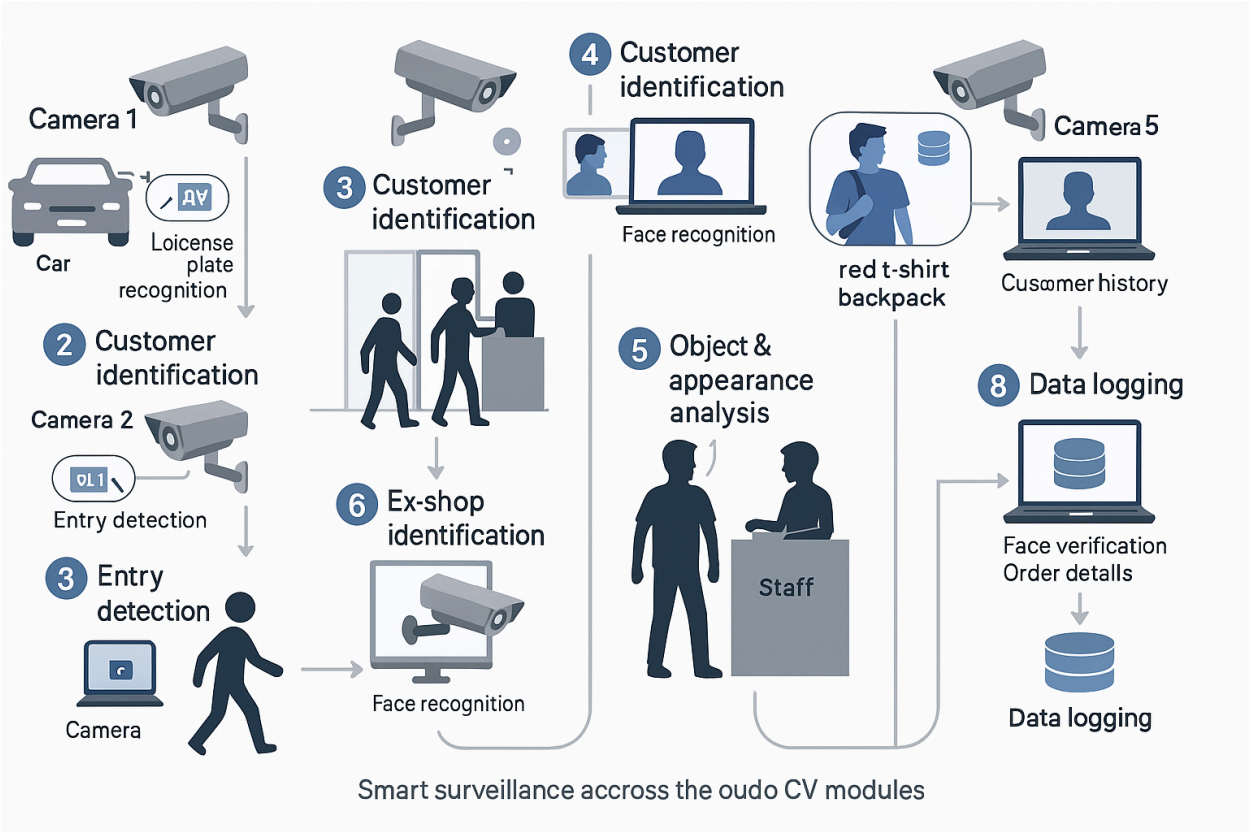
📚 Relevant Research Papers

No.	Title	Summary
1	**Advanced Customer Behavior Tracking and Heatmap Analysis with YOLOv5 and DeepSORT** (Mohamed et al., 2024)	Uses YOLOv5 and DeepSORT to analyze customer movement, generate heatmaps, and optimize product placement in real-time.
2	**System and Method for Retail Customer Tracking in Surveillance Camera Network** (Burke, 2016, Patent)	Describes a multi-camera retail tracking system matching faces at POS to earlier footage for behavior and interaction analysis.
3	**Towards In-Store Multi-Person Tracking Using Head Detection and Track Heatmaps** (Musaev et al., 2020)	Uses head detection and heatmaps for accurate multi-person tracking in store environments, addressing occlusions and trajectory mapping.
4	**Video-CRM: Understanding Customer Behaviors in Stores** (Haritaoglu et al., 2013)	One of the earliest systems for group detection at checkout and product interaction tracking using stereo cameras.
5	**Deep Learning-Based Approach to Detect Customer Age, Gender, and Expression in Surveillance Video** (Ijjina et al., 2020)	Proposes WideResNet and Xception for demographic and emotion detection in low-quality retail CCTV footage.

These papers can guide both your implementation strategy and technical choices for modules like face tracking, multi-camera identity re-matching, behavioral analytics, and demographic tagging.

⭐WORKFLOW

➤Here's a **comprehensive end-to-end workflow** for your **TRINETRA** system — from the **moment a customer arrives** at the shop until they **exit** — detailing every **camera's role**, every **analytic recorded**, and how the system interacts in real time.



Smart surveillance accross the oudo CV modules

🧠 TRINETRA Smart Surveillance Workflow

🏪 Scenario:

A customer visits a retail store equipped with **multi-camera AI-powered computer vision system**.

🟢 1. Customer Arrival (Outside the Shop)

🎥 Camera 1: Outdoor Entry Camera

Function: Detects approaching individuals and vehicles.

- **License Plate Recognition (LPR):**
    - Detects and OCRs vehicle number using **OpenALPR** or **PaddleOCR**.
    - Matches to existing customer database.
    - Links vehicle ID to customer profile.

🚶 2. Entry Detection

🎥 Camera 2: Overhead Entrance Camera (Inside)

Function: Detects when people enter or exit.

- **People Detection** (YOLOv8) + **Tracking** (ByteTrack or Deep SORT)
    - Draws virtual line across entrance to classify entry vs exit.
    - Increments **footfall count**.
    - Triggers the **Face Capture Event** on entry.

🧑 3. Customer Identification

🎥 Camera 3: Face Recognition Camera at Entry

Function: Captures face and runs recognition.

- **Face Detection + Embedding Comparison** (DeepFace or face_recognition)
    - If **recognized**:
        - Fetches **Customer ID** from database.
        - Adds timestamped **visit log**.
    - If **unrecognized**:
        - Classifies as **new customer**.
        - Stores face encoding and snapshot.
        - Flags for **registration at billing counter**.

🕵️ 4. In-Shop Tracking

🎥 Camera 4: Top-View or Corridor Cameras

Function: Re-identifies and follows customer through store.

- **Person Re-ID** based on face, clothing (color histograms), or deep embeddings.
- Logs:
    - **Dwell time** at different zones
    - **Movement path (heatmap)**
    - **Waiting time** (e.g. in queue)

🤖 5. Object & Appearance Analysis

🧠 Triggered on Any Camera Where Full Body Visible

Function: Describes what the customer is **wearing or carrying**.

- **Object Detection + Image Captioning** (YOLOv8 + CLIP/BLIP)
- Output:
    - "Red t-shirt, black jeans, carrying backpack"
    - Saved as **text description** in customer profile.

🧾 6. Billing & Final Face Confirmation

🎥 Camera 5: Billing Counter Camera

Function: Captures face + context at checkout.

- **Face Verification**:
    - Cross-matches with entry face → confirms identity.
- **Fetch Bill Details** (manual input or POS system OCR)
    - Total order value
    - Items bought
    - Staff name serving them
- **Logs:**
    - Visit duration = Exit time - Entry time
    - Average order value

- Most frequent purchases (over time)

🟣 7. Exit Detection

🎥 Camera 2 (Reused): Exit Line Crossing

Function: Detects when person leaves.

- Tracking ID used to mark exit time.
- Updates visit record with:
  - **Total time spent**
  - **Zone-specific time**
  - **Queue duration**
  - **Served by staff X**

📊 8. Real-Time Data Logging & Dashboard Update

- **Database Updated:**
  - `Customer_Profile`
  - `Visit_History`
  - `Vehicle_Tracking`
  - `Staff_Interaction`
- **Dashboard Triggers:**

- Regular customer alert
- High-value customer → Assign experienced staff
- VIP alerts for staff awareness

🛡️ 9. Privacy & Security Checks

- Unknown faces are **blurred** or **anonymized**.
- All embeddings are **encrypted**.
- Data is retained under **consent-driven retention policies**.

📉 Sample Timeline

Time	Action	Module
10:02	Vehicle detected	LPR
10:03	Face captured at entrance	Face Recognition
10:04	Customer enters store	Person Counting
10:06–10:15	Browsing inside	Re-ID + Tracking
10:16	At billing	Face match + POS link
10:18	Exits shop	Exit tracking