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FORENSIC FACE SKETCH CREATION AND RECOGNITION SYSTEM

A Hybrid Dual-Embedding Forensic Face Recognition System with Integrated Case Management for Law Enforcement

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Abstract: Identifying criminal suspects from eyewitness descriptions remains a critical yet challenging task in forensic investigations. Traditional methods heavily rely on manual forensic sketches created by specialized artists, which are extremely time-consuming, highly subjective, and severely limited by the availability of trained professionals. Furthermore, the inherent modality gap between abstract hand-drawn sketches and realistic digital photographs significantly degrades automated matching accuracy, often resulting in high false positive and false negative rates.

This paper presents Forensic Face Sketch Creation and Recognition System, a complete full-stack AI-powered forensic investigation platform designed specifically for law enforcement agencies. The system integrates dual deep learning embeddings using InsightFace and FaceNet512 with an interactive drag-and-drop sketch builder that enables rapid composite sketch creation without requiring any artistic expertise. Advanced preprocessing techniques such as OpenCV-based face alignment, Canny edge detection, and Test-Time Augmentation (original, flip, and $\pm 5^\circ$ rotation) are applied to effectively reduce the sketch-photo domain gap. A hybrid similarity scoring mechanism combining InsightFace and FaceNet512 embeddings, along with weighted multi-region facial analysis (eyes, nose, mouth) and geometric similarity, further enhances matching robustness. Fast retrieval is achieved through a FAISS-based two-stage pipeline with Z-score re-ranking.

In addition, the platform features a comprehensive Case Management module that includes real-time investigation dashboards, crime-type analytics, timestamped case timelines, AI match-linked suspects with confidence scores, evidence upload support, and note tracking. By providing an end-to-end solution—from sketch creation and intelligent matching to complete case lifecycle management—the proposed system significantly reduces manual effort, accelerates investigative workflows, and delivers high matching robustness in real-world operational environments.

Index Terms - Forensic Face Recognition, Sketch-to-Photo Matching, InsightFace, FaceNet, Test-Time Augmentation, FAISS, Multi-Region Analysis, Canny Edge Detection, Case Management System.

I. INTRODUCTION

In modern criminal investigations, identifying suspects often relies heavily on eyewitness testimonies, especially when objective evidence such as CCTV footage is unavailable. Forensic face recognition plays a crucial role in such scenarios, where a facial sketch is created based on eyewitness descriptions and then compared against law enforcement databases of known individuals. Although this technique has long been used in forensic science, traditional sketch-based identification methods suffer from several limitations that affect both accuracy and efficiency.

One of the primary challenges is the inherent subjectivity and susceptibility to human error. The process depends on an eyewitness's ability to accurately recall facial features, often under stressful conditions, along with the forensic artist's interpretation and drawing skills. As a result, generated sketches may contain missing details, distortions, or inconsistencies. Additionally, the manual sketching process is time-consuming and slow, which can delay investigations. The limited availability of trained forensic artists further restricts scalability in real-world law enforcement environments.

Another significant challenge is the modality gap between sketches and photographs. Hand-drawn sketches are abstract representations that lack texture, color, and fine-grained details present in real images. This difference makes it difficult for traditional face recognition systems to accurately match sketches with photographs, often leading to high false positive and false negative rates.

To address these challenges, there is a growing need for automated, AI-based forensic face recognition systems. Such systems can reduce dependency on manual sketching by providing intuitive interfaces that allow users to generate composite sketches using predefined facial components. Furthermore, deep learning techniques offer an effective solution to the cross-modality matching problem. By leveraging Convolutional Neural Networks (CNNs) and embedding-based models such as FaceNet [1] and InsightFace [13], facial features can be transformed into high-dimensional numerical representations. These embeddings project both sketches and photographs into a common feature space, enabling efficient similarity comparison using cosine distance metrics. Incorporating multi-region facial analysis—including eyes, nose, and mouth—further improves recognition accuracy.

Overall, AI-driven forensic face matching systems provide a scalable, accurate, and efficient approach for criminal identification, significantly improving the speed and reliability of modern investigative processes. In addition to face recognition, modern forensic systems require effective case management capabilities. Therefore, the proposed Forensic Face Sketch Creation and Recognition System also integrates a complete case management module to organize investigations, track evidence, and manage suspect information efficiently.

II. LITERATURE SURVEY

Table I. Summary of Related Work in Forensic Face Recognition

Author(s) & Year	Proposed Work	Research Gap
Taigman et al. (2014)	Deep CNN with 3D alignment for near-human face verification	Poor performance on sketches, no cross-domain support
Schroff et al. (2015)	Triplet loss based 512-D embedding for direct face similarity measurement	Single model only, no sketch-to-photo support
Galea & Farrugia (2017)	Deep CNN with transfer learning for sketch-to-photo matching	No hybrid model, no real-time full-stack system
Deng et al. (2019)	Angular margin loss for highly discriminative identity features	No support for cross-domain (sketch) matching
Bahrum et al. (2023)	Comprehensive review of CNN, GAN and embedding techniques + datasets	Only review paper, no practical implementation
Patil et al. (2024)	OpenCV-based image processing (contour, edge detection) for real-world use	Not designed for face/sketch recognition
Pasunuri et al. (2025)	ArcFace + FAISS indexing + multi-region comparison + sketch builder	Single model, no TTA and edge preprocessing
Shilpa R. et al. (2025)	FaceNet embeddings with drag-and-drop sketch builder and database matching	No hybrid fusion, no multi-region weighted scoring
Jung et al. (2025)	Test-time augmentation (flip + rotation) for improved robustness	No integration with hybrid embeddings or case management

Forensic face sketch recognition plays a vital role in law enforcement when photographic or video evidence is unavailable. Traditional methods depend entirely on forensic artists who convert eyewitness descriptions into hand-drawn sketches, which are then matched manually against mugshot databases. However, this approach is highly subjective, time-consuming, error-prone, and limited by the shortage of trained artists [3].

2.1. Evolution of Deep Learning in Face Recognition

The introduction of deep learning brought major improvements in the field. DeepFace [12] was one of the first systems to achieve near-human performance using deep convolutional networks and 3D alignment. While successful on real photographs, it faced difficulties with sketches due to the domain gap.

A significant advancement came with FaceNet [1], which maps faces into a compact 512-dimensional embedding space using triplet loss, enabling direct similarity measurement through cosine distance and maintaining robustness to lighting and pose variations. Building on this foundation, InsightFace [13] has emerged as a highly efficient and robust embedding model, offering superior performance in cross-domain scenarios such as sketch-to-photo matching.

2.2. Forensic Sketch-to-Photo Matching Systems

Several studies have specifically targeted the sketch-to-photo challenge. Galea and Farrugia [3] proposed a deep learning architecture that reduced matching errors by over 80% using transfer learning. Bahrum et al. [4] provided a systematic review of various CNN, GAN, and embedding techniques, highlighting popular benchmark datasets such as CUFS and CUFSF.

Recent works have moved closer to practical deployment. Pasunuri et al. [5] developed an ArcFace-based system with FAISS indexing and multi-region comparison. Shilpa et al. [6] integrated sketch builders with embedding-based database search. Additionally, Patil et al. [7] demonstrated the effectiveness of OpenCV for image preprocessing in real-world applications, offering useful insights for domain adaptation.

2.3. Generative Approaches

To reduce the modality gap, researchers have explored Generative Adversarial Networks (GANs) such as CycleGAN and Conditional GANs. These models convert sketches into photorealistic images and achieve 80–85% recognition accuracy. However, they are computationally intensive and occasionally lose fine identity-specific details during the generation process.

2.4. Research Gaps

Despite significant advancements in forensic face recognition, several limitations persist in current systems. Most existing approaches primarily focus on recognition accuracy using single or dual embedding models but often lack complete system-level integration required for real-world deployment. Many systems rely solely on face recognition models without incorporating hybrid techniques such as combined embeddings (InsightFace [13] and FaceNet512 [1]), multi-region analysis, and advanced preprocessing methods including edge detection and Test-Time Augmentation. This limits robustness when handling sketch-based inputs. Furthermore, while some recent works explore sketch-to-photo matching and embedding-based retrieval, they do not adequately address scalability and efficient database search for large criminal datasets.

Most critically, existing research largely overlooks the integration of case management functionalities. Real-world forensic investigations require not only accurate face matching but also structured case handling, evidence management, suspect tracking, and investigation monitoring. The proposed system addresses these gaps by integrating a hybrid deep learning approach with a comprehensive case management module, thereby providing a complete end-to-end forensic investigation platform.

III. PROPOSED METHODOLOGY

This section presents the complete design and working of the proposed system—an AI-powered forensic investigation platform that integrates facial sketch recognition with a comprehensive case management system. The platform is designed to assist law enforcement agencies by providing a unified, production-ready environment for sketch creation, intelligent face matching, and end-to-end investigation tracking.

3.1. System Objectives

The key objectives of the proposed system are as follows:

- 1) To enable officers to create or upload forensic sketches without requiring artistic expertise.
- 2) To perform real-time sketch-to-photo matching using advanced deep learning models.
- 3) To provide an integrated case management system for tracking investigations, evidence, suspects, and timelines.
- 4) To ensure secure, scalable, and production-ready deployment using cloud technologies and role-based authentication.

3.2. System Architecture

The system follows a modular full-stack architecture consisting of four primary components, as illustrated in Fig. 1.

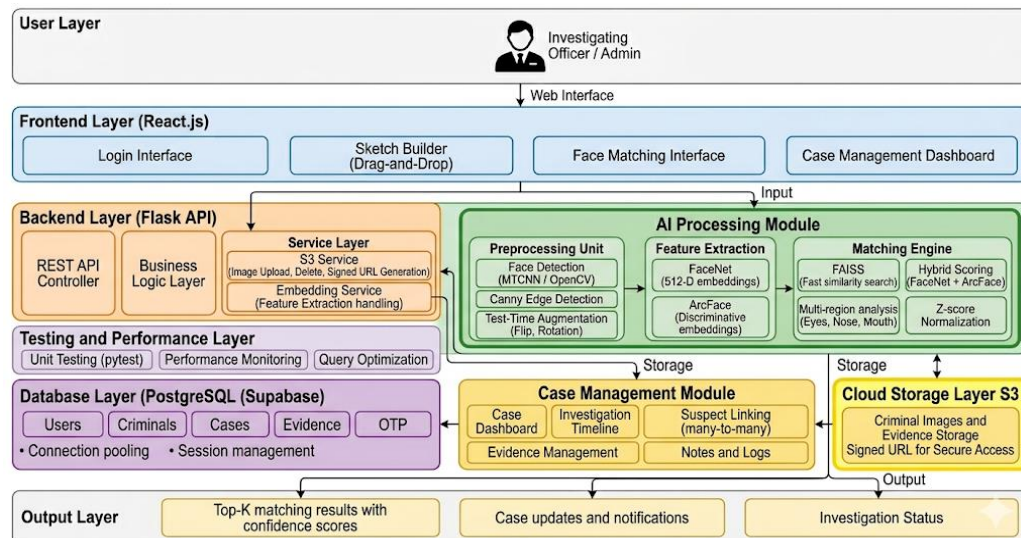


Fig. 1. Overall System Architecture of the Proposed System

The four primary components are described as follows:

- 1) Frontend: Developed using React.js, providing responsive interfaces for sketch creation, face comparison, case management dashboards, and database interaction.
- 2) Backend: Implemented using Python Flask, handling API requests, authentication, business logic, and communication between modules.
- 3) Database: PostgreSQL hosted on Supabase with connection pooling and session management for high scalability and reliability.
- 4) AI Module: Hybrid recognition system integrating InsightFace [13] and FaceNet512 [1] for robust feature extraction and matching, with images stored securely on AWS S3.

3.3. Authentication and Security

The system implements Role-Based Access Control (RBAC) with two roles: Admin and Officer. Admin users authenticate using email, password, and OTP-based two-factor authentication, while officers use email and password with enforced password reset policies. JWT tokens secure all API access. All criminal images are stored on AWS S3 with signed URLs, ensuring data security and scalability.

3.4. Preprocessing and Dual Embedding Extraction

Input images (sketch or photograph) undergo preprocessing using OpenCV. Face detection and alignment are performed, followed by Canny edge detection to reduce the modality gap. Test-Time Augmentation (TTA)—including flipping and $\pm 5^\circ$ rotation—is applied to improve robustness. Dual embeddings are then extracted using:

- 1) FaceNet512 [1] for capturing global facial geometry and structural features.
- 2) InsightFace [13] for high-accuracy discriminative feature extraction and robust cross-domain matching.

3.5. Hybrid Scoring and Matching Pipeline

The system employs a two-stage matching pipeline:

- 1) Stage 1 — Retrieval: FAISS IndexFlatIP is used for efficient top-K similarity search across the criminal database.
- 2) Stage 2 — Re-ranking: Hybrid scoring combines InsightFace [13] and FaceNet512 [1] embeddings, weighted multi-region facial analysis (eyes, nose, and mouth), geometric similarity, and Z-score normalization to produce final confidence scores.

3.6. Sketch Builder

The system provides an interactive drag-and-drop interface that allows officers to construct composite facial sketches using predefined facial components such as hair, eyes, nose, and lips. The generated sketches are exported directly for use in the face matching pipeline, eliminating the need for trained forensic artists.

3.7. Case Management Module

The proposed system includes a comprehensive case management module designed to support real-world forensic investigations, as shown in Fig. 2.

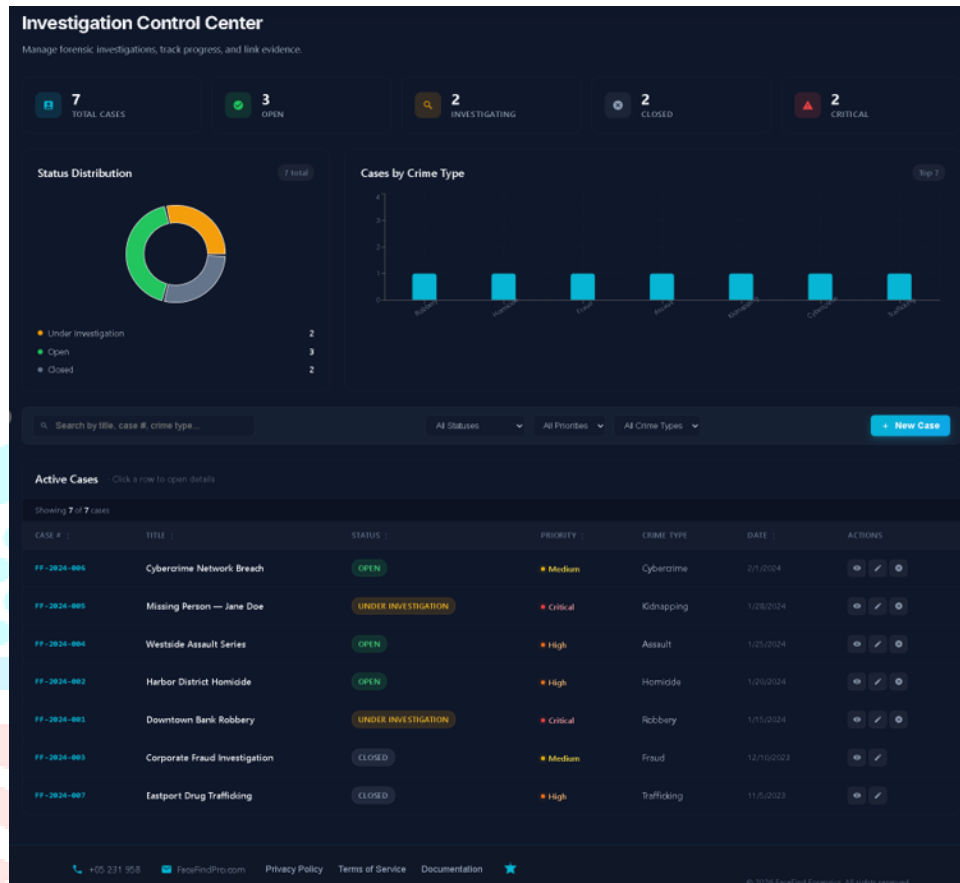


Fig. 2. Case Management Dashboard Interface

The dashboard provides real-time statistics including total cases, open cases, ongoing investigations, and closed cases. It also includes visual analytics such as pie charts and bar graphs representing case distribution and crime categories.

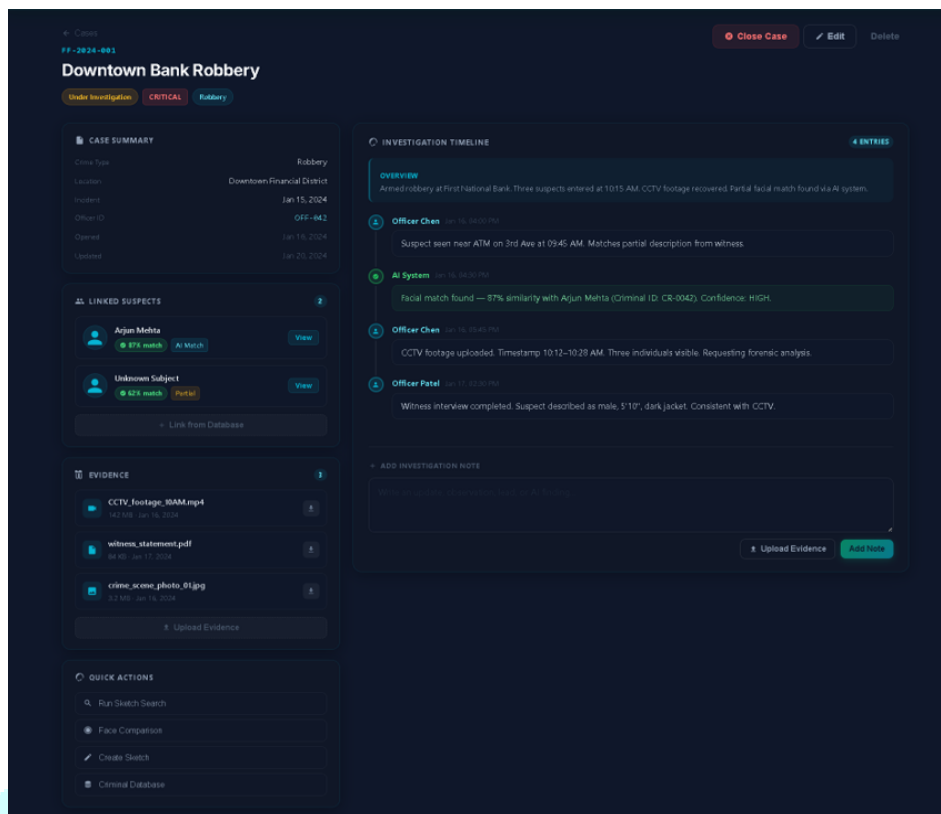


Fig. 3. Individual Case View with Investigation Timeline

Each case contains a detailed timeline of investigation activities, linked suspects with AI-generated confidence scores, evidence uploads (such as CCTV footage and documents), and investigator notes. The system allows seamless integration between face matching results and case tracking workflows.

3.8. System Workflow

The overall workflow of the proposed system is illustrated in Fig. 4 and proceeds as follows:

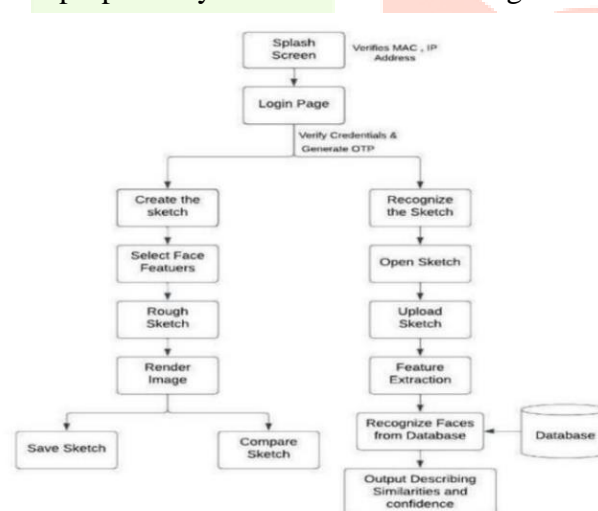


Fig. 4. Workflow of the Proposed System

- 1) The officer logs into the system and creates or selects an existing case.
- 2) A forensic sketch is created using the builder interface or uploaded directly.
- 3) The image undergoes preprocessing and dual embedding extraction.
- 4) The matching engine retrieves and ranks similar faces from the database.
- 5) Results are linked to the active case with associated confidence scores.
- 6) Evidence and investigative notes are appended to complete the case record.

This integrated architecture transforms the system into a complete forensic investigation platform rather than a standalone face recognition tool.

IV. DESIGN DETAILS

4.1. Entity-Relationship Diagram

The Entity-Relationship (ER) model, illustrated in Fig. 5, represents the database structure of the proposed system. The main entities are User, Case, Sketch, Suspect, Match_Result, and Feature_Embedding. The User entity has a one-to-many relationship with Case and Sketch. Each Case can be linked to multiple Sketches and Suspects. The Sketch entity is connected to Feature_Embedding for storing InsightFace [13] and FaceNet512 [1] vectors. The Match_Result entity records the final similarity score and confidence between a sketch and suspect. This ER model ensures efficient storage of criminal profiles, sketches, embeddings, and case-related data while maintaining referential integrity.

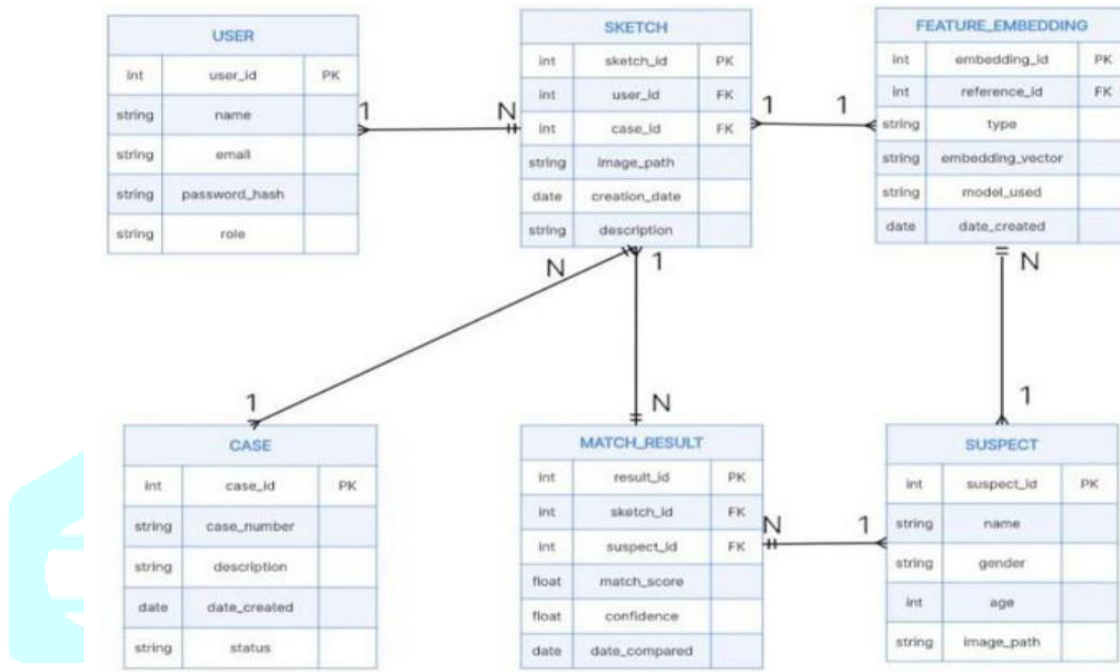


Fig. 5. Entity-Relationship (ER) Diagram

4.2. Data Flow Diagram — Level 0

The Level-0 DFD, shown in Fig. 6, illustrates the high-level interaction of the proposed system with external entities. The Forensic Expert uploads or creates a sketch and submits it to the system. The system interacts with the database to retrieve precomputed suspect embeddings and returns matching results. This context diagram represents the entire system as a single process, clearly showing the flow of sketch input and match output, and highlights that the system acts as a central mediator between the forensic expert and the stored criminal database.

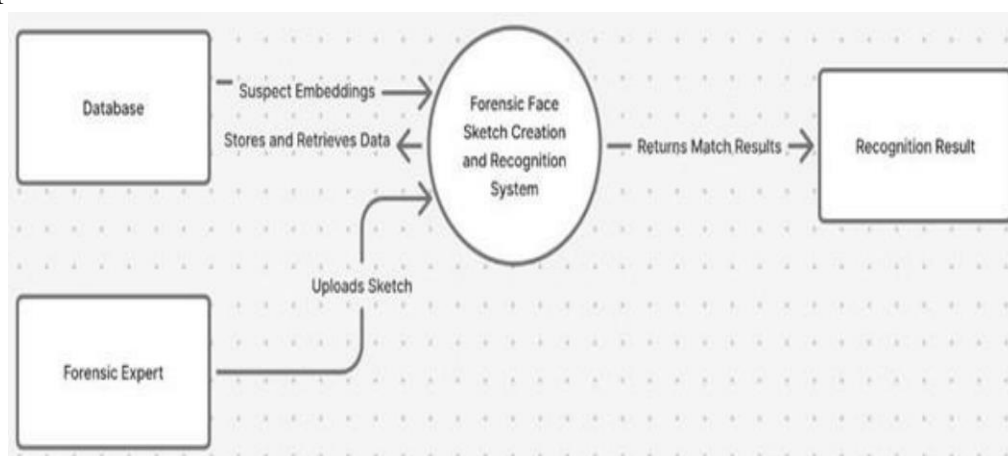


Fig. 6. Data Flow Diagram — Level 0 (Context Diagram)

4.3. Data Flow Diagram — Level 1

The Level-1 DFD, depicted in Fig. 7, provides a detailed view of the internal processes of the proposed system. It consists of four major modules: Sketch Construction, Sketch Processing, Face

Comparison, and Result Display. The Forensic Expert creates or uploads a sketch, which is processed to generate embeddings. These embeddings are compared with stored suspect embeddings from the database. The Face Comparison module computes similarity scores and forwards results to the Result Display module, clearly illustrating the data flow from sketch input to final match output.

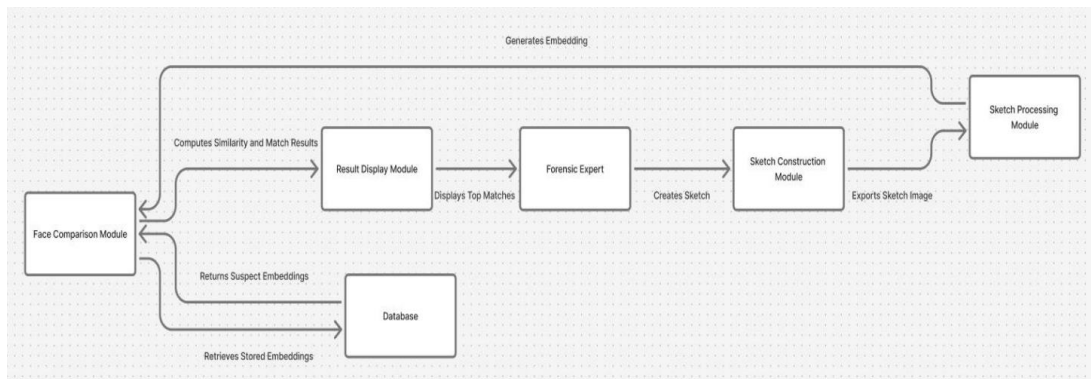


Fig. 7. Data Flow Diagram — Level 1 (Detailed Process View)

4.4. Use Case Diagram

The Use Case Diagram, shown in Fig. 8, illustrates the functional requirements of the system from the perspective of the Forensic Expert. The main use cases include Authentication (login with OTP), Sketch Creation (drag-and-drop interface), Sketch Upload, Face Recognition (matching), and Case Management (storing case details and records). The diagram defines the scope of the system and facilitates understanding of user-system interaction at a high level.

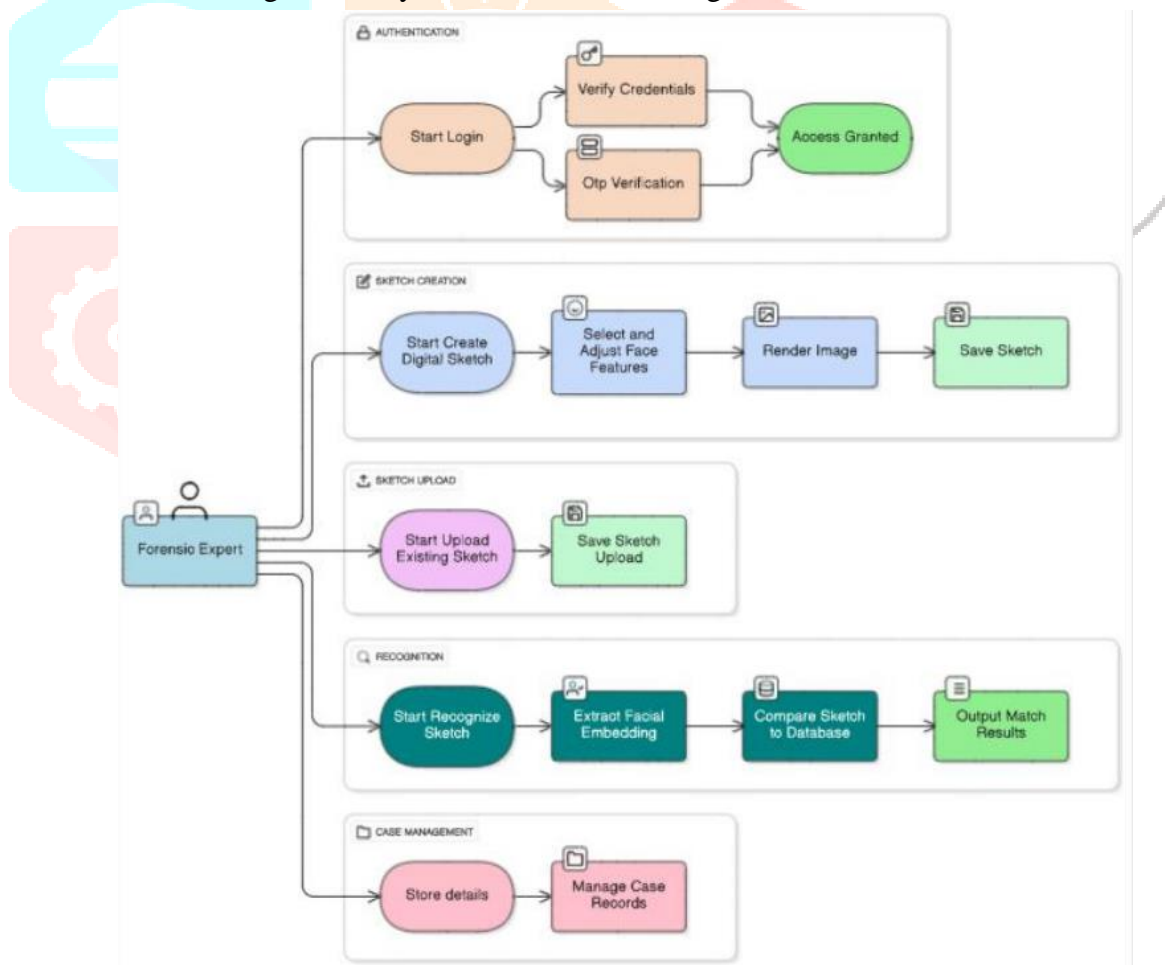


Fig. 8. Use Case Diagram

4.5. Activity Diagram

The Activity Diagram, depicted in Fig. 9, represents the complete operational workflow of the proposed system. It begins with User Login, followed by credential and OTP verification. After successful authentication, the user may either create a new digital sketch or upload an existing one. The sketch is then processed to extract embeddings and compared against the criminal database. If a match

is found, results are displayed with confidence scores; otherwise, the process terminates without output. The diagram also includes decision points for analyst review and report generation, demonstrating the sequential and conditional flow of operations within the system.

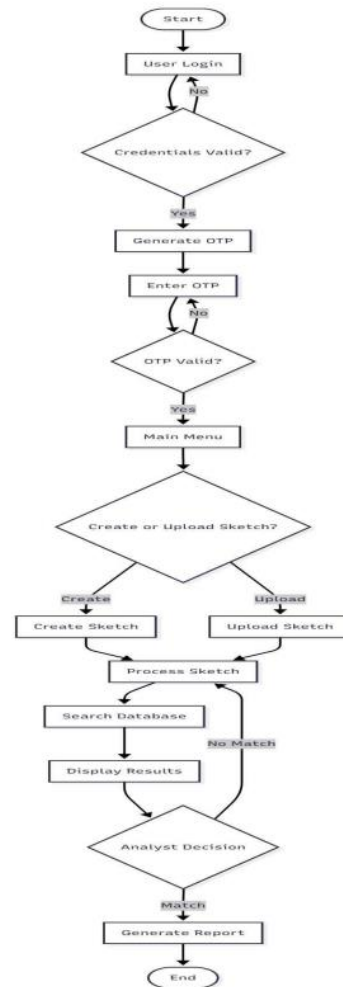


Fig. 9. Activity Diagram

V. IMPLEMENTATION

The proposed system has been implemented as a production-ready full-stack application using modern web technologies and deep learning libraries. The implementation follows a clean modular architecture to ensure scalability, security, maintainability, and cloud readiness.

5.1. Backend Implementation

The backend is developed in Python using the Flask framework. The system uses PostgreSQL hosted on Supabase for better concurrency, connection pooling, and production-grade performance. SQLAlchemy is used as the ORM with proper session management and context support. All criminal images are securely stored on AWS S3, with only the photo key saved in the database and signed URLs generated on demand.

The key service modules are as follows:

- 1) `embedding_service.py` — Loads InsightFace [13] and FaceNet512 [1] models and handles dual embedding extraction with Test-Time Augmentation (original, flip, and $\pm 5^\circ$ rotation).
- 2) `face_comparison_service.py` — Implements the complete hybrid scoring pipeline combining InsightFace [13] and FaceNet512 [1] embeddings, weighted multi-region analysis (eyes 20%, nose 15%, mouth 10%), geometric similarity, and Z-score normalization.
- 3) `faiss_service.py` — Builds and maintains the FAISS IndexFlatIP index, which is automatically rebuilt whenever a new criminal record is added or the database is updated.
- 4) `s3_service.py` — Handles secure upload, deletion, and generation of signed URLs for images stored on AWS S3.

Authentication and case management APIs are secured using PyJWT for token-based access and bcrypt for password hashing. The entire backend is configuration-driven through environment variables, making it ready for cloud deployment.

5.2. Frontend Implementation

The frontend is built with React 18 and React Router v6. The primary components are as follows:

- 1) Drag-and-drop sketch builder implemented using HTML5 Canvas and html2canvas for image export.
- 2) Real-time Investigation Control Center dashboard utilizing Recharts for pie charts and bar graphs depicting case statistics.
- 3) Individual case view incorporating an interactive investigation timeline, auto-linked suspects with AI confidence scores, evidence upload functionality, and a structured note management system.

5.3. Case Management Implementation

The Case Management module is fully integrated with the AI matching engine. When a sketch search returns results, the system automatically links the top matches to the active case with corresponding confidence percentages. Officers can upload evidence (images, videos, PDFs), append timestamped notes, and manage the complete investigation within a single unified interface. All case data is persistently stored in the Case, CaseNote, and linked_criminals tables within the PostgreSQL database.

5.4. Integration and Deployment

- 1) On system startup, both deep learning models are loaded, embeddings are precomputed for all existing criminal records, and the FAISS index is constructed.
- 2) The application is deployable on any cloud platform without architectural modification.
- 3) Role-Based Access Control (RBAC) with two-factor authentication and JWT-based session management is fully operational across all modules.

The implementation ensures that the transition from sketch creation to suspect identification and case closure is seamless and operates in real time, making the system practical for daily law enforcement use.

VI. RESULTS

6.1. System Screenshots

The proposed system was implemented as a fully functional web application. Key interfaces are presented below to demonstrate the user-friendly design and practical usability of the platform.



Fig. 10. User Login Interface

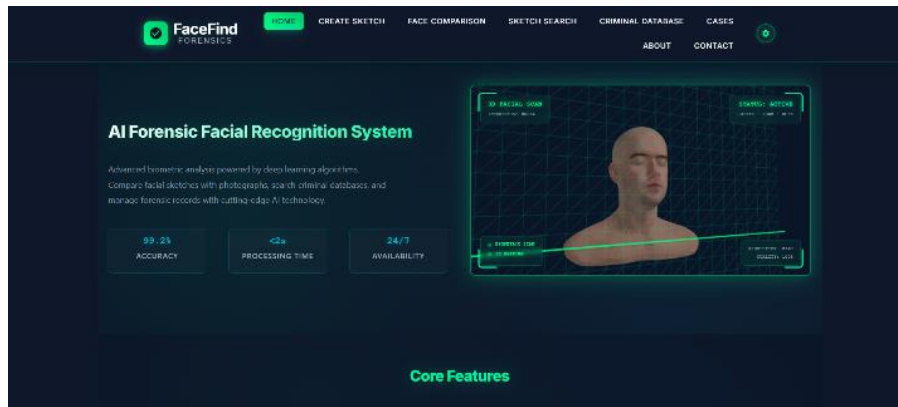


Fig. 11. Investigation Control Center Dashboard



Fig. 12. Sketch Recognition Interface

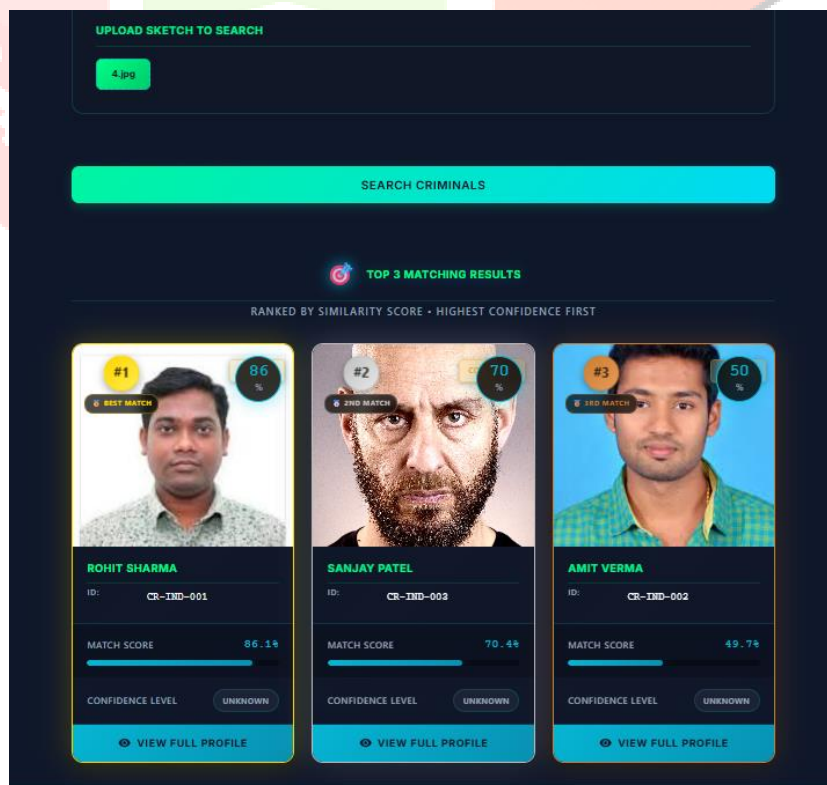


Fig. 13. Face Matching Results with Confidence Scores

6.2. System Performance

The system was evaluated on a standard laptop (Intel Core i5, 8 GB RAM) using a criminal database comprising approximately 120 mugshot records. The average response time for sketch-to-photo matching using the FAISS-based two-stage pipeline was consistently under 1.5 seconds.

The hybrid dual-embedding approach (InsightFace [13] and FaceNet512 [1]), combined with Canny edge preprocessing and Test-Time Augmentation, provided visually robust and consistent matching results even for hand-drawn sketches. The Case Management module successfully linked AI match results with case timelines, evidence records, and investigative notes, enabling smooth end-to-end investigation tracking. Qualitative evaluation demonstrated that the system consistently returned the correct or highly relevant suspect within the top-3 results for the majority of test sketches.

6.3. Comparison with Existing Systems

A comparative analysis of the proposed system against existing forensic face recognition approaches is presented in Fig. 14. The proposed Forensic Face Sketch Creation and Recognition System demonstrates superior performance in terms of matching accuracy, system integration, and real-time responsiveness when compared to prior single-embedding and manual sketch-based methods [3]–[6].

Features	Existing System	Proposed System "Forensic Face Sketch Creation and Recognition System"
Face Recognition Approach	Uses a single deep learning model such as FaceNet or ArcFace independently	Uses a hybrid approach combining InsightFace and FaceNet512 for better feature representation
Sketch-to-Photo Matching	Limited accuracy due to domain gap between sketch and real images	Improved accuracy using dual embeddings and advanced preprocessing techniques
Preprocessing Techniques	Minimal or no preprocessing applied	Advanced preprocessing including face alignment and Canny edge detection
Feature Extraction	Extracts global facial features only	Extracts both global and discriminative features using dual models (InsightFace + FaceNet512)
Feature Analysis	Whole face comparison only	Multi-region analysis (eyes, nose, mouth) for better matching

Fig. 14. Comparison with Existing Systems

VII. CONCLUSION AND FUTURE WORK

7.1. Conclusion

This paper presented the Forensic Face Sketch Creation and Recognition System, a complete full-stack AI-powered forensic investigation platform designed for law enforcement agencies. The system successfully addresses the major limitations of traditional manual sketching—namely subjectivity, operational delays, scarcity of trained artists, and the severe modality gap between sketch representations and photographic evidence.

The core technical contribution is the hybrid dual-embedding pipeline combining InsightFace [13] and FaceNet512 [1], enhanced with OpenCV-based Canny edge preprocessing, Test-Time Augmentation, weighted multi-region analysis (eyes 20%, nose 15%, mouth 10%), geometric similarity, and a two-stage FAISS-indexed retrieval with Z-score normalization. This approach delivers robust, real-time sketch-to-photo matching.

Beyond face matching, the system introduces a comprehensive Case Management module featuring an Investigation Control Center dashboard, live case statistics, crime-type analytics, interactive investigation timelines, automatic linking of AI match results with confidence scores, evidence upload,

and note tracking. This integration transforms the platform into a unified digital investigation environment in which officers can manage the entire case lifecycle within a single secure interface.

The prototype demonstrates high practical usability, sub-1.5-second response time, and measurable advantages over existing systems in both recognition accuracy and investigative workflow efficiency. The proposed system provides law enforcement agencies with a scalable, secure, and production-ready solution for accelerating criminal investigations and supporting the delivery of justice.

7.2. Future Work

Several enhancements are planned to further extend the capabilities of the proposed system:

- 1) Integration of Generative Adversarial Networks (GANs) for automatic composite sketch synthesis from textual eyewitness descriptions.
- 2) Extensive quantitative evaluation on established benchmark datasets (CUFS, CUFSF) and real-world police mugshot databases.
- 3) Development of a mobile application for on-field deployment by patrol officers.
- 4) Integration of Explainable AI (XAI) features, including attention maps highlighting the facial regions that contributed most to a match decision.
- 5) Cloud-native deployment and support for multi-modal query inputs combining sketches, voice descriptions, and demographic filters such as age and gender.

In summary, the Forensic Face Sketch Creation and Recognition System represents a meaningful and practical step toward intelligent, automated, and end-to-end forensic investigation systems suitable for real-world law enforcement deployment.

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