Design and Implementation of a Real-Time Facial Recognition Entry Management System for Campus Security

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***Abstract*—This paper presents a detailed design and implementation of a facial recognition-based entry management system developed with Flask and integrated with advanced computer vision techniques for secure and automated campus access control. The system incorporates real-time face detection, automated access control, and immediate notification features to alert security personnel about unauthorized access attempts. The solution efficiently combines computer vision technologies with web-based application frameworks, offering a robust security platform for campus environments. Performance results highlight the system's ability to handle real-time processing, maintain detailed logs, and generate actionable insights for security management. Key features include live monitoring, automated email notifications, and comprehensive reporting capabilities, all of which contribute to improved campus security.**

***Index Terms*—facial recognition, campus security, entry management, real-time processing, Flask, computer vision**

I. Introduction

Ensuring campus security is increasingly important as educational institutions face growing concerns regarding unauthorized access and safety. Traditional security methods often rely on physical identification or manual checks, which may be time-consuming, error-prone, and difficult to manage at scale. This study introduces a solution using facial recognition technology, offering a secure and efficient alternative.

A. Background

Biometric-based security systems provide a unique approach to access control. Facial recognition is especially advantageous because it is non-intrusive and allows for quick verification, enhancing user experience. Integrating this technology into a campus environment via a web application framework offers a scalable and maintainable approach. Web technologies, specifically Flask, provide the flexibility needed to implement real-time monitoring and management features.

B. Research Objectives

The main objectives of this study are:

1) **Real-Time Facial Recognition**: Develop a system capable of real-time facial recognition for entry management.
2) **Automated Security Notifications**: Integrate an automated alert system for notifying security personnel about unauthorized attempts.
3) **Comprehensive Logging and Reporting**: Implement a logging mechanism for tracking entry and exit times, capturing both authorized and unauthorized attempts.
4) **Scalability and Maintainability**: Design a system that can be easily scaled and maintained.
5) **Performance Evaluation**: Assess the system's effectiveness and performance in real-world campus scenarios.

II. System Architecture

The architecture of the facial recognition entry management system is designed to balance real-time processing requirements with secure and reliable access control management. This section outlines the main components and their interactions within the system.

A. Core Components

The system consists of several primary components that work in concert to deliver real-time facial recognition, access management, and security notifications:

1) Web Application Framework (Flask): Flask is a Python-based micro-framework that provides the foundational structure for the application. Flask handles HTTP requests, routing, and rendering templates for the web-based user interface, making it an ideal choice for building scalable and modular applications. Flask's simplicity and flexibility allow for quick prototyping and easy integration of real-time video streaming, database interactions, and API endpoints. The framework also supports asynchronous task handling, making it suitable for high-frequency, concurrent requests necessary for real-time security operations.

2) Facial Recognition Module: The facial recognition functionality relies on the `face_recognition` library, which is built on deep learning algorithms for detecting and encoding facial features. This module's main tasks include:

- **Face Detection**: Identifying faces within a given video frame or image. The module uses a pre-trained model

based on convolutional neural networks (CNNs) to locate faces within an image.
- **Face Encoding**: Once a face is detected, the system extracts distinctive features to create a unique encoding for each individual, allowing it to be matched against known encodings of authorized individuals.
- **Face Comparison**: The system compares new encodings with existing encodings in the `authorized_data` database. If a match is found, the system authorizes entry; otherwise, it logs the attempt as unauthorized.

3) Database Management System (SQLite): SQLite is a lightweight, file-based relational database that is used to store all user data and access logs. It has three main tables:

- **`authorized_data`**: Stores data about authorized users, including student IDs, names, and facial encodings.
- **`captured_data`**: Maintains entry and exit logs for authorized personnel, recording timestamps for tracking and auditing purposes.
- **`unauthorized_attempts`**: Logs details of unauthorized access attempts, including facial encoding, timestamp, and status, to monitor repeated unauthorized access attempts.

4) Email Notification System: The email notification system alerts security personnel about unauthorized access attempts in real-time. It uses SMTP for automated email alerts. The system includes:

- **Queue-Based Processing**: Unauthorized attempts are queued, and a background worker processes notifications asynchronously.
- **HTML-Formatted Emails**: Each email alert includes information about the unauthorized attempt, such as timestamp and verification link, with clickable "allow" or "deny" options.
- **Image Attachment Handling**: The captured image of the unauthorized individual is attached to the email to help security personnel quickly verify incidents.

5) Real-Time Video Processing Module: The video processing module, built with OpenCV, captures and processes video frames from a connected camera:

- **Frame Capture**: Continuously captures video frames, processed by the face recognition module.
- **Real-Time Monitoring**: Displays the video feed on the dashboard for real-time monitoring by security personnel.
- **Face Detection and Encoding**: Analyzes each frame to detect and encode faces, then checks encodings for authorization.

B. Database Design

The SQLite database structure is designed to efficiently store and retrieve data. It includes three main tables:

- **`authorized_data`**: Contains `student_id`, `name`, and `face_encoding`.
- **`captured_data`**: Records access events with fields `student_id`, `entry_timestamp`, and `exit_timestamp`.
- **`unauthorized_attempts`**: Logs unauthorized access attempts with fields `face_encoding`, `timestamp`, and `status`.

III. Implementation

The implementation integrates each system component into a cohesive and functional solution for secure access control.

A. Face Recognition Module

The face recognition module detects, encodes, and matches faces:

- **Face Detection**: The system uses CNNs to detect faces within a frame, optimized for real-time performance.
- **Face Encoding**: Creates a unique 128-dimensional vector representing the face, enabling robust comparison across different conditions.
- **Face Comparison and Authorization Check**:
  - **Encoding Comparison**: Compares the encoding to entries in the `authorized_data` table.
  - **Authorization Decision**: If a match is found, the entry is logged; otherwise, it is queued for notification.

B. Security Notification System

Ensures prompt responses to unauthorized access attempts:

- **Background Processing**: Unauthorized attempts are queued and processed by a background worker to maintain real-time performance.
- **Email Composition**: Each email includes details of the attempt, a preview image, and "allow/deny" links that update the attempt status in the database.
- **Delivery and Error Handling**: SMTP ensures timely notifications, with error handling to log any delivery issues.

C. Access Control Logic

Designed to provide accurate, real-time feedback:

- **Face Detection and Encoding**: Captures frames and encodes detected faces for comparison.
- **Database Comparison**: Matches the encoding against entries in `authorized_data`.
- **Access Logging and Notifications**:
  - **Authorized Entry**: Logs entry with timestamp and updates on exit.
  - **Unauthorized Entry**: Logs the attempt and triggers email notification.

D. Real-Time Video Processing Module

Uses OpenCV for capturing, processing, and displaying the video feed:

- **Frame Capture and Processing**: Resizes frames and runs face detection and encoding on each frame.
- **Live Video Feed Display**: Displays processed frames on the dashboard for real-time monitoring.
- **Overlay Information**: Displays authorized individuals' details on the video stream and flags unauthorized attempts.

E. Administrative Interface

Allows security personnel to manage users and monitor logs:

- **User Management**: Admins can add/remove users and edit records.
- **Real-Time Monitoring**: Provides live video feeds and recent access logs.
- **System Status Monitoring**: Displays status of camera and database for quick diagnostics.

IV. Conclusion

This paper demonstrates the successful design and implementation of a real-time, facial recognition-based entry management system tailored for campus security. By leveraging Flask, SQLite, and the `face_recognition` library, the system enhances access control by automating face detection, response times, and notification processes. The solution also allows for effective monitoring, user management, and auditing. Future work includes integrating cloud databases, mobile monitoring, and multi-camera support to broaden the system's applicability to various security-sensitive environments.

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