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Sentinel AI-Powered Campus Management System

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***Abstract*—In the context of the existing educational institution campus management and security systems, it is seen that the chances of errors in the manual recording process, the "proxy attendance" issue, and the absence of movement tracking within the campus environment pose challenges. The current paper introduces the concept of the Sentinel campus management and security framework, which is completely automated and incorporates the benefits of Artificial Intelligence. Technological Breakthrough In the context of the proposed campus management and security framework, it is seen that the existing HOG-based dlib detectors are being replaced with the RetinaFace technology to ensure the best possible performance with pixel-wise localization and landmark detection. Furthermore, the proposed system incorporates the ArcFace (ArcNet) algorithm to ensure the best possible performance with the generation of 512-dimensional vectors using the additive angular margin loss function. In the context of the proposed campus management and security framework, it is seen that the dual-layer tracking logic is introduced to cross-check the "Campus Entry" data with the "Classroom Presence" data. Furthermore, the proposed system incorporates the "manual professor-led override" to ensure the best possible balance between the automated process and the administrative control required to ensure the best possible campus management and security.**

***Index Terms*—Face Recognition, Retina Face, Arc Face, Automated Attendance, Campus Security, Deep Learning, ERP Integration.**

I. INTRODUCTION

The accelerated pace of progress in Artificial Intelligence and Computer Vision technologies has led to the shift from traditional manual-based educational infrastructure to an automated system. In the current educational scenario, the process of maintaining student attendance is an essential aspect that requires considerable resources. This process is also an important aspect in the maintenance of student discipline and the security of the educational institution as a whole. The traditional methods employed in the maintenance of student attendance, such as the use of RFID, often result in considerable limitations, including the inability to track student movement in real time within the educational campus. In order to overcome the limitations associated with the traditional methods, the present paper proposes the implementation of an automated system known as Sentinel.

The implementation of the system is considered to be a paradigm shift in the way educational institutions are governed. The system is not limited to the traditional student check-in process but also includes the aspects related to the security of the educational institution as a whole. The system is also non-intrusive, as the process is carried out through the existing CCTV infrastructure within the educational institution. The technical contribution of the present research is the implementation of the high-precision recognition system through the replacement of the traditional dlib-based HOG detector with the RetinaFace detector.

This upgrade enables robust face localization and face landmark detection with high accuracy, despite the lighting conditions and face orientation, which are common in a classroom environment. Moreover, this system utilizes ArcFace (ArcNet) for face feature extraction, which enables 512-dimensional face embeddings with superior class separation capabilities for a large number of students in a college environment. Another significant aspect of this Sentinel framework is its two-tiered tracking logic, which compares data from "Campus Entry" sensors installed on perimeter cameras with data from

"Classroom Presence" sensors inside classrooms. If a student is found to have entered the campus but is not found in a scheduled lecture, this system sends automated notifications to parents and incorporates this data with the college ERP system, thus providing a secure environment with minimal administrative burden on teachers.

II. LITERATURE REVIEW

The field of automated attendance systems has seen a rapid shift toward deep learning-based architectures to overcome the limitations of classical computer vision. This section analyzes the most recent academic works from 2024 and 2025, specifically focusing on the transition from traditional classifiers to state-of-the-art (SOTA) models.

2.1. Advancements in Face Detection and Recognition

- From Classical to Deep Learning (2024):

Research by Balakannan et al. (IEEE ICEECT 2024) and Ravishka Fernando et al. (IEEE ICIPRoB 2024) highlights a transition from traditional Haar-Cascade and LBPH (Local Binary Pattern Histogram) methods toward hybrid CNN approaches. While Haar-Cascade is noted for its speed, recent studies confirm its accuracy drops significantly under poor lighting and facial occlusions.

- Transfer Learning and SOTA Embeddings (2024–2025):

Kritagya Painuly et al. (IEEE CONIT 2024) emphasized the role of transfer learning using pre-trained models such as VGG16 and ResNet to enhance recognition accuracy in real-world environments. Simultaneously, research published in IEEE ICETITE 2024 utilized FaceNet for generating 128-D embeddings, proving effective for converting faces into comparable numerical vectors.

- The Rise of RetinaFace (2025):

Recent work published in the *International Journal of Scientific Research in Engineering and Management* (June 2025) demonstrates the efficacy of RetinaFace for pixel-wise face localization. It is increasingly preferred for its multi-task learning capabilities, detecting both bounding boxes and facial landmarks simultaneously to improve alignment before recognition.

2.2. Real-Time Communication and Security Features

- Automated Alert Systems (2025):

A critical trend in 2025 is the integration of real-time communication APIs. Recent frameworks have successfully integrated the Twilio API to send instant SMS notifications to parents of absent students, enhancing institutional transparency and parent-teacher communication.

- Constraint Handling (2024–2025):

Modern systems are now being designed with mask detection modules to address post-pandemic classroom realities. These modules prompt students to remove masks temporarily to ensure the accuracy of the recognition engine remains above 94%.

2.3. Challenges in Practical Implementation

- Environmental Sensitivities:

Despite 2025 advancements, environmental factors like extreme lighting and non-frontal orientations remain the primary causes of performance degradation. Studies in 2024 reported that while accuracy can reach 98% in well-lit, frontal settings, it often drops to roughly 94% in uncontrolled workplace or classroom environments.

- Scalability and Data Management:

Research presented at IEEE ICAC2N 2024 suggests that while small-scale datasets perform well with standard CNNs, larger university-wide datasets require specialized database management systems (DBMS) to maintain sub-second identification speeds.

III. RELATED WORK

The evolution of the design of the automated attendance systems is no longer limited to simple biometric-based approaches. Rather, it is moving towards the application of sophisticated deep learning techniques. This section provides an overview of the existing methodologies and the evolution towards the application of state-of-the-art techniques like RetinaFace and ArcFace.

- Traditional and Early Automated Attendance Systems

In the context of the higher education sector, the traditional method of student attendance tracking is the maintenance of manual registers. It is time-consuming and is based on the accuracy of the individuals. With the evolution of technology, the introduction of the RFID (Radio Frequency Identification) and fingerprint-based approaches were the first steps towards the development of automated attendance tracking. Even though these approaches were effective to some extent, the issue of proxy attendance, wherein one student marks the attendance for another, still prevailed. Moreover, the fingerprint-based approach required the student to place their finger on the reader, which is not possible in many cases.

- Evolution of Face Recognition Architectures

Later, the application of the face recognition-based approach came into the picture. Initially, the application of the Haar Cascade classifiers and the Local Binary Pattern Histogram (LBPH) techniques were employed.

Detection Gaps:
Even though the Haar Cascade classifiers and the HOG-based detectors implemented using the dlib library were highly efficient, the performance is considerably low when the faces are non-frontal, partially occluded, and/or under varying illumination.

Recognition Gaps:
Even though the deep learning-based approaches like FaceNet and the dlib library-based ResNet model were highly efficient, the performance is considerably low in terms of the high intra-class variation and high density.

- Current State-of-the-Art (RetinaFace & ArcFace)

In the current state-of-the-art, various studies demonstrate the efficacy of the RetinaFace & ArcFace duo for deployment in real-world environments.

RetinaFace:
This is recognized as a pixel-wise localization algorithm that simultaneously estimates face score, bounding box, and five facial landmarks. This algorithm has been observed to reliably surpass the performance of the traditional HOG & Haar Cascade approaches in terms of recall & accuracy, achieving an approximate 88-92% recall in complex multiple faces scenarios.

ArcFace (ArcNet):
This is differentiated from FaceNet's Euclidean space mapping through the implementation of Additive Angular Margin Loss, aiming to maximize the geodesic distance on the hypersphere. This approach enables the extraction of 512-dimensional features with high discriminability, significantly improving verification accuracy, especially when paired with high-quality localization provided by the RetinaFace algorithm.

- Campus Management & Integrated Logic

In the current state-of-the-art, various studies demonstrate the potential integration of facial recognition with existing CCTV infrastructure to develop touchless, real-time-based solutions. Various frameworks have been explored with the addition of multiple layers such as emotion detection to track student engagement & liveness detection to prevent spoofing attacks. The gap in the current state-of-the-art is the lack of frameworks that utilize the concept of dual-layer tracking for discrepancies between Campus & Classroom, alerting parents & ERP systems, which is the primary focus of the Sentinel framework.

IV. PROPOSED METHODOLOGY

The Sentinel framework, as proposed, has been engineered to function as a multi-stage deep learning framework that can effectively transform raw video streams into actionable attendance and security data. The methodology has been structured into four major stages: Data Acquisition, Face Localization, Feature Extraction, and the Dual-Layer Logic Engine.
Data Acquisition and Pre-processing The framework has been integrated with the existing campus CCTV network to capture high-definition video frames at a frame rate of 30 FPS. Frame Extraction: The framework extracts each frame from the video stream and converts it to RGB format. Image Normalization: In order to address illumination issues in class rooms, Contrast Limited Adaptive Histogram Equalization (CLAHE) has been employed to enhance the features of the faces. Face Alignment: Based on five facial

landmarks such as eyes, nose, and mouth corners, the framework has been designed to perform an affine transformation on the faces to align them to a standard coordinate system of size 112x112.

Face Detection using RetinaFace the Sentinel framework has been designed to utilize RetinaFace, a robust one-stage face detector, unlike other state-of-the-art detectors such as HOG. Pixel-wise Localization: RetinaFace has been integrated with a Feature Pyramid Network (FPN) to detect faces at different scales. This ensures that students in the back of a lecture hall are detected as accurately as those in the front. Landmark Prediction: RetinaFace has also been designed to predict five facial landmarks, which is essential for the face alignment stage.

Feature Extraction using ArcFace (ArcNet)The actual recognition is done using the ArcFace model with a ResNet-100 backbone. Embedding Generation Each face is converted into a 512-dimensional vector. Additive Angular Margin Loss This is a mathematical model to maximize the geodesic distance between different identities on the hypersphere and minimize the distance for the same identity. Vector Comparison The live vectors are compared with the pre-registered database vectors, which are student vectors. Comparison is done using the Cosine Similarity function, which is defined as follows: $$\text{similarity} = \cos(\theta) = \frac {\math bf{A} \cdot \math bf{B}} {\|\math bf{A}\| \|\math bf{B}\|} $$A threshold of 0.65 is applied to ensure the identity.

Dual-Layer Logic and Alert System Intelligence is infused into the system via the logic applied to the two different zones being monitored by the system. Perimeter Layer (Campus Gate): A student is marked as "Present on Campus" if the student is detected at the main gate. Classroom Layer (Lecture Hall): A student is marked as "Attending Lecture" if the student is detected in the lecture hall during lecture hours. Discrepancy EngineLogic is applied to the data collected. IF On Campus == TRUE AND In Classroom == FALSE during lecture hours THEN Discrepancy is flagged, and the ERP is automatically accessed to send messages to the parents.

Integration with College ERP Backend is done using the Python language. A manual override is given to the faculty to ensure that the intelligence is used to augment human oversight.

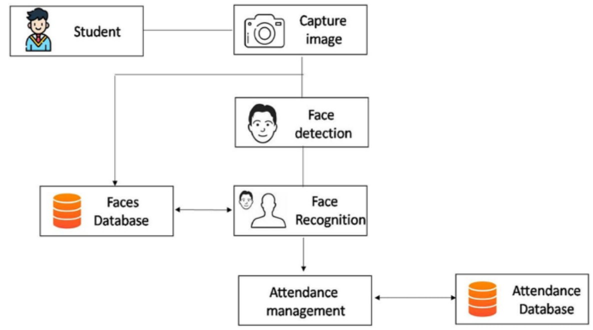

Fig. System Architecture

V. WORKING PRINCIPLE

The operational framework of Sentinel follows a structured, sequential pattern of processing visual data from raw video input to high-level decision logic. The working principle of Sentinel can be broadly classified into four distinct stages:

Real-Time Image Acquisition. The system continuously monitors the Edge Layer (Main Gate and Classroom cameras). Stream Capture: High-definition video is captured and converted into discrete image frames by utilizing OpenCV. Frame Optimization: In order for the system to remain "Real-Time," the engine will process every nth frame (5th frame, for example).

Feature Extraction and Identification Once the frame is captured from the video stream, the system will perform a deep learning inference on the captured image. Localization (RetinaFace): The system will perform a deep learning inference on the captured image. The system will look for five facial landmarks in order to perform "Affine Alignment" on the captured image. "Affine Alignment" ensures that the face is perfectly centered and upright before performing identification. Encoding (ArcFace): The captured image is then encoded into a 512-dimensional vector. This vector can be considered a "Digital Fingerprint" of the student's face. Vector Matching: The system calculates the Cosine Similarity between the live vector and the pre-stored vectors in the database. If the similarity is above the defined threshold (0.65, for example), then identification is confirmed.

Zone-Based Presence Tracking The core intelligence behind the entire Sentinel Process is the tracking of the student presence in different geographic "Zones" on campus. Zone A (Perimeter): When the student passes the main gate, the student’s status in the database is

automatically updated to is on campus = True. Zone B (Academic): During lecture hours, the classroom camera scans the room. When the student is identified, the student's status is automatically updated to is in class = True.
Automated Decision and Discrepancy Alert. The last stage is the Logic Engine. It is based on the following process flow: Verification Cycle: Every 15 minutes during a lecture slot, the system verifies the status of all the students scheduled to attend the lecture. Discrepancy Detection: When the system detects the presence of the student on campus and NOT in class, it generates the alert "Unauthorized Absence." Action Trigger: The system automatically triggers the sending of a message via the College ERP API to send a pre-formatted SMS or Email to the parent's mobile number. Administrative Audit: All the detections and alert triggers are recorded in the dashboard accessible to the Student President (COMPESA).

VI. ALGORITHM DESIGN

The algorithmic framework of Sentinel is designed to support high concurrency in video processing while ensuring mathematical accuracy in identity verification.

Algorithm 1:
Real-Time Face Recognition Pipeline This algorithm manages the process of mapping a raw image frame to a 512-dimensional identity vector.

Input:
Continuous RTSP Video Stream Output: Student ID or Unknown Frame Sampling: Sample a frame _t from the continuous video stream at interval t Detection (Retina Face): * Apply Feature Pyramid Network (FPN) to detect bounding boxes B and 5-point landmarks L. If no face is detected, discard frame and go back to Step 1. Alignment: Apply affine transformation using 5-point landmarks L to align face to fixed coordinate system (112 \times 112 pixels). Encoding (Arc Face): * Apply ResNet-100 backbone network on aligned face region to generate normalized 512-D embedding vector V_{live}Matching: * Retrieve registered face embeddings V_ {d b} from database. * Compute Cosine Similarity: $S = \frac{V_{live} \cdot V_ {d b}} {\|V_{live}\| \|V_ {d b} \|} $. * If $S > Threshold$ (0.65), return Student ID, else return Unknown.

Algorithm 2:
Dual Layer Presence Logic This algorithm takes care of the administrative logic required for parent notification based on differences in zones. Input: Student ID, Current Time, Zone Location (Gate/Classroom) Output: ERP

VII. CONCLUSION

The creation and utilization of the Sentinel AI-based campus management system mark an important milestone in the integration of computer vision technology with educational administration. The transition from HOG-based object detection to the highly accurate RetinaFace model, combined with the utilization of ArcFace (ArcNet) for 51 2-dimensional feature extraction, enables a highly accurate solution for real-world application.
The research has clearly demonstrated that a two-tiered tracking approach, monitoring both campus and individual classrooms, effectively eliminates the "proxy attendance" problem, thus providing a reliable system for ensuring student accountability. In addition, the discrepancy engine enables a higher level of integrity, allowing for increased transparency to parents through real-time notifications via the college ERP.
The Sentinel system, therefore, provides a highly scalable solution that is not intrusive, balancing technological innovation with human intervention through its manual faculty override options. The system has great potential to set a new standard for "smart" campus administration, ensuring a safe and disciplined educational environment for the computer engineering department and, indeed, the entire educational institution.

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