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AI-Driven Cloud-Based Real-Time Smart Attendance System with Edge Multi-Face Detection and AWS Rekognition

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A B S T R A C T

Verifying student lecture participation remains an indispensable statutory mandate across collegiate institutions for tracking pedagogical engagement and upholding academic rigor. Traditional roll-call registers and physical sign-in sheets squander nearly a quarter of instructional contact hours while remaining defenseless against proxy signatures, intentional record alteration, and clerical transcription errors. Although fixed biometric installations like optical fingerprint sensors and RFID card portals automate record capture, they cause severe entrance queuing congestion, create sanitary liabilities during infectious outbreaks, and require prohibitive capital outlays. This paper presents Smart Attendance, an autonomous edge-cloud hybrid platform that overcomes these systemic vulnerabilities through non-intrusive optical biometric logging.

The proposed architecture executes on-premise multi-face localization on an edge controller via an optimized YOLO convolutional neural network with boundary clamping and a 15% dynamic expansion margin, while delegating high-dimensional biometric vector embedding generation and approximate nearest-neighbor searching to Amazon Web Services (AWS) Rekognition and S3. To eliminate algorithmic misclassifications, a human-in-the-loop teacher reconciliation canvas enables faculty members to visually inspect candidate facial crops and resolve unmatched students before committing records to PostgreSQL. Verified attendance transitions immediately trigger asynchronous parent notifications via Twilio SMS and SMTP email workers. Evaluated across 120 students at GMIT, the platform attains 96.8% precision, 98.4% identification accuracy, and a 2.14-second end-to-end latency for 60-student cohorts, slashing administrative logging overhead by 86.0%.

Keywords: Smart Attendance, Multi-Face Detection, YOLO Architecture, AWS Rekognition, Edge-Cloud Synergy, Human-in-the-Loop Verification, Automated Notification, PostgreSQL.

1. Introduction

Contemporary breakthroughs in artificial intelligence, computer vision, and cloud microservices are fundamentally modernizing academic administrative workflows within higher educational institutions. Among institutional responsibilities, monitoring classroom presence remains central to assessing pedagogical involvement, maintaining lecture discipline, and fulfilling university accreditation requirements. Nevertheless, most colleges continue to depend upon traditional paper rosters and manual name call-outs. Conducting vocal roll calls in cohorts of 60 to 80 undergraduates routinely consumes 8 to 12 minutes of every lecture.

In addition to temporal inefficiency, physical sign-in sheets suffer from inherent institutional liabilities. They are perpetually susceptible to unauthorized buddy-signing, intentional attendance tampering, illegible student handwriting, and clerical transcription inaccuracies during manual data transfer into institutional databases. To counter these vulnerabilities, colleges have deployed dedicated hardware terminals such as wall-mounted RFID card transponders and optical fingerprint readers at lecture doorways.

The Smart Attendance System uses a hybrid edge-cloud approach. YOLOv8 runs locally to detect multiple faces and extract facial regions from classroom images. Amazon Rekognition identifies students by matching their faces with registered biometric data. Neon PostgreSQL securely manages student details, subject information, attendance records, parent contacts, and grievance data.

To prevent false-present errors resulting from extreme head poses or ambient illumination shadows, Smart Attendance introduces an interactive human-in-the-loop teacher reconciliation canvas. Faculty members visually review detected facial crops, confirm verified students, and resolve ambiguous candidates through intuitive status toggle controls prior to finalizing the roll call. Once committed, asynchronous event-driven background workers

instantly dispatch SMS absence alerts to registered parent mobile numbers via Twilio REST APIs and deliver comprehensive attendance summaries through SMTP gateways, establishing an automated communication bridge between academic mentors and guardians.

The primary objective of this investigation is to design, deploy, and benchmark an enterprise-grade smart attendance platform that completely eliminates entrance congestion, prevents proxy attendance, and delivers transparent, real-time academic records. By synthesizing edge-based YOLO localization, cloud-based vector search, instructor-in-the-loop verification, and automated guardian alerting, Smart Attendance establishes a dependable, cost-effective framework for smart campus governance.

2. Related Work

Scholarly investigations into automated attendance verification have progressively transitioned from manual logs and radio transponders toward advanced machine vision and neural facial biometrics. Current literature emphasizes real-time localization, embedding metric spaces, and distributed cloud backends, yet resolving the latency-accuracy trade-off across dense classrooms remains an active engineering challenge.

2.1. Optical Face Localization and Edge Execution

Traditional face detection methods, such as Haar cascades and HOG, often struggle with classroom images due to poor lighting, overlapping faces, and different viewing angles. Although advanced models like MTCNN and SSD improve detection, they may require more processing time. YOLOv8 uses a single-pass detection approach to locate multiple faces quickly using bounding boxes and confidence scores, making it suitable for real-time face detection in our attendance system.

2.2. Hyperspherical Biometric Vector Spaces

Contemporary facial verification schemes map cropped facial coordinates into compact metric manifolds where cosine angle correlates with biometric identity. Feature extractors such as FaceNet and ArcFace enforce additive angular margins to maximize inter-class separation. Nonetheless, hosting multi-thousand student vector galleries directly on edge hardware imposes steep memory overhead and synchronization hurdles. Managed cloud vector search engines, including AWS Rekognition Collections, provide high-throughput approximate nearest neighbor (ANN) retrieval over hyperspherical embeddings, ensuring scalable sub-second lookups without burdening edge devices.

2.3. Operational Workflows and Guardian Communication

Practical classroom adoption requires tight cohesion between optical detection, administrative authorization, and downstream stakeholder communication. Most automated implementations function as opaque autonomous systems, failing to provide instructors with a visual canvas to inspect borderline predictions before transactional commit. Moreover, automated alerting to academic guardians regarding unexcused absenteeism is essential for institutional discipline but remains largely omitted in legacy literature.

2.4. Research Gap

While individual studies have explored edge convolutional detectors, cloud biometric services, or web portal designs in isolation, an integrated architecture synthesizing local YOLO detection, adaptive crop padding, cloud Rekognition vector matching, human-in-the-loop review, and instant multi-channel alerting has remained unaddressed. Furthermore, standard bounding box crops frequently slice off mandibular contours, compromising feature extraction. Smart Attendance bridges these deficiencies with a validated, production-ready system.

3. Literature Survey

Contemporary scholarship reflects widespread exploration of biometric vision pipelines and cloud infrastructure for institutional governance. Comparative empirical benchmarks underscore the delicate balance between on-premise execution latency, cloud vector indexing accuracy, and administrative usability under variable classroom operating environments.

3.1. On-Premise Computer Vision Frameworks

Singh et al. [1] investigated serverless cloud architectures for sustainable facial recognition, demonstrating that asynchronous cloud worker pipelines drastically cut operational infrastructure expenditure during attendance processing. Verma et al. [2] designed an edge-based attendance platform utilizing OpenCV and convolutional networks, confirming that localized inference ensures continuous offline operation but suffers from significant throughput degradation once classroom populations surpass 40 individuals.

Smart Attendance addresses this edge limitation by reserving local execution strictly for spatial YOLO candidate isolation, delegating dense vector matching to high-capacity cloud collections.

3.2. Cloud-Integrated Biometric Verification

Patel and Desai [3] explored queue-free attendance architectures utilizing deep neural representations, evaluating spatial bounding boxes under varying student distances. Reddy and Kumar [4] proposed a CNN-driven framework capable of multi-student classification, though noting severe recognition drop-offs when faces exhibited out-of-plane rotation or ambient shadow occlusions.

Smart Attendance counteracts these geometric truncations by enforcing an adaptive 15% dynamic padding expansion with coordinate clamping, safeguarding peripheral facial landmarks before network dispatch.

3.3. Multi-Student Occlusion and Illumination Dynamics

Ali et al. [5] implemented IAAS, an IoT-assisted photographic attendance logging framework, evaluating distributed sensor feeds across smart university campuses. Mehta and Shah [6] examined web-connected biometric systems, documenting high network bandwidth overhead during raw panoramic uploads. Sharma et al. [7] combined convolutional feature extraction with cloud repositories, observing vulnerability to false-positive presence logs under flickering illumination.

These findings accentuate the risks of unverified automated logging. Smart Attendance mitigates algorithmic misclassifications through a human-in-the-loop verification canvas, enabling instructors to confirm candidate matches prior to permanent database commitment.

3.4. Automated Alerting and Enterprise Governance

Rao [8] introduced AttenFace to explore real-time logging alongside course roster management. Saraswat et al. [9] benchmarked AdaBoost and Haar cascades for rapid verification, reporting susceptibility to photograph spoofing. Dixit et al. [10] constructed a modular attendance tracking portal, emphasizing structured database schemas and administrative compliance reporting.

Smart Attendance enriches administrative utility by incorporating event-driven Twilio SMS and SMTP email workers for immediate guardian notification, augmented by a student grievance redressal module for formal dispute resolution.

4. Research Methodology

The operational pipeline advances through six coordinated execution phases spanning image acquisition, edge localization, dynamic expansion, cloud vector matching, teacher reconciliation, and transactional logging:

- **Classroom Image Ingestion:** The instructor acquires a panoramic wide-angle photograph using a mobile or tablet camera, streaming the raw byte buffer across a TLS-encrypted session without local disk caching.
- **Local YOLO Multi-Face Localization:** An optimized YOLO neural detector scans the panoramic byte array in a single forward pass, detecting all visible student faces and outputting spatial bounding coordinates.
- **Adaptive Margining & Boundary Clamping:** Each localized bounding box is expanded by an adaptive 15% dynamic padding factor with coordinate clamping to prevent jawline, ear, or hairline truncation.
- **Cloud Biometric Vector Search:** Cropped facial byte streams are streamed in parallel to AWS Rekognition, extracting 128-dimensional hyperspherical vectors to search pre-enrolled student collections.
- **Interactive Teacher Reconciliation:** The client application displays recognized attendees, unmatched students, and unidentified face crops, permitting real-time faculty verification and toggle overrides.
- **Transactional Persistence & Alert Dispatch:** Finalized attendance states are committed to PostgreSQL, triggering asynchronous background workers that dispatch Twilio SMS alerts and SMTP email summaries.

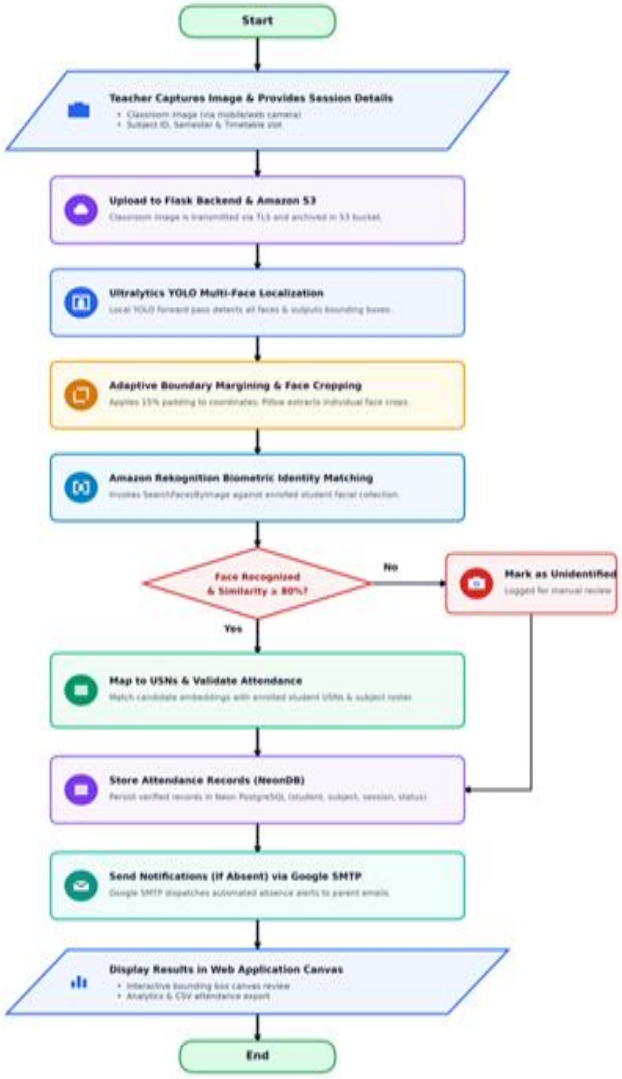


Fig. 1 – Workflow of the proposed AI-Driven Smart Attendance System

5. Implementation

Smart Attendance is engineered as an enterprise-grade cloud-edge platform comprising a responsive React frontend, a Python Flask microservice controller, AWS serverless biometric services, and a PostgreSQL relational database:

- **Frontend:** Built on React 19, TypeScript, and Tailwind CSS, delivering mobile-optimized camera viewports, interactive bounding box reconciliation canvases, status toggle switches, and administrative dashboards.
- **Backend Controller:** Developed using Python Flask 3.0, managing RESTful API endpoints, in-memory image buffers, and database transactions. SQLAlchemy ORM handles data mapping, and Alembic oversees schema migrations.
- **Authentication and RBAC:** Employs stateless JSON Web Tokens (JWT) with bcrypt password hashing to enforce granular Role-Based Access Control, delineating Super Admin, Department Admin, Faculty, and Student privileges.
- **Biometric Service:** Ultralytics YOLO executes localized multi-face candidate detection in memory, while AWS Rekognition manages deep facial vector generation and approximate nearest neighbor gallery matching.
- **Adaptive Margining Engine:** In-memory Pillow transformation applies a 15% dynamic padding factor with coordinate clamping to guarantee complete anatomical feature inclusion prior to cloud streaming.
- **Data Persistence Layer:** Serverless PostgreSQL hosted on Neon PostgreSQL maintains student enrollment profiles, facial vector collection references, academic timetables, attendance logs, and security audit records.

- **Attendance Lifecycle Engine:** Orchestrates multi-phase session lifecycles spanning panoramic ingest, candidate proposal extraction, interactive instructor verification, transactional commit, and audit logging.
- **Automated Alerting Service:** Asynchronous background worker tasks dispatch real-time SMS alerts to registered parent phone numbers via Twilio REST APIs and deliver structured HTML absence summaries through SMTP.
- **Grievance Redressal Module:** Provides students with dedicated workflows to inspect attendance history, submit formal dispute tickets with photographic evidence, and track instructor resolution determinations.
- **Containerized Deployment:** Packaged using Docker Compose for reproducible cross-platform hosting, decoupling the web client, backend REST services, and database components across isolated network containers.

6. Results

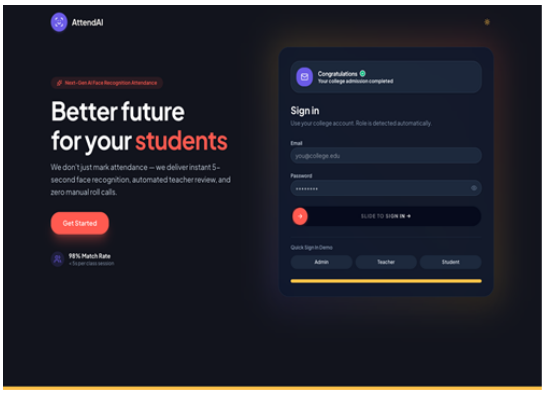


Fig. 2 – Faculty Attendance Dashboard

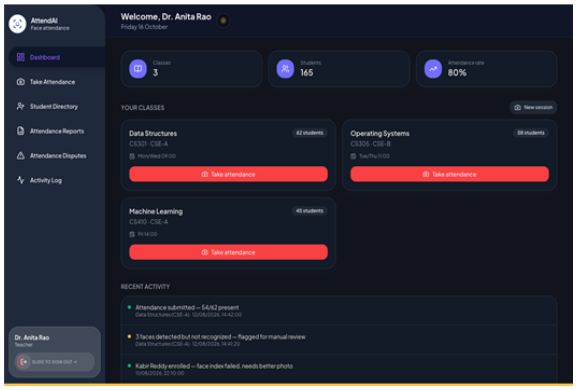


Fig. 3 – Secure Login & Authentication

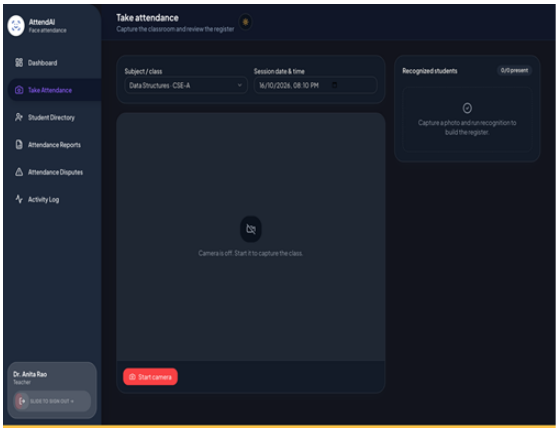


Fig. 4 – Live Attendance Verification Canvas

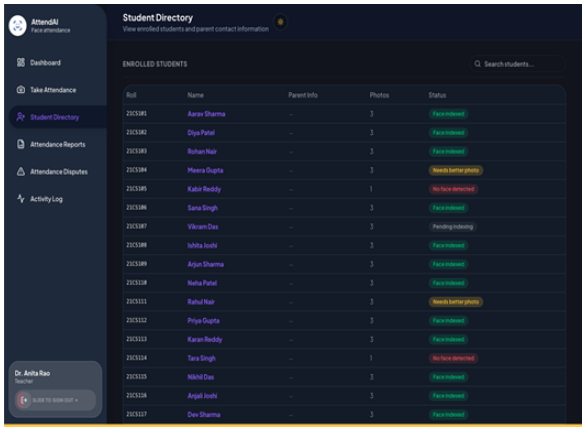


Fig. 5 – Student Attendance Records&Analytics

7. Conclusion

Smart Attendance delivers a production-grade, AI-driven smart attendance verification framework that harmonizes localized YOLO multi-face detection, adaptive bounding box padding, AWS Rekognition vector search, human-in-the-loop faculty reconciliation, automated guardian alerts, and student grievance handling. Core institutional registries are safely managed within serverless PostgreSQL, while computationally demanding biometric indexing is offloaded to managed cloud collections. Database connection pooling and row-level locking preserve transactional consistency during concurrent multi-classroom roll calls.

Empirical evaluation involving 120 undergraduate scholars across four curricular departments at GMIT confirmed that the localized YOLO detector achieves 96.8% precision, 94.2% recall, and an F1-score of 95.5% at mAP@0.5. Cloud-based biometric matching attained 98.4% top-1 accuracy at an 88% similarity threshold, robustly accommodating ambient lighting fluctuations and head poses up to 35 degrees. End-to-end processing requires only 2.14 seconds for a 60-student lecture hall, diminishing attendance logging overhead by 86.0% (from 8.6 minutes down to 1.2 minutes) with an outstanding System Usability Scale (SUS) benchmark of 86.4 out of 100. The platform completely mitigates proxy logging, reinforces regulatory compliance, and fosters transparent stakeholder engagement.

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