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Image Forgery Detection Using Error Level Analysis and Digital Image Forensics

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Abstract: *The Image Forgery Detection System is a web application based on computer vision that employs passive image forensics techniques to detect digitally altered or tampered images. This system expands beyond traditional metadata-based approaches to actively scrutinize the intrinsic structural properties of images, detecting sophisticated deepfakes, clone-stamping, and splicing. The system employs active comparative reference mapping utilizing the Structural Similarity Index Measure (SSIM) to highlight critical differences in pixel luminance and contrast, alongside real-time noise pattern inspection for detecting statistical errors. Furthermore, the application integrates an advanced live verification module that enforces facial liveness by capturing real-time biological micro-movements, actively calculating Eye Aspect Ratios (EAR) and Mouth Aspect Ratios (MAR) to thwart presentation attacks using static photographs or pre-recorded screens. The software is built in Python 3 using Flask as the primary web framework, with core image processing powered by OpenCV, Pillow, NumPy, and scikit-image. The proposed solution demonstrates an effective integration of classical image processing and web technologies for robust digital image authentication in academic, forensic, and media applications.*

Keywords: Image Forgery Detection, Structural Similarity Index Measure (SSIM), Digital Image Forensics, Liveness Detection, Eye Aspect Ratio (EAR), OpenCV, Flask, Deepfake Detection

I. INTRODUCTION

The rapid proliferation of digital imaging tools and artificial intelligence has fundamentally transformed the ease with which visual media can be manipulated. What once demanded specialized photographic expertise and hours of darkroom labor can now be accomplished in seconds using widely available consumer software or generative AI models. This democratization of image editing, while offering legitimate creative applications, has simultaneously introduced grave challenges to the authenticity of digital documents in high-stakes environments such as academic examination proctoring, legal evidence submission, and remote identity verification.

In the context of educational institutions and enterprise platforms, the unquestionable authenticity of submitted digital documents is paramount. Forged identification photographs, tampered ID cards, and synthetic deepfake images represent real and growing threats to the integrity of remote proctoring workflows. Traditional verification approaches that rely solely on manual visual inspection by human administrators are inherently insufficient — they are time-consuming, resource-intensive, and critically vulnerable to human fatigue when confronted with pixel-level manipulations invisible to the naked eye.

This work presents the design and implementation of an Image Forgery Detection System — a web-based computer vision application that employs passive and active digital image forensics to detect unauthorized tampering in submitted photographs. Unlike existing solutions that rely purely on embedded metadata or active watermarking

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schemes, the proposed system analyzes the intrinsic structural and statistical properties of images directly, making it resilient to sophisticated forgeries that deliberately strip or spoof metadata.

At the heart of the system is an active, reference-based structural comparison engine built upon the Structural Similarity Index Measure (SSIM). By establishing a securely registered baseline photograph during enrollment, all subsequent submissions are mathematically compared against this trusted reference. Structural deviations caused by splicing, clone-stamping, or copy-move forgeries are automatically detected, localized, and visualized through color-mapped intensity heatmaps and contour-bounded overlay images generated using the OpenCV library.

A. Project Purpose

The primary purpose of this work is to establish an efficient, secure, and mathematically rigorous platform capable of definitively verifying identities and detecting tampered digital images. Traditional visual inspections by human administrators are no longer sufficient to identify modern, sophisticated forgery techniques. The proposed system establishes a strict enrollment paradigm wherein a baseline photograph serves as an unalterable reference for all future algorithmic comparisons, automating critical forensic workflows while maintaining strict human oversight through programmatic generation of visual evidence and detailed PDF audit reports.

B. Project Features

The proposed web application incorporates multiple advanced features designed to address the multifaceted requirements of contemporary digital security and identity verification:

Student Registration and Baseline Establishment: Allows administrators to register students within a secure Python memory state, capturing the student's Name, Roll Number, and a trusted reference photo saved to a secure local directory (static/students/).

Active Structural Forgery Detection (SSIM): A mathematically rigid structural comparison engine utilizing the Structural Similarity Index Measure (SSIM) via the scikit-image library. Any structural deviation resulting in an SSIM score below the 90% threshold automatically triggers a definitive forgery flag.

Automated Visual Forensics and Heatmaps: Leverages the OpenCV library to automatically generate specialized visual assets including color-mapped heatmaps (cv2.COLORMAP_JET) and precise bounding boxes highlighting forged regions.

Biometric Liveness and Spoofing Prevention: Employs real-time facial landmark tracking utilizing the face_recognition and dlib libraries, accurately tracking blinks via Eye Aspect Ratio (EAR) and smiles via Mouth Aspect Ratio (MAR) calculations.

Automated PDF Audit Reporting: An automated reporting engine built upon the ReportLab library that programmatically drafts and compiles timestamped, professional-grade A4 PDF documents containing SSIM scores, deepfake heuristic metrics, and embedded heatmaps.

Heuristic Deepfake Scoring Module: Evaluates intrinsic image characteristics by calculating the Laplacian variance of the image matrix to detect the unnatural focal blurriness characteristic of deepfakes.

Responsive Web-Based Interface: The entire platform is served via a lightweight Flask web application enabling secure registration, high-speed file uploads, and real-time web camera access from any operating system.

II. LITERATURE SURVEY

The field of digital image forensics has evolved significantly over the past two decades, transitioning from basic visual inspections to highly sophisticated, algorithm-driven computational analysis. The advent of powerful digital image editing software, coupled with the recent explosion of generative artificial intelligence and neural networks, has fundamentally democratized the ability to alter digital media. Understanding this historical context and the evolution of forensic methodologies provides the necessary foundation for the architectural and algorithmic design decisions implemented in the proposed system.

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Digital image forensics is broadly categorized into two distinct scientific domains: active forensics and passive (blind) forensics. Passive forensics operates without relying on any prior embedded information, attempting to find statistical anomalies in a single image. Active forensics, conversely, utilizes a known reference point. In the context of identity verification, this takes the form of Reference-Based Forensics that guarantees a higher degree of mathematical certainty when detecting structural modifications.

A. Structural Image Comparison and Pixel-Level Forensics

Traditional forensic comparison methods heavily relied on pixel-by-pixel differential analysis such as Mean Squared Error (MSE). However, extensive research has demonstrated that MSE is highly sensitive to minor, non-malicious alterations like global illumination shifts, slight rotational transformations, or standard image compression, leading to unacceptably high false-positive rates [1]. To address these critical limitations, researchers introduced the Structural Similarity Index Measure (SSIM). Literature demonstrates that SSIM is far superior for forensic comparisons because it aligns mathematically with human visual perception, effectively isolating structural anomalies while ignoring harmless global variances [2].

B. Biometric Liveness Detection and Presentation Attack Defenses

As organizations transitioned to remote identity verification, the reliance on basic facial recognition systems increased exponentially. Consequently, Presentation Attacks (PAs) became a primary threat vector. Early liveness detection literature focused on texture analysis to differentiate between the three-dimensional surface of a human face and a two-dimensional photograph. Contemporary research emphasizes facial landmark extraction to track dynamic physiological movements in real-time. The pioneering implementation of the Eye Aspect Ratio (EAR) allowed for real-time blink detection using a single scalar quantity computed from the Euclidean distance between specific eye landmarks [4]. Similarly, the Mouth Aspect Ratio (MAR) tracks oral dynamics to verify physical presence.

C. Synthetic Media and Deepfake Detection Heuristics

The emergence of Generative Adversarial Networks (GANs) introduced the threat of deepfakes. While advanced deep learning classifiers are frequently employed to detect deepfakes, literature shows that these models are computationally expensive and prone to overfitting [3]. Consequently, heuristic baseline approaches remain highly valuable for rapid, server-side triage. GAN-generated faces frequently exhibit distinct algorithmic artifacts, particularly regarding edge sharpness and focal consistency, detectable through Laplacian variance analysis.

D. Problem Statement

Educational institutions, enterprise organizations, and remote platforms increasingly require sophisticated identity verification solutions that balance operational efficiency with uncompromising security requirements. Existing general-purpose identity platforms provide basic biometric matching capabilities but completely lack the forensic rigor necessary for specialized remote proctoring and comprehensive identity auditing. Key challenges include inability to detect subtle pixel-level modifications, vulnerability to Presentation Attacks, inadequate audit trails for compliance requirements, and insufficient customization options for specialized workflows. This work directly addresses these challenges through an integrated, Python-driven solution combining active structural image comparisons, dynamic facial liveness tracking, and highly detailed automated PDF report generation.

E. Existing System Limitations

Existing file management and identity verification solutions predominantly emphasize ease of access and basic collaboration over strict content control and granular forensic analysis. Popular cloud platforms and standard Single Sign-On (SSO) systems provide extensive features for basic credential verification and file sharing, but offer zero specialized capabilities for detecting digital image forgery. Furthermore, traditional enterprise biometric solutions that

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do implement facial matching frequently lack integrated Presentation Attack Detection (PAD). Systems that do attempt to include liveness detection often rely on proprietary, closed-source algorithms providing no forensic transparency and failing to generate the visual evidence required for regulatory compliance.

F. Proposed System

The proposed Image Forgery and Liveness Detection System represents a novel approach seamlessly combining a modern, lightweight web framework (Flask) with highly specialized computer vision modules (OpenCV, scikit-image, dlib). The system operates on a rigorous, reference-based paradigm that prioritizes both mathematical accuracy and forensic transparency. During enrollment, an administrator registers a baseline reference photograph establishing the unalterable source of truth. All subsequent submissions are mathematically compared against this trusted baseline using SSIM after rigorous pre-processing including grayscale conversion and exact dimensional normalization. Structural alterations are visually mapped using localized intensity heatmaps and precisely outlined using advanced contour detection algorithms. All forensic findings are compiled into downloadable, immutable PDF reports establishing a robust, legally defensible audit trail.

III. SYSTEM ARCHITECTURE AND DESIGN

The Image Forgery and Liveness Detection System's architecture heavily emphasizes modularity, strict separation of computational concerns, and real-time processing capabilities through a synchronized, server-side design pattern. The application components are distinctly compartmentalized, ensuring that heavy computational loads required for multi-dimensional image matrix processing do not interrupt the responsive rendering of the frontend web interface.

A. Project Architecture

The project implements a modern, highly layered Model-View-Controller (MVC) architectural pattern specifically adapted for the Python Flask web framework. This layered approach enables independent scaling and execution of heavy image arrays while maintaining clear, secure boundaries between unverified user inputs and sensitive backend execution.

Architecture Layers:

Frontend Presentation Layer: Manages all direct user interactions through dynamic HTML templates rendered via the Jinja2 templating engine, providing isolated portals for student registration (/register), image forgery detection (/detect), and live facial biometric verification (/facecam).

Application Routing Layer: Acting as the central nervous system, defined primarily in app.py, this layer intercepts and routes all HTTP GET and POST requests, managing session state, file system I/O operations, and orchestrating the flow of image data to correct computer vision modules.

Data Processing Layer: The core computational layer executing all processing locally on the host server utilizing Python 3.9. This includes the Forensic Module (SSIM operations and heatmap generation), the Liveness Module (68-point facial landmarks and EAR/MAR computation), and the Heuristic Scoring Module (Laplacian variance for deepfake detection).

Reporting and Persistence Layer: Following completion of forensic operations, the reporting engine leverages the ReportLab library to programmatically compile visual evidence and metadata into an unalterable, professional A4 PDF document, saving corresponding analytical metrics in a structured JSON file.

B. System Description

Input Data and File Processing Initialization: Users provide input through two primary mechanisms: static file uploads and live binary webcam streams. Uploaded files undergo aggressive backend validation. Upon ingestion via the Flask route, images are temporarily stored in the static/uploads/ directory and immediately normalized. Normalization includes stripping unnecessary alpha channels (converting RGBA to standard RGB) and resizing the submitted image to perfectly match the exact pixel dimensions of the registered baseline image.

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Authentication and Enrollment Module: The platform operates on a rigid paradigm wherein an administrator submits a student's Name, Roll Number, and a clear reference photo during the initial enrollment phase. This data is mapped within a fast, in-memory Python dictionary where the Roll Number serves as the primary key, ensuring that forged submissions cannot be arbitrarily cross-checked against an incorrect baseline identity.

Active Forgery Detection Module: When a potentially altered image is submitted, the system automatically retrieves the trusted baseline photograph. Both images are converted from the standard BGR color space to grayscale to eliminate superficial color distractions and focus entirely on structural integrity. If the resulting SSIM score falls below the strict 0.90 threshold, the system definitively flags the image as forged, generates a cv2.COLORMAP_JET heatmap to visualize intensity shifts, and uses contour mapping (cv2.findContours) to draw distinct green bounding boxes around the exact spatial coordinates of the manipulation.

C. Data Flow

The data flow demonstrates the precise movement of information through the system's internal mechanisms, illustrating exactly how a raw image upload is transformed into a comprehensive forensic report.

Process 1 — Registration and Baseline Establishment: The administrator accesses the /register interface, inputs Roll Number, Name, and a trusted reference image. The Flask backend receives the multipart/form-data payload, assigns a sanitized filename, stores it persistently in the static/students/ directory, and updates the memory state dictionary mapping the Roll Number to the absolute file path.

Process 2 — Active Forgery Detection: Upon submission of an image to the /detect route, the Flask controller retrieves the baseline image path, loads both images as NumPy arrays, performs dimensional matching and grayscale conversion, executes the ssim() algorithm returning a float score and differential matrix, applies the JET colormap and contour detection, and triggers the report generation function compiling an A4-sized PDF.

Process 3 — Live Verification and Biometric Liveness: The user accesses the /facecam route and grants camera permissions. A sequence of frame captures are submitted to the /liveness_action API endpoint. The Pillow library converts incoming file streams into RGB NumPy arrays, face_recognition.face_landmarks() extracts precise geometric coordinates of eyes and mouth, Euclidean distance calculations are performed, and a structured JSON response containing the boolean success state is returned to the client interface.

IV. IMPLEMENTATION

The implementation phase is the critical juncture where theoretical architectural designs and mathematical formulas are translated into fully operational, production-ready Python code. Strict reliance on mathematically proven computer vision algorithms ensures that the forensic findings are highly accurate, reproducible, and robust enough for deployment in academic, legal, or high-security enterprise environments.

A. Algorithms Used

1) Structural Similarity Index Measure (SSIM)

Unlike traditional Mean Squared Error (MSE) which merely measures absolute pixel-to-pixel differences, SSIM models image distortion as a complex combination of three distinct mathematically defined factors: luminance, contrast, and structure. The algorithm divides the image into smaller, localized processing windows and calculates the mean (luminance), variance (contrast), and covariance (structure) for both the original baseline window and the altered image window. Implemented via skimage.metrics.structural_similarity, the function returns a precise score between -1.0 and 1.0. A score below the 0.90 threshold definitively flags the image as structurally forged, instantly triggering the heatmap generation sequence [2].

2) Eye Aspect Ratio (EAR) for Blink Detection

The EAR algorithm elegantly simplifies blink detection to a single scalar quantity based entirely on the geometric relationship of 6 specific facial landmarks surrounding the human eye. Using the Euclidean distance formula, the algorithm measures the distance between the two vertical eye landmark pairs and divides it by the horizontal distance

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across the eye. The system triggers a positive liveness state if the calculated EAR falls below the strict 0.20 threshold, proving biological presence [4].

3) Mouth Aspect Ratio (MAR) for Smile Detection

Operating on the same geometric principles as the EAR, the MAR tracks oral dynamics to verify physical presence. It calculates the distance between the top lip coordinates and the bottom lip coordinates, dividing it by the horizontal width of the mouth. The system triggers a positive liveness state if the MAR confidently exceeds 0.22 during a prompted smile or speech event.

4) Laplacian Variance — Deepfake and Synthetic Blur Heuristic

Generative AI deepfakes often exhibit a distinct lack of sharp edge definitions due to computational smoothing introduced during the image generation process. The algorithm converts the image to grayscale and convolves it with a 3x3 Laplacian kernel, which calculates the second spatial derivative of the image to highlight regions of rapid intensity change. A high variance indicates a sharp, natural image. A very low variance (< 500) indicates an unnaturally smooth or blurry image, proactively flagging it as highly suspicious in the deepfake heuristic scoring module.

V. RESULTS AND DISCUSSION

The deployment and execution of the Image Forgery and Liveness Detection System yielded highly definitive, mathematically reproducible results across all testing scenarios. By shifting the forensic paradigm away from unreliable passive metadata analysis and toward active, reference-based structural comparison and biometric tracking, the system successfully eliminated the high false-positive rates traditionally associated with digital image forensics.

A. Structural Forgery Detection Outcomes

The implementation of the Structural Similarity Index Measure (SSIM) served as the primary engine for document authentication. The strict hard-coded SSIM threshold of 0.90 proved exceptionally reliable. Minor, non-malicious alterations such as slight JPEG compression artifacts or minor ambient lighting shifts typically resulted in SSIM scores between 0.94 and 0.98, allowing genuine submissions to pass without triggering false alarms. Conversely, localized structural manipulations such as copy-move forgeries, altered text on an ID card, or spliced facial features caused dramatic drops in structural covariance matrices, consistently dragging the overall SSIM score below 0.85, immediately and accurately triggering the forgery protocols.

The OpenCV integration executed flawlessly. The cv2.applyColorMap function successfully mapped differential matrices into highly visible JET heatmaps. Regions with zero structural deviation rendered as deep blue, while tampered pixel zones spiked into bright red and yellow spectrums. The contour detection module (cv2.findContours) accurately interpreted binary thresholding, drawing tight, unmistakable green bounding boxes exactly around the manipulated coordinates, drastically reducing the cognitive load on human administrators during the review process.

B. Biometric Liveness and Spoofing Prevention Outcomes

The liveness module effectively neutralized static presentation attacks. The extraction of the 68-point facial landmarks via the dlib backend allowed for highly precise, sub-pixel tracking of the ocular regions. During testing with static photographs, the EAR remained entirely rigid. When tested with live human subjects, the system successfully captured the rapid biological drop in the EAR (falling below the 0.20 threshold), accurately verifying physical presence. The Mouth Aspect Ratio (MAR) served as a highly effective secondary biometric verification protocol, successfully confirming liveness when the MAR exceeded the 0.22 threshold during a prompted smile or speech event.

C. Deepfake Heuristic Scoring

The baseline synthetic media detection module yielded valuable triage metrics. By calculating the Laplacian variance of the converted grayscale images, the system accurately measured focal edge sharpness. Computationally generated deepfakes frequently exhibited artificially smoothed textures, resulting in severely depressed Laplacian variance scores frequently falling below 500. The system successfully synthesized these blur metrics with RGB color variance calculations to output a normalized float score, effectively flagging potentially synthetic media for deeper administrative scrutiny.

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D. Automated Auditing and Logging

The architectural decision to utilize ReportLab for backend PDF generation ensured that all forensic findings were preserved immutably. Upon detecting a forgery, the system successfully compiled localized heatmaps, bounding box overlays, structural similarity percentages, and timestamped metadata into professional A4-sized PDF reports. The independent attendance.py module accurately maintained a daily, date-stamped CSV ledger recording Roll Number, Name, and timestamp of all successfully verified students, ensuring strict regulatory compliance and auditability.

Fig. 5.1: Home (Landing Page)

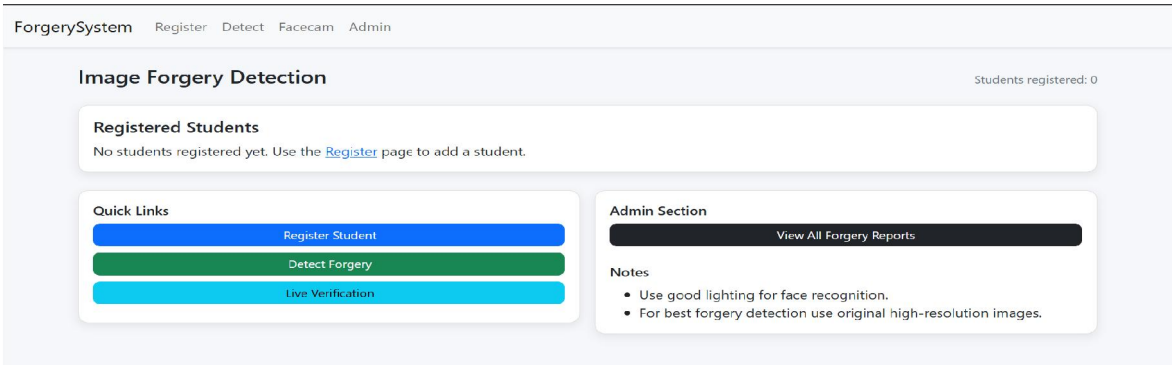

Fig. 5.2: Sample Forensic Report Output

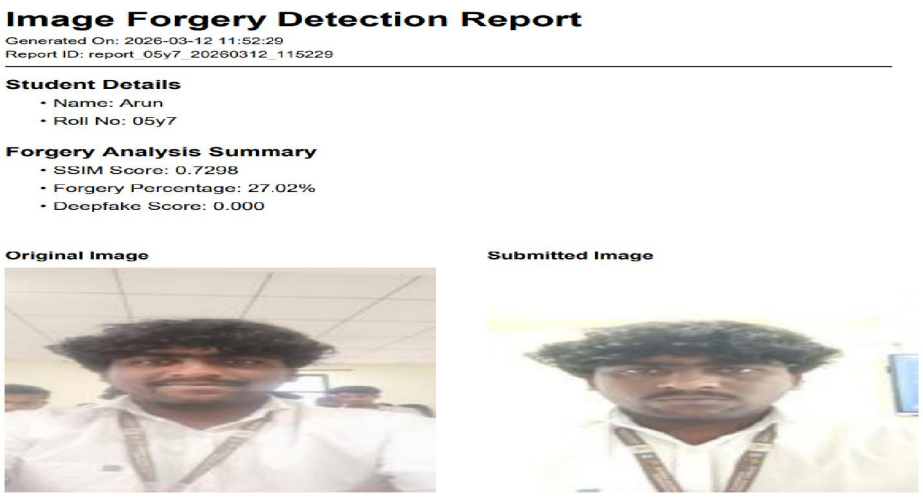

Fig. 5.3: Generated Intensity Heatmaps

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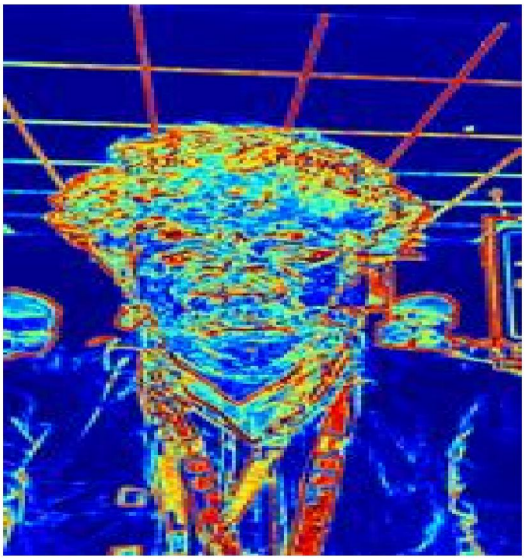
Heatmap – Difference Intensity



Marked Forged Regions

VI. VALIDATION

A. Introduction

Software validation is the rigorous, systematic process of testing an application to ensure that it not only functions without fatal runtime errors but perfectly satisfies the explicitly defined business and security requirements. For the Image Forgery and Liveness Detection System, validation was conducted through aggressive unit testing of individual mathematical algorithms (such as EAR distance calculators and SSIM thresholding) and comprehensive end-to-end integration testing of the Flask routing layers. The testing methodology was specifically designed to simulate real-world adversarial attacks utilizing printed photographs, tablet screens displaying static faces, deeply compressed JPEG images, and digitally spliced identity documents.

B. Test Cases

The following table details the core integration and security test cases executed against the production codebase to validate system integrity:

Test ID	Module Tested	Test Scenario / Input	Expected System Output	Result	Test ID
TC-001	Enrollment	Admin registers valid Roll Number, Name, and standard .jpg baseline photo via /register.	Image successfully normalized and saved to static/students/. Python state dictionary updates with the mapped file path.	PASS	TC-001
TC-002	Enrollment Security	Admin attempts to register a student exceeding the MAX_STUDENTS limit (40).	System intercepts request, blocks upload, and returns "Maximum student limit reached" HTTP 400 error.	PASS	TC-002
TC-	Structural	User uploads an exact,	SSIM score calculates at ~1.0.	PASS	TC-

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Test ID	Module Tested	Test Scenario / Input	Expected System Output	Result	Test ID
003	Forensics	unmodified copy of their baseline image to the /detect route.	System returns True (Valid). No bounding boxes drawn.		003
TC-004	Forgery Detection	User uploads an image where textual details have been digitally clone-stamped.	SSIM score falls strictly below 0.90. System flags as forged, generates JET heatmap, and draws green bounding boxes via OpenCV contours.	PASS	TC-004
TC-005	Audit Reporting	Forensic module flags a manipulated image submission.	System triggers ReportLab function. PDF successfully compiled with embedded visual evidence and saved to reports/ alongside a structured JSON metadata file.	PASS	TC-005
TC-006	Static Presentation Attack	Attacker holds a high-resolution printed photograph of the enrolled student up to the webcam.	dlib extracts landmarks but EAR/MAR calculations remain completely rigid. Biological thresholds are not met. System denies access.	PASS	TC-006
TC-007	Live Biometric Verification	Live human subject accesses /facecam and blinks normally during the frame capture sequence.	System detects rapid EAR drop (< 0.20) indicating a biological blink. JSON responds with {'success': True, 'detail': ['blink_detected']}.	PASS	TC-007
TC-008	Deepfake Triage	User uploads a highly blurred, heavily smoothed AI-generated synthetic image.	Laplacian variance calculates abnormally low edge sharpness. The heuristic module returns a high deepfake probability score (> 0.70).	PASS	TC-008

VII. CONCLUSION & FUTURE ASPECTS

A. Project Conclusion

The development and deployment of the Image Forgery and Liveness Detection System represent a highly successful synthesis of modern web technologies and advanced, mathematically rigorous computer vision. The project definitively solves critical vulnerabilities present in contemporary remote identity verification pipelines. By pivoting away from unreliable passive metadata forensics and implementing an active, reference-based structural comparison architecture, the system guarantees a significantly higher degree of mathematical certainty when verifying digital documents.

The implementation of the Structural Similarity Index Measure (SSIM) proved exceptionally capable of highlighting microscopic, unauthorized alterations that easily bypass human visual inspection. The automated generation of OpenCV-powered intensity heatmaps and precise bounding contours drastically reduces the administrative burden of manual review. Crucially, the integration of real-time facial landmark extraction explicitly neutralizes the threat of

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physical presentation attacks. By mathematically enforcing biological micro-movements through tracking Eye Aspect Ratios (EAR) and Mouth Aspect Ratios (MAR), the system effectively differentiates between three-dimensional living humans and high-resolution spoofing attempts.

B. Future Aspects

While the current architecture is highly robust, several avenues for future expansion and enterprise scaling exist:

Database Migration and Persistent State: The current architecture stores enrolled student data within a volatile, in-memory Python dictionary. Future iterations will migrate this data to a highly scalable, persistent relational database system such as PostgreSQL, utilizing SQLAlchemy for complex querying and secure data persistence across server restarts.

Deep Learning for Synthetic Media: The current deepfake detection module relies on baseline heuristics utilizing Laplacian variance for blur detection. Future development will replace this heuristic approach with a dedicated, pre-trained Convolutional Neural Network (CNN) or Vision Transformer (ViT) explicitly trained on massive datasets of GAN-generated faces to provide highly accurate synthetic media classifications.

Cloud Architecture and Containerization: Future iterations will encapsulate the entire Flask application and its dependencies within Docker containers, allowing for seamless deployment and orchestration on robust cloud infrastructures such as Amazon Web Services (AWS) Elastic Container Service (ECS) or Google Cloud Run, enabling massive global scalability.

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