The Role of Facial Recognition Technology in Strengthening Academic Integrity in Higher Education E-Learning

Nur Aisyah Mohd Nasir[1], Muhammad Firdaus Mustapha[2*], Mohd Nasir Ismail[3], Mohd Azry Abdul Malik[4]

[1,2,4]Faculty of Computer & Mathematical Sciences, Universiti Teknologi MARA Kelantan Branch, Bukit Ilmu, 18500 Machang, Kelantan, Malaysia

[3]Faculty of Information Science, Universiti Teknologi MARA Kelantan Branch, Bukit Ilmu, 18500 Machang, Kelantan Malaysia

DOI: https://doi.org/10.47772/IJRISS.2025.91200100

Received: 12 November 2025; Accepted: 19 November 2025; Published: 01 January 2026

ABSTRACT

The rapid growth of higher academic online education has posed new challenges to academic integrity, particularly in the legitimization of student identity and assuring of authentic classes. Despite the widespread use of e-learning platforms, most of the existing systems lack reliable methods for real-time verification during online sessions. This paper presents the opportunities of facial recognition technology in solving these problems by creating Learnify which is an e-learning attendance management system. The system automates real-time attendance monitoring to validate student presence and identity during online sessions. Learnify was created using PHP, Python, Flask, MySQL, and OpenCV and evaluated under the controlled conditions to assess its performance, usability, and influence on the ethical process of learning. The experimental results showed that the Learnify achieved the highest facial recognition confidence score of 81.95, while the System Usability Scale (SUS) result revealed that more than 80% of the participants agreed that Learnify is user-friendly and time-saving. Studies have shown that implementation of facial recognition in the e-learning systems can enhance accountability, reduce impersonation, and create fairness in online learning. The study highlights the importance of moral data management and technological reliability in supporting academic honesty in online education settings.

Keywords: Facial recognition, academic integrity, online learning, higher education, attendance tracking system.

INTRODUCTION

The introduction of online education has revolutionized the learning world and provides flexibility and access to students in different settings. E-learning has been shown to help students remember things better (25–60%) than traditional classrooms (8–10%) and to help them learn faster (40–60% less time) [1]. The uncontrolled growth in online learning has highlighted a major gap in maintaining academic integrity with respect to the identification of student identity in virtual classes. With the growing use of digital learning, the issue of protecting academic integrity has become a common concern. Particularly, establishing the legitimacy of student attendance and interaction is a major challenge to lecturers and organizations [2]. Traditional methods of attendance such as manual roll calls or web-based check-ins can be impersonated and inaccurate thus undermining credibility and fairness in the learning process[3]–[5].

The integrity of academic education is based on quality education and despite the availability of various technology solutions that allow one to learn online, most of the existing systems still rely on poor verification mechanisms that can be exploited. Facial recognition and other biometric systems can be considered a viable option as they automate the process of identity confirmation and diminish the chances of committing a crime [3], [4]. Technologies like facial recognition to improve security has led to continuous discussions on the issue of security and privacy and reconciliation of the two issues have not been accomplished [2]. Meanwhile, the best

verification methods have yet to be developed, and e-learning facilities are still of risk of losing certain credibility when lecturers are unable to be sure of the integrity and involvement of the participants.

Therefore, this paper introduces Learnify, an online based e-learning attendance management system, which uses facial recognition technology to verify attendance in real-time, automatically and safely to meet the current limitations. Learnify, in comparison to the traditional systems, focuses on improving academic integrity through mitigating the threat of impersonation and providing both usability and accessibility to students and lecturers. This study evaluates the effectiveness of facial recognition in enhancing the precision of attendance, equity and efficiency of operation in higher education e-learning environments. System usability is also analyzed, and ethical issues such as privacy, data security, and system reliability are discussed.

LITERATURE REVIEW

Digital Learning and Academic Integrity

This section is going to discuss the role of digital learning in the contemporary academic world and how it is related to academic and personal integrity. E-learning enables distance and flexible learning but at the same time it increases the chances of bad behavior such as absenteeism and proxy attendance [6]. Online attendance is a vital indicator of student attendance and academic achievements, but manual verification or password-based approaches means that the level of verification is inadequate [7]. Checking attendance of enrolled students in the sessions is a critical approach towards upholding academic integrity. Besides, the present literature indicates that attendance checks are usually done manually using either unsupervised sign-in sheets or roll calls which are both highly limiting. The unmonitored approaches will divert the classes and allow students to mark students present on their behalf, whereas continuous roll calling will prove unproductive and time-consuming during large classes. Such constraints are since students will be required to attend one at a time making this process not smooth [8].

Biometric Authentication in Education

The system has introduced biometric authentication (fingerprint, iris and facial recognition) into the education sector to enhance the accuracy of verification [9]. The usage of facial recognition is preferred because of the non-invasive and camera-based implementation. Haar Cascade, Eigenfaces, and Convolutional Neural Networks (CNN) algorithms can be used to detect and compare the features of the face in an efficient way [10], [11]. Besides, the technology of face recognition is explained as one of the most powerful technologies that recognize people in pictures or videos according to distinctive features of faces. Its uses are vast including the security systems and the monitoring of people in different places. For an example, Chandra et al. [12] presented a visual attendance system, which combines the use of Histogram of Oriented Gradients (HOG) to extract features and CNN to classify features. This combination was meant to enhance the efficiency and accuracy of managing attendance in institutions and businesses through simplification of the step of recording and validating attendance. Fernando and Athauda [2] also proposed a feature-based feature face detection methodology, which relies on a highly accurate facial recognition method in matching pictures and training a facial biometry set. The work included system design, software simulation, and integration of the facial recognition component into the program to ensure smooth and reliable operation. Moreover, Geetha et al. [11] introduced a machine learning-based facial detection and recognition system designed for monitoring students during online examinations by employing the Support Vector Machine (SVM) model for training and the Eigenface technique for feature extraction to improve recognition precision and efficiency. This system aims to maintain academic integrity through real-time monitoring to identify potential cheating. All the studies have shown that use of facial recognition technology in e-learning systems increases accuracy in attendance as well as promoting equity and accountability in students.

Resistance to Implementation

Despite the advantages, biometric technologies are the cause of concerns about privacy, data security, and ethical use [13]. Facial data storage is security-related, and when not properly handled, it can cause security risks. Besides, recognition accuracy can vary depending on the light conditions, quality of the device, and the location

of the user. To achieve a balance between technology and ethical responsibility in education, it is important to mitigate these limitations.

METHODOLOGY

This study adopted the Waterfall approach while moving sequentially through analysis, design, implementation, testing, and evaluation. This systematic approach provides order, progress and quality control throughout each system development phase. The Waterfall model was selected because it clearly defines the system requirements at early stage and the sequential phases that were required in the development process to integrate facial recognition module that requires a strong specification. Unlike iterative models such as Agile, the Waterfall model allows the implementation of each step to be properly tested until successful before moving on to the next step [14]. Therefore, it reduces implementation risks and ensures that all system documentation is consistent.

System Architecture and Implementation

For the Learnify system, the backend processing was done in Python and Flask, while MySQL was used for database management as shown in Table I. Real-time facial recognition was performed by the OpenCV library through live video frame captures and comparisons to archived datasets. The interface that provided access for the three user roles - administrators, lecturers, and students was built with HTML, CSS, and JavaScript.

1) Administrator: Oversees user registration and system documentation.

2) Lecturer: Examines attendance records and confirms students identified through the system.

3) Students: Join the sessions and are authenticated by the system through automatic facial recognition.

Table I: software tools used during the development

No	Software	Specification
1.	Frontend Development	HTML, CSS, JavaScript
2.	Backend Development	PHP, Python, Flask, Visual Studio
3.	Local Server Environment	XAMPP (Apache, MySQL, PhpMyAdmin)
4.	Project Management	Gantt Chart
5.	Design tool	draw.io, Visual Paradigm

Fig. 1 shows the Learnify system's Use Case Diagram, which explains how different user roles are related to the actions they can take on the platform. The working process starts with the registration and enrolment of a student on courses. Courses are created by lecturers, attendance sessions are coordinated, and the registration in administration and the authentication of all the profiles are confirmed. When a virtual session starts, students enter the session and the system will then automatically use the facial recognition module to identify each student. The system checks the data received and records the results in the database, minimizing the possibility of manual errors and impersonation. Lecturers then analyze the records that have been validated and generate attendance reports. Finally, the administrators will manage the reporting. This structured flow of work ensures the proper interaction of all user positions and preservation of the accuracy of attendance data.

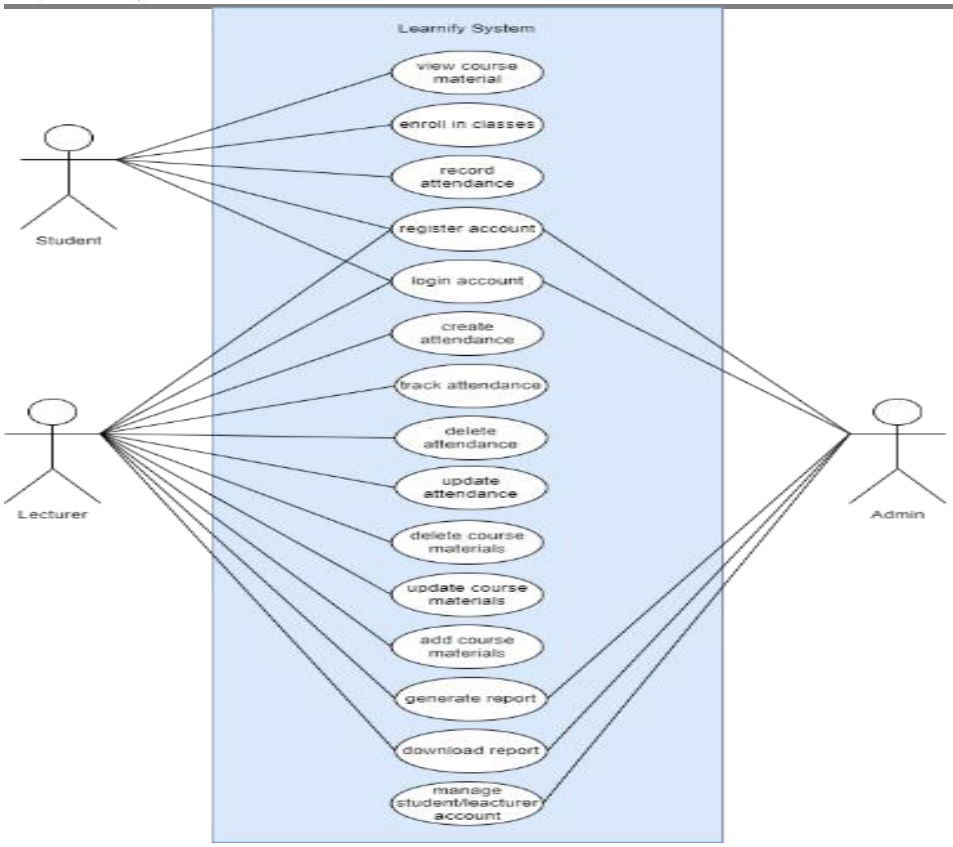

Fig. 1 Use case diagram of Learnify system

Facial Recognition Implementation

The main advantage of the Learnify system is facial recognition, which aims to automate the authentication of students and track their attendance throughout online classes. This system utilizes the OpenCV which is a free computer vision library to perform real-time face recognition and face detection through a web camera. Its implementation process consisted of a sequence of activities that included students, lecturers, the system and the administrators. It has three main stages; face detection, feature extraction and face recognition and matching.

Face Detection

The process began with the student having a profile with a photograph that was used as the reference image to identify the student. When the registration was checked by the administrator, the student received access to online classes through the Learnify platform. After placing the student in a classroom, the web camera was used to send a video stream, and OpenCV was used to recognize the face of the student in real-time.

To improve accuracy, the system first converted the camera information into greyscale and then used Haar Cascade classifier that detects face regions using edge gradient and intensity changes. The facial features of each frame were analyzed and on detection, the facial region was removed, scaled and normalized to ensure that the quality was the same before moving to the next step. The preprocessing stage helped reduce the level of noise caused by background objects and changes in light, allowing the recognition algorithm to be focused only on relevant facial features.

Feature Extraction

When the facial detection was successful, the system went ahead and activated the verification process to verify the identity of the student. At this point, the student has successfully logged into the Learnify platform, accessed the educational materials available on the platform, and followed an online class using the integrated link of online class.

When the student entered the virtual classroom, the system automatically initiated a facial recognition check

which used the photo stored in the process of registration. The web camera would capture the live image of the student and would compare the image with the reference photograph stored in the database.

The system used Local Binary Pattern Histogram (LBPH) method at this comparative stage to isolate distinct facial patterns. It was a method used to analyze local textures through pixel-to-pixel comparison to form binary integers which later were summed to produce a histogram. The histograms acted as mathematical measures of identifying the facial structure of the student so that the system could match the live face to the stored data.

The LBPH model was trained using the registered facial photos in the database whereby each student would provide many samples to improve the accuracy of recognition. LBPH was selected because it has shown good results in various lighting conditions and the data needs are minimal making it suitable in regulated academic environments. LBPH also well-known for its accuracy and performance, which can recognize a person's face from both front and side [15].

After scanning the face against the stored record, the system confirmed the identity of the student and marked the student as present. In case there was no match in the facial recognition, the system was able to register the attendance as absent. Regardless of the result, the student was allowed to continue with the online classroom session.

The checking system ensured that the enrolled students were only checked as present, and the integrity of attendance monitoring in virtual classes was maintained.

Face Recognition and Matching

The last step of the lecturer involved analysis and verification of the results of the face recognition process. When students entered the virtual class, the system automatically carried out facial detection and recognition as a way of recording attendance. The results of the recognition were then available to the lecturer through the Learnify dashboard.

The matching technique relied on the calculation of a score of confidence based on the similarity between the histogram live and the database face. A lower score was an indication of better competition. When the score was beyond the recognition threshold, the algorithm was used to classify the face as recognized. Otherwise, it was considered unrecognized and the student was not counted as present. For Learnify system, the recognition threshold is set to 50. This threshold was selected to minimize false acceptance while maintaining acceptable recognition accuracy under varying lighting and pose conditions. These results were logged in the system through the Flask server, and an audit trail of successful and failed attempts was created.

The lecturer used the attendance verifying panel and this showed all recognized and non-recognized entries of students. On successful facial recognition of a student, the status was updated to the present. In case recognition had failed or the face has not been identified, the system indicated the student as absent.

The lecturer followed up after reviewing the automated findings by verifying the records to determine their accuracy. In cases of anomalies, i.e., in cases where students were not identified or cases where records had been entered incorrectly, the lecturer made changes to the attendance records manually. After verifying all the records, the lecturer came up with the attendance report that summarized the presence and absence data during that session.

The final report was then forwarded to the administrator to be checked and archived. Such process allowed lecturers to manage attendance properly while at the same time maintaining accuracy, transparency and accountability in the Learnify framework.

Evaluation

The system's accuracy and usability were evaluated based on user testing done in controlled environments. A usability evaluation was done on a small set of representatives from Universiti Teknologi MARA (UiTM) Kelantan branch rather than conducting a full-scale user study. The usability of the Learnify was evaluated using

the System Usability Scale (SUS). Only small participants were needed for the SUS since the sample size is sufficient to discover 85% of the system's usability issues [16].

Using Learnify, five participants were assigned to register into system, attend a virtual class and verify attendance. System performance tests allowed the collection of quantitative data by measuring the accuracy of the system in recognizing participants in various lighting conditions and camera angles. On the other hand, qualitative data covered ease of use, satisfaction, and integrity perceptions and were captured from the SUS questionnaires and short interviews. The SUS questionnaire consists of ten questions measured on a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Higher scores indicate better perceived usability of the system.

RESULT AND DISCUSSION

The Learnify system was designed and tested to see how well it worked technically and how it affected academic honesty in online education. This section lists the main results of the study, which are organized into four main areas: system interface, evaluation results, contributions to academic integrity, and the problems and moral issues that came up during implementation. Each aspect is analyzed in relation to the study's objectives and relevant literature to provide a comprehensive understanding of how facial recognition technology can improve secure and dependable e-learning environments.

System Interface

Learnify system had an automated facial recognition system built into its online classes module to confirm the attendance of students in real time as shown in Fig. 2. The system interface provided students with a well-organized dashboard with information about classes, such as course title, date, session time, and a button for joining a class. When this choice was made, the system automatically initiated the authentication mechanism to confirm them before it proceeded to offer access. This was done as a security feature that ensures only registered and verified users got access to the virtual classroom thereby allowing academic integrity to be prioritized.

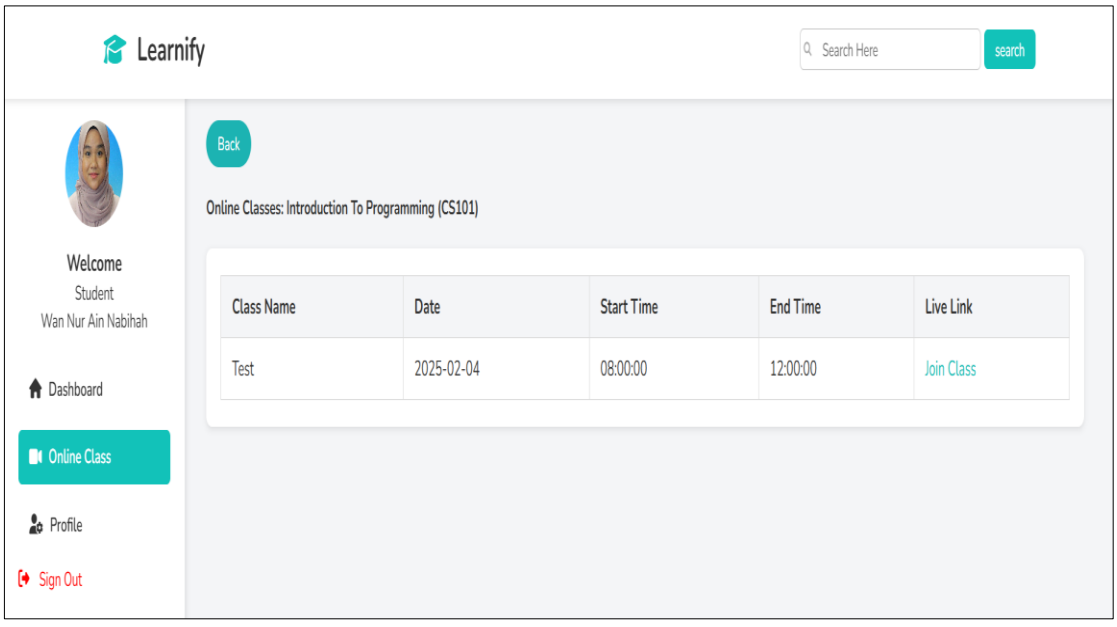

Fig. 2 Online class page for student

When the join class command was activated, as shown in Fig. 3, the student sent a live image by the web camera to the Flask server, which analyzed the image immediately and sent the results to the student. Preprocessing the image was done by converting it to greyscale, normalizing, and resizing the image before feeding it to the recognition model. The system then compared the extracted facial characteristics with stored representations in the database with the use of a trained LBPH model optimized on the feature matching and verification accuracy.

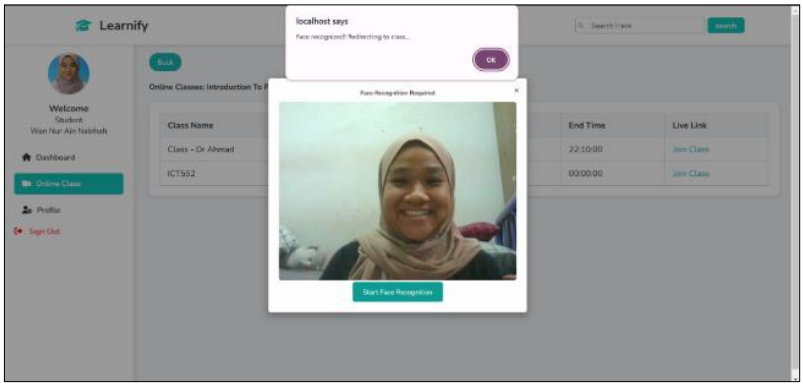

Fig. 3 Face recognition process for student

The output of the Flask server after successful recognition was recorded as displayed in Fig. 4 and confirmed that the output of a single face was correctly identified, and a registered student ID had been correctly identified with a measurable confidence value. When the match was confirmed, the system automatically recorded the attendance of the student in the database. A confirmation message was displayed to give an indication of a successful authentication which made it easier to proceed with the verification to class participation. The records of the attendance were immediately noted in the backend logs which increased the clarity and reliability of the process.

```
127.0.0.1 - - [22/Jan/2025 00:15:12] "OPTIONS /api/recognize_face HTTP/1.1" 200
Image successfully decoded and received in Flask
Faces detected: 1
Predicted label: 5, Confidence: 81.95051097706153, Expected user_id: 5
Attendance logged for user_id: 5.
```

Fig. 4 Flask server output when the system recognized face

Lastly, the reporting tools included in the Learnify user interface provide both lecturers and administrators with effective access to manage attendance data. The system gives lecturers detailed reports that include records of attendance, absences, and other important information as shown in Fig. 5. Thus, lecturers find this tool indispensable during their efforts to track attendance patterns and resolve arising problems. Lecturers can spot students who often miss class and take early steps to either help them or discover why they are not attending. The report's structured layout enables lecturers to continuously monitor attendance efficiently by presenting information cleanly and helping them maintain focus with their students while avoiding confusing data sets. The reporting features also help the administrative tasks by giving full attendance information for evaluations and academic records.

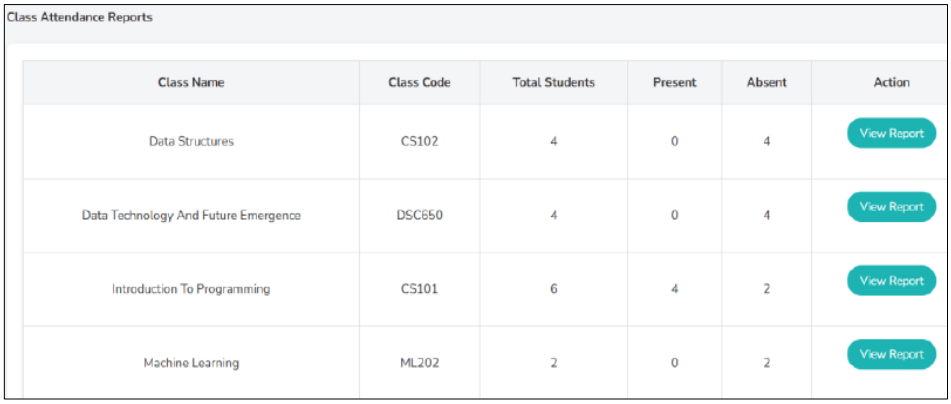

Fig. 5 Lecturer’s class report for assigned courses

Evaluation Results

The result from System Usability Scale (SUS) as summarized in Table II clearly shows that the participants evaluated Learnify as convenient to use. All positive questions in the SUS recorded mean scores above 4.0, demonstrating strong participant satisfaction with the system. In contrast, negative questions produced mean scores of 2.0 or lower, suggesting minimal usability concerns among participants. More than 80% of the participants agreed that the interface was user-friendly, and the automated system for attendance recognition saved time compared to manual method of recording attendance. Most of the participants rated positive questions with high score of 4 and 5 indicating agree and strongly agree. Meanwhile, for negative questions they chose strongly disagree and disagree with low score of 1 and 2. Therefore, it can be concluded that most of the participants were giving positive feedback and were satisfied with the Learnify system. According to students, automated attendance verification applied in system for active participation can improve equity and transparency in the system. For lecturers, the increase in their confidence in accuracy of attendance was evidence that the system has reduced their administrative load.

Table II Summary results of the SUS for Learnify

No.	Statement	Mean Score (out of 5)	Interpretation
Positive questions			
1.	I intend to utilize this system regularly.	4.3	Agree
2.	I perceived the system as user-friendly.	4.4	Agree
3.	I observed that the system's various functions are well integrated.	4.2	Agree
4.	I believe that the majority of individuals will rapidly get used to utilizing the system.	4.5	Agree
5.	I felt exceedingly assured in utilizing the system.	4.3	Agree
Negative questions			
6.	I perceived the system as excessively intricate.	1.8	Disagree
7.	I believe I require the assistance of a technical expert to utilize this system.	1.9	Disagree
8.	I perceived excessive inconsistency within this system.	2.0	Disagree
9.	I found the system exceedingly unwieldy to operate.	1.7	Disagree
10.	I had to require extensive knowledge before I could commence with this system.	1.8	Disagree

In term of system accuracy, the recognition system achieved an accuracy of 80% where it successfully identified 4 out of 5 participants but failed to recognize the remaining one. The success cases demonstrate that the facial recognition model used in Learnify correctly matched the captured facial data with high confidence scores that exceeded threshold levels. Within confined settings, the system reached the highest confidence score of 81.95 for the successful cases. On the other hand, for the failure case, the system was able to detect the participant's face but with confidence score lower than accepted threshold. Thus, the result demonstrates the system recognition performances on participants within standard and typical online classes in a situation with identifiable areas for system improvement. Several features of the environment such as the intensity of

illumination, contrast of the background, and quality of the web camera used determine the consistency of detection.

Contribution to Scholarly Integrity

The use of facial recognition systems also increased integrity by reducing impersonation and fostering accountability. Students became aware that their attendance were recorded biometrically and became aware of their punctuality. Lecturers felt that the system-built trust and reduced attendance-related disputes. These results support the findings of [1], [13] where the integrity-focused implementation of technology positively impacted ethical behaviour within learning environments and the trustworthiness of the institution.

Problems and Moral Issues

Although the results are positive, some challenges remain. Accuracy issues were created by poorly lit environments and low-resolution cameras. Since facial photographs are sensitive biometric attributes, there are ethical implications regarding the potential violation of privacy. For the ethical use of such systems, mechanisms ensuring privacy, informed consent, and data encryption must be implemented. Future work should focus on improving facial recognition technology and using encrypted cloud storage to protect the privacy of users.

CONCLUSION

This study demonstrates the potential of facial recognition technology to improve academic integrity in higher education. The Learnify system made it easier to keep track of attendance, lowered the risk of impersonation, and made things more open between lecturers and students. Learnify system also can improve honesty, trust, and productivity in the digital learning environment. By using biometric verification, e-learning platforms can make people more responsible and encourage ethical behaviour in learning.

However, the Learnify system have some limitations that affected the performance of the system mainly due to the constraint of hardware and environmental factors. Change in illumination, camera resolution, and orientation of the user significantly influenced the recognition accuracy with poor lighting leading to lower confidence ratings. The system was tested under the controlled environment, and with a small number of participants, and it restricted the range of conditions, which prevented a comprehensive test of its potential. In addition, the facial recognition module was faced with challenges of recognizing individuals wearing spectacles or with different facial expressions.

Therefore, future research will use a more holistic and diversified training dataset, as well as large-scale testing in a variety of situations and a larger user base. The system should use more advanced deep learning algorithms, like CNN-based recognition, to improve accuracy and adaptability in a wider range of situations. The Learnify solution may be linked to existing institutional Learning maintenance Systems (LMS) to allow attending verification effortlessly and maintenance of academic records in a centralized manner. For example, the Learnify system can be integrated into the institutional LMS through secure Application Programming Interface (API) and Learning Tools Interoperability (LTI) standards, enabling automated, real-time attendance recording while maintaining compliance with data privacy regulations.

Moreover, the ethical issues may be resolved in the future by creating formal consent procedures, implementing role-based access control, and providing safe and adequate biometric data storage on the basis of institutional and regulatory requirements. Long-term studies are needed to look at how biometric attendance affects students' participation and success in higher education.

REFERENCES

1. K. Agrawal, S. Borkar, S. Jain, A. Kulkarni, and D. Jadhav, “Enhancing E-Learning with Face Recognition and Linear Regression Analysis,” in 2023 International Conference on Integration of Computational Intelligent System (ICICIS), 2023, pp. 1–6.
2. R. Fernando and H. Athauda, “Image Processing based Real-Time Online Attendance Monitoring

System using Facial Recognition," in 2024 International Conference on Image Processing and Robotics (ICIPRoB), 2024, pp. 1–6.
3. S. Rajadurai, N. Dhinesh, S. Karthikeyan, and C. Kalamani, "Photographic Attendance Tracking System Online (PATSO)," in 2023 2nd International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies (ViTECoN), 2023, pp. 1–6.
4. D. Vengaimarbhan, I. Nandhini, S. Duraiarasu, C. Gobi, S. Dhenathayalan, and C. Bhuvanesh, "An Efficient Online Attendance Monitoring System Using FaceNet-Based FacialRecognition Technology," in 2025 3rd International Conference on Artificial Intelligence and Machine Learning Applications Theme: Healthcare and Internet of Things (AIMLA), 2025, pp. 1–5.
5. D. Yadav, S. Maniar, K. Sukhani, and K. Devadkar, "In-Browser Attendance System using Face Recognition and Serverless Edge Computing," in 2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT), 2021, pp. 1–6.
6. A. Ghodekar, T. Gunjal, A. Landage, A. Phapale, D. Thorat, and R. Nikam, "A Face Recognition-Based Smart Student Attendance and Activeness Monitoring System," in 2023 4th International Conference on Computation, Automation and Knowledge Management (ICCAKM), 2023, pp. 1–5.
7. S. Dev and T. Patnaik, "Student Attendance System using Face Recognition," 2020 Int. Conf. Smart Electron. Commun., pp. 90–96, 2020.
8. Z. Gao et al., "A Student Attendance Management Method Based on Crowdsensing in Classroom Environment," IEEE Access, vol. 9, pp. 31481–31492, 2021.
9. M. Abuzar, A. Ahmad, and A. A. bin Ahmad, "A Survey on Student Attendance System Using Face Recognition," 2020 8th Int. Conf. Reliab. Infocom Technol. Optim. (Trends Futur. Dir., pp. 1252–1257, 2020.
10. H. Yang and X. Han, "Face Recognition Attendance System Based on Real-Time Video Processing," IEEE Access, vol. 8, pp. 159143–159150, 2020.
11. M. A. Geetha, R. S. Latha, S. K. Nivetha, S. Hariprasath, S. Gowtham, and C. S. Deepak, "Design of face detection and recognition system to monitor students during online examinations using Machine Learning algorithms," 2021 Int. Conf. Comput. Commun. Informatics, pp. 1–4, 2021.
12. T. B. Chandra, K. M. S. Chandra, N. A. Reddy, S. Abhishek, and A. T, "DeepVision Attendance: A Visual Recognition System for Automated Attendance Tracking," in 2023 Global Conference on Information Technologies and Communications (GCITC), 2023, pp. 1–7.
13. G. Moukhliss, R. F. Hilali, and H. Belhadaoui, "Intelligent solution for automatic online exam monitoring," Int. J. Electr. Comput. Eng., vol. 13, no. 5, pp. 5333–5341, 2023.
14. A. L. Santonanda, R. Nathaniel, W. L. Putra, M. S. Anggreainy, M. Danaparamita, and A. Elok Amalia, "Online Craftsman Ordering Application Development using Waterfall Methodology," in 2022 5th International Conference of Computer and Informatics Engineering (IC2IE), 2022, pp. 150–155.
15. A. Budiman, R. Aryatama, A. Budiman, and R. Kurniawan, "Student attendance with face recognition (LBPH or CNN): Systematic literature review," Procedia Comput. Sci., vol. 216, pp. 31–38, 2023.
16. J. Nielsen and T. K. Landauer, "A mathematical model of the finding of usability problems," in Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems, 1993, pp. 206–213.