

An AI-Driven Multimodal Smart Classroom Framework for Adaptive Automation, Secure Attendance and Student Engagement Analytics

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Abstract: Smart classroom technologies are increasingly being developed to improve classroom management, attendance monitoring, interaction, and learning environments. Existing systems have demonstrated the integration of artificial intelligence with voice commands, gesture recognition, facial recognition, and IoT-based automation. However, many existing approaches primarily concentrate on individual functions such as attendance or device control and provide limited integration with student engagement analysis, adaptive automation, privacy protection, and real-time decision-making. This research proposes an *AI-Driven Multimodal Smart Classroom Framework* that integrates face recognition, liveness detection, voice recognition, gesture recognition, IoT-based classroom automation, and student engagement analytics into a unified system. The proposed framework automatically records attendance using facial recognition while liveness detection is used to reduce proxy attendance attempts. Voice and gesture interfaces allow teachers to control classroom devices without physical interaction. In addition, computer vision and machine learning techniques can be used to estimate classroom engagement indicators such as attention, participation, and classroom activity. An adaptive decision module uses attendance and environmental information to control classroom resources such as lights, fans, projectors, and audio systems. Unlike conventional smart classroom systems, the proposed framework also introduces privacy-aware local/edge processing and a teacher dashboard for real-time monitoring. The proposed system aims to reduce manual workload, improve classroom resource utilization, provide reliable attendance records, and support data-driven classroom management.

Keywords: Smart classroom, artificial intelligence, computer vision, data-driven classroom management

I. INTRODUCTION

The rapid development of Artificial Intelligence (AI), Internet of Things (IoT), computer vision, and machine learning has created new opportunities for improving traditional classroom environments. A smart classroom can collect information from students, teachers, devices, and environmental sensors and use this information to support teaching and classroom management.

Previous research has explored AI-based smart classrooms using different technologies. A 2024 IEEE conference paper proposed a smart classroom system combining voice commands, gesture-based sound control, and facial recognition for automated attendance. The reported system demonstrated the feasibility of integrating these technologies in a classroom environment.



However, research on AI in smart classrooms has also identified important limitations. A 2024 IEEE Access study reported that many AI-based smart classroom proposals remain at relatively low technology-readiness levels and that real-world deployment, privacy/security, and learning impact require further attention.

Recent research has expanded toward edge computing, robust multi-pose face recognition, IoT-based learning environments, and adaptive classroom resource management.

Based on these developments, this research proposes a unified multimodal smart classroom framework that does not limit AI to attendance or device control. The proposed framework combines secure attendance, multimodal interaction, adaptive automation, and student engagement analytics.

II. PROBLEM STATEMENT

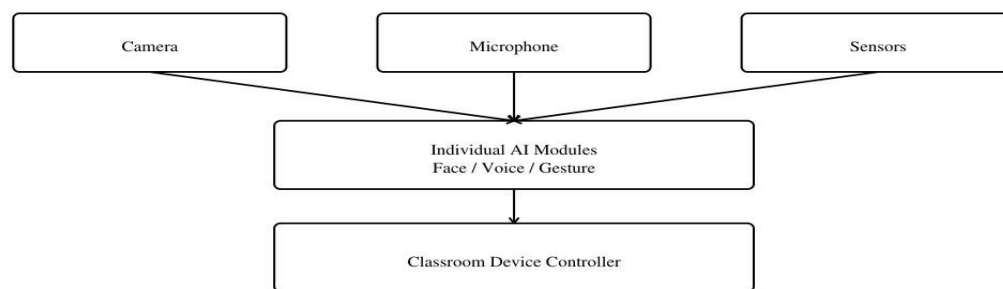
Traditional classroom management involves several manual activities, including: 1. Taking student attendance manually. 2. Controlling classroom devices manually3. Monitoring classroom conditions4. Identifying student participation and engagement. 5. Maintaining attendance records. 6. Managing energy consumption7. Preparing reports for classroom activities.

Existing smart classroom systems automate some of these activities but often operate as separate modules.

Therefore, there is a need for an integrated AI-based framework capable of combining attendance, classroom interaction, automation, and learning-related analytics while considering privacy and security

III. RESEARCH GAP

Existing Approach	Limitation	Proposed Improvement
Face recognition attendance	Can be affected by lighting, pose and spoofing	Face recognition + liveness detection
Voice-controlled classroom	Mainly device control	Voice-based multi-device classroom control
Gesture control	Limited to selected devices	Gesture-based multimodal interaction
Manual classroom automation	Requires human operation	Adaptive AI-based automation
Attendance-only systems	Do not analyze classroom activity	Attendance + engagement analytics
Cloud-dependent processing	Privacy and latency concerns	Local/edge processing
Separate modules	Limited integration	Unified multimodal framework
Basic dashboards	Mostly attendance records	Attendance + device + engagement dashboard



IV. OBJECTIVES

The main objectives of the proposed research are: 1. To design an AI-driven smart classroom framework integrating multiple AI technologies 2. To automate student attendance using facial recognition. 3. To introduce liveness detection for improving attendance security. 4. To provide voice-based control of classroom devices. 5. To implement gesture-



based classroom interaction. 6. To develop adaptive automation based on classroom conditions. 7. To analyze student engagement using computer vision-based indicators. 8. To provide a real-time teacher dashboard. 9. To reduce unnecessary energy consumption. 10. To improve privacy by supporting local/edge processing of sensitive data.

V. PROPOSED SYSTEM

The proposed system consists of six major layers:

Data Acquisition Layer: This layer collects information using classroom camera, microphone, temperature sensor, light sensor, motion sensor, and IoT devices. The camera provides visual information for attendance and engagement analysis, while sensors provide environmental information.

AI Perception Layer: The AI perception layer processes the collected data and includes face detection, face recognition, liveness detection, voice recognition, gesture recognition, and student activity analysis.

Multimodal Decision Layer: The system combines information obtained from different AI modules. For example: Face detected + identity verified + liveness confirmed → Attendance marked. Similarly: Teacher voice command + recognized command → Required classroom device controlled.

Adaptive Automation Layer: The system automatically controls lights, fans, projector, speaker, smart board, and air-conditioning system based on number of students, classroom occupancy, environmental conditions, teacher commands, and class schedule.

Analytics Layer: The analytics module generates information about attendance percentage, present/absent students, classroom occupancy, device usage, energy consumption, and engagement indicators.

Teacher Dashboard: The teacher can view real-time attendance, student list, classroom device status, attendance reports, engagement indicators, environmental conditions, and system alerts.

VI. PROPOSED SYSTEM ARCHITECTURE

The proposed architecture integrates camera, microphone, sensors, AI perception, multimodal decision-making, and adaptive automation into one framework.

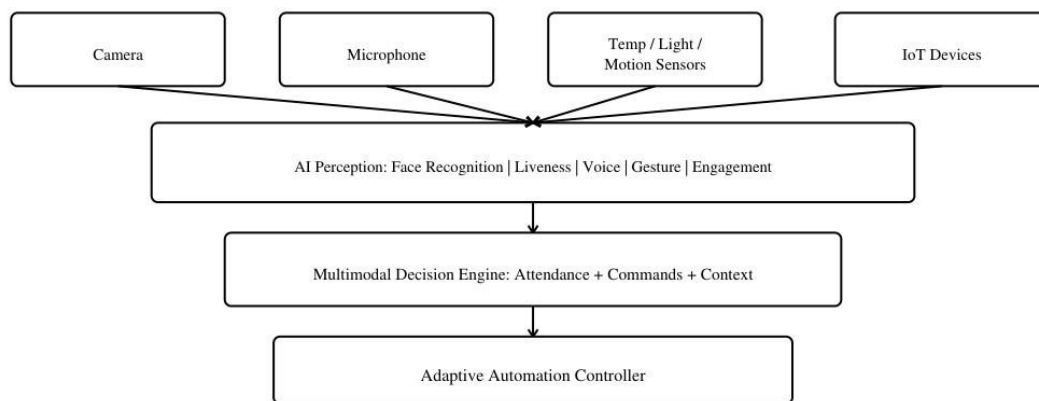


Fig.1 Proposed AI-Driven Multimodal Smart Classroom Framework

EXISTING SYSTEM

The proposed framework combines secure attendance, multimodal interaction, adaptive automation, analytics, and teacher monitoring. Privacy-aware local/edge processing is recommended for sensitive biometric and classroom data.



Existing classroom systems may use separate tools for attendance, electrical-device control, environmental monitoring, and reporting.

Manual attendance can consume class time, while basic face-recognition systems may be affected by lighting, pose, or occlusion.

Separate control modules can require teachers to switch between interfaces. In addition, many systems provide limited classroom-level engagement summaries and may not clearly describe how biometric information is protected.

Attendance and device control may be handled by separate modules.

Simple facial matching may be vulnerable to presentation attacks if liveness checks are absent.

Environmental control may depend on manual switching or fixed rules.

Reporting and engagement analytics may be limited or disconnected.

Privacy and data-retention practices need explicit consideration.

Existing System Diagram

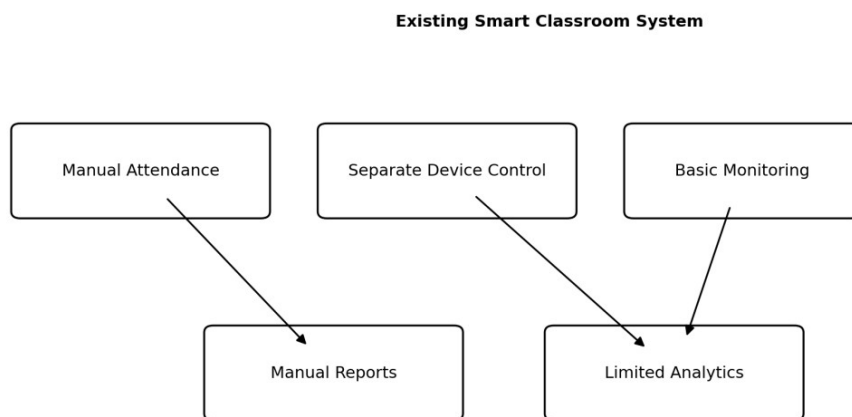


Fig. 2. Existing smart classroom system showing separate functions and limited integration.

VII. FACE RECOGNITION AND SECURE ATTENDANCE

The attendance module captures classroom images using a camera.

The processing pipeline consists of: Image Capture → Face Detection → Face Alignment → Feature Extraction → Face Matching → Liveness Verification → Attendance Update

A conventional face-recognition system may be affected by changes in pose, illumination and occlusion. Recent research specifically investigates multi-pose face recognition for intelligent classrooms to improve robustness under such conditions. The proposed system therefore adds a liveness verification stage.

Attendance Decision: If Face Match = True and Liveness = True, then Attendance = Present. Otherwise, Attendance = Not Confirmed. This additional verification layer is proposed to reduce simple spoofing attempts using photographs or displayed images

VIII. VOICE-BASED CLASSROOM CONTROL

The voice module allows the teacher to control classroom devices using natural-language commands. Example



commands include “Turn on the projector,” “Switch off the lights,” “Start the classroom fan,” “Increase the volume,” and “Turn off all devices.”

The processing pipeline is: Voice Input → Speech Recognition → Command Processing → Device Identification → IoT Controller → Device Action

The original 2024 smart classroom research demonstrated voice-based control of classroom electrical devices. The proposed system extends this concept by connecting voice control with the adaptive decision engine.

IX. GESTURE-BASED INTERACTION

The gesture module provides touch-free interaction. A camera detects predefined hand gestures using computer vision. For example: Open palm — Pause/stop; Thumbs up — Confirm; Hand left — Previous slide; Hand right — Next slide; Raised hand — Request attention; Specific gesture — Control audio.

The gesture recognition module converts the detected gesture into a command and sends it to the classroom controller. This can improve interaction when the teacher is away from the control panel.

X. STUDENT ENGAGEMENT ANALYSIS

One of the major extensions of the proposed system is student engagement analysis. Instead of only determining whether a student is present, the system can generate classroom-level engagement indicators using visual and interaction data.

Possible indicators include face visibility, head orientation, classroom activity, participation frequency, interaction events, and attention-related visual cues.

The system should treat these as probabilistic indicators rather than definitive measurements of a student's mental state. The purpose is to provide teachers with general classroom-level information rather than making high-stakes judgments about individual students. Research on AI in smart classrooms has identified analysis of student attitude, activity, and affective states as an important area of application.

XI. ADAPTIVE CLASSROOM AUTOMATION

The proposed system introduces an adaptive automation module. Instead of simply switching devices ON/OFF, the system considers multiple inputs.

For example: Number of Students + Light Level + Temperature + Class Status → AI Decision Engine → Required Devices.

If classroom occupancy is high and temperature increases, fan/AC control can be activated. If the classroom is empty, lights, fans and projector can be switched OFF. If sufficient natural light is available, artificial lighting can be reduced. Recent IEEE research has also explored adaptive classroom power automation based on occupancy/attendance information.

XII. PRIVACY AND SECURITY

Because facial recognition uses biometric information, privacy and security are important considerations.

The proposed framework therefore recommends: 1. Local/edge processing wherever practical. 2. Encrypted communication. 3. Secure storage of attendance records. 4. Access control for teachers/administrators. 5. Minimum retention of biometric information. 6. Explicit institutional policies and consent requirements. 7. Separation of identity data from analytics data where possible.

The importance of privacy and information security has been highlighted in research reviewing AI applications in smart classrooms.

XIII. ALGORITHM

Algorithm: Multimodal Smart Classroom Automation

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Input: Camera data, voice input, gesture input and sensor data Output: Attendance record, classroom actions and analytics

1. Start the system. 2. Initialize camera, microphone and IoT sensors. 3. Capture classroom video. 4. Detect faces. 5. Extract facial features. 6. Compare features with registered student data. 7. Perform liveness verification. 8. If identity and liveness are verified, mark attendance. 9. Capture voice input from the teacher. 10. Convert voice into a command. 11. Detect predefined gestures. 12. Process environmental sensor data. 13. Send all relevant information to the multimodal decision engine. 14. Determine required classroom action. 15. Control IoT devices. 16. Generate attendance and classroom analytics. 17. Display information on the teacher dashboard. 18. Store required records securely. 19. Repeat the process during the class. 20. Stop the system after the class.

XIV. EXPECTED RESULTS

The proposed framework is expected to provide automated attendance recording, reduced manual attendance workload, improved resistance to simple attendance spoofing, touch-free classroom interaction, faster device control, adaptive classroom automation, real-time classroom monitoring, attendance analytics, classroom engagement indicators, improved resource management, reduced unnecessary device operation, and a centralized teacher dashboard.

The exact accuracy, latency, energy savings and engagement performance should be reported only after conducting experiments on the actual prototype and dataset. They should not be presented as achieved results without experimental validation.

PROPOSED PERFORMANCE METRICS

Module	Evaluation Metric
Face Detection	Precision, Recall
Face Recognition	Accuracy, FAR, FRR
Liveness Detection	Spoof Detection Rate
Voice Recognition	Word Error Rate
Gesture Recognition	Accuracy
Attendance	Attendance Accuracy
Automation	Response Time
IoT Communication	Latency
Energy Management	Energy Consumption
Engagement Module	Classification/estimation metrics
Dashboard	Response Time and usability

COMPARISON WITH EXISTING SYSTEM

Feature	Existing 2024 System	Proposed Framework
Face Recognition	Yes	Yes
Voice Control	Yes	Yes
Gesture Control	Yes	Yes
Automated Attendance	Yes	Yes
Liveness Detection	Limited/Not central	Proposed
Engagement Analytics	No major focus	Proposed
Adaptive Automation	Limited	Proposed
IoT Integration	Yes	Extended
Teacher Dashboard	Basic/limited	Integrated
Edge/Local Processing	Limited	Proposed



Privacy-aware Design	Limited	Explicit design focus
Multimodal Decision Engine	Limited	Proposed

The original 2024 system reported 98% face-recognition accuracy in its experimental setup and a fastest device-command response around 0.68 seconds; these are results of that specific study and should not be copied as results of the proposed system.

XVI. ADVANTAGES

- Reduces manual attendance work.
- Provides multiple interaction methods.
- Supports touch-free classroom control.
- Provides adaptive device management.
- Provides centralized classroom information.
- Can reduce unnecessary energy usage.
- Supports real-time analytics.
- Can improve classroom management.
- Provides a foundation for edge-based AI.
- Can be extended to multiple classrooms

XVII. LIMITATIONS

The proposed system may face several challenges: face recognition may be affected by poor lighting; occlusion and extreme head poses may reduce recognition performance; voice recognition can be affected by classroom noise; gesture recognition requires suitable camera positioning; AI processing requires computational resources; biometric data introduces privacy and security concerns; engagement estimation cannot perfectly represent a student's actual learning state; and different classroom environments may require model adaptation.

XVIII. FUTURE SCOPE

Future versions of the system can include: 1. Multilingual voice commands. 2. Advanced anti-spoofing techniques. 3. Edge-AI hardware for faster processing. 4. Personalized learning recommendations. 5. Automatic timetable integration. 6. Predictive energy management. 7. Mobile application for teachers. 8. Federated learning for privacy-preserving model training. 9. Integration with Learning Management Systems. 10. Large-scale deployment across multiple classrooms.

Recent smart classroom research has already started exploring combinations of IoT, machine learning, adaptive interfaces, and realtime monitoring, suggesting that future systems can move beyond isolated automation functions toward integrated learning environments.

XIX. CONCLUSION

This research proposes an AI-driven multimodal smart classroom framework that integrates facial recognition, liveness detection, voice recognition, gesture recognition, IoT automation, and student engagement analytics.

The major contribution of the proposed framework is the integration of these technologies into a unified adaptive decision-making architecture. Unlike systems that primarily focus on attendance or device control, the proposed approach aims to provide secure attendance, intelligent classroom interaction, adaptive resource management, and classroom-level analytics.

The framework also considers privacy and security as important design requirements because biometric information is involved. The proposed architecture can serve as a foundation for future smart classrooms in which AI is used not only for automation but also for supporting teachers with timely, responsible, and data-driven classroom information.



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REFERENCES

1. M. R. Khan, A. A. Ahad, A. A. Tania, T. Das, and B. Das, "Smart Classroom Automation: A Fusion of AI with Voice, Gesture, and Face Recognition Attendance System," 2024 International Conference on Advances in Computing, Communication, Electrical, and Smart Systems (iCACCESS), 2024, doi: 10.1109/iCACCESS61735.2024.10499545.
2. E. Figueroa, E. Batista, R. Palau, O. Unciti, et al., "The Use of Artificial Intelligence Techniques in Smart Classrooms is in Its Infancy," IEEE Access, vol. 12, pp. 125179–125193, 2024, doi: 10.1109/ACCESS.2024.3454372.
3. "Smart Classroom Management Software for Enhanced Learning Environments," 2025 2nd International Conference on Integration of Computational Intelligent System (ICICIS), IEEE, 2025, doi: 10.1109/ICICIS65613.2025.11371197.
4. "Automated Attendance System in the Classroom Using Artificial Intelligence and Internet of Things Technology," IEEE Conference Publication, doi: 10.1109/ICAISC58445.2023.10200650.
5. U. Syamimi, L. C. Hong, and L. Y. K. Wang, "IoT-based Smart Attendance System using Face Recognition and Motion Detection," 2024 Asia Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC), 2024, doi: 10.1109/APSIPAASC63619.2025.10849070.
6. "Integration of Artificial Intelligence and Internet of Things Technology in Classroom Attendance Systems," 2023 Seventh International Conference on Image Information Processing (ICIIP), IEEE, 2023, doi: 10.1109/ICIIP61524.2023.10537709.
7. "Face Recognition-Based Mobile Automatic Classroom Attendance Management System," 2017 International Conference on Cyberworlds (CW), IEEE, 2017, doi: 10.1109/CW.2017.34.
8. "A Low-Power IoT-Based Smart Desk Integrated with a Facial Recognition Attendance System," IEEE SoutheastCon 2025, 2025, doi: 10.1109/SoutheastCon56624.2025.10971263.
9. "Design of Student Attendance System Based on Face Recognition and IoT Communication," 2025 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET), IEEE, 2025, doi: 10.1109/ICRAMET67419.2025.11350120.
10. M. Saini, H. Sharma, and E. Sengupta, "Artificial Intelligence Based Framework for Student Engagement Assessment in Classroom Environments," Cognitive Computation, vol. 18, article 108, 2026, doi: 10.1007/s12559026-10629-z.

