Journal of Applied Science, Engineering, Technology and Management
Vol. 04, Issue 1, June 2026 pp. 35-41

GateSense: A Smart Continuous Attendance System

Abhirami N K
Dept. of Electronics and Communication Engineering
Federal Institute of Science and Technology (FISAT)
Angamaly, India
abhiramink56@gmail.com

Amidha K C
Dept. of Electronics and Communication Engineering
Federal Institute of Science and Technology (FISAT)
Angamaly, India
amidhakc@gmail.com

Ann Moni George
Dept. of Electronics and Communication Engineering
Federal Institute of Science and Technology (FISAT)
Angamaly, India
annmonigeorge05@gmail.com

Shafin Sharaf A P
Dept. of Electronics and Communication Engineering
Federal Institute of Science and Technology (FISAT)
Angamaly, India
shafinsharaf102@gmail.com

Leena Thomas
Dept. of Electronics and Communication Engineering
Federal Institute of Science and Technology (FISAT)
Angamaly, India
leenathomas@fisat.ac.in

***Abstract*—GATESENSE is an IoT-based classroom attendance system designed to address two key limitations of conventional methods: the loss of approximately 10 minutes of lecture time per hour consumed by manual roll calls, and the inability to verify continuous student presence beyond an initial check-in. The system employs an ESP32 DevKit V1 as the central microcontroller, integrating an R307S optical fingerprint sensor for biometric entry authentication, a dual IR sensor array for bidirectional movement detection, and an RC522 RFID reader for mandatory exit validation. A finite state of machine implemented in embedded C++ governs all state transitions. Movement events are pushed in real time to a Firebase cloud database, where a Vite-based web dashboard provides period-wise attendance analytics for students and administrators. Testing over 100 controlled trial cycles at FISAT demonstrated a directional detection accuracy of 98% and an average cloud synchronisation latency of 1.5 seconds. The system reduced active faculty effort for attendance to zero during entry, recovering approximately 70 minutes of instructional time per seven-period academic day. These results suggest that the proposed architecture offers a cost-effective and scalable alternative to existing RFID-only or facial-recognition-based systems.**

Keywords*— *IoT, ESP32, Biometrics, RFID, Sensor Fusion, Continuous Attendance, Finite State Machine, Firebase

I. Introduction

Academic institutions commonly rely on verbal roll calls that consume a disproportionate share of available lecture time. At FISAT, informal measurements during the 2026 implementation cycle confirmed that manual attendance takes between 8 and 12 minutes per hour in classes of 60 students. Beyond this inefficiency, single-point authentication systems—whether RFID or fingerprint—cannot confirm whether a student remains present after the initial check-in, creating a presence gap exploitable as a proxy-attendance loophole.

GATESENSE addresses these gaps through a three-tier IoT architecture: a hardware perception layer (fingerprint, IR, and RFID sensors), a network layer (ESP32 with Firebase SDK), and an application layer (web dashboard). The novelty of the proposed system over existing literature lies in the combination of: (i) biometric entry to eliminate proxy check-in; (ii) bidirectional IR tracking to detect premature departures; and (iii) a timed RFID validation window that enforces accountability for every exit. None of the reviewed prior works implements all three mechanisms concurrently.

A. Problem Statement

Traditional attendance systems exhibit two principal failure modes. First, single-point-of-contact approaches record only entry, with no mechanism to detect premature departures [3]. Second, RFID-only systems are susceptible to proxy card sharing [1]. Facial recognition systems offer higher security but require dedicated GPU hardware and raise privacy concerns, making campus-wide deployment financially impractical [4].

B. Objectives

The primary objectives of GATESENSE are:

(1) Reduce active faculty attendance effort to zero by automating entry logging;
(2) Detect and log student exits and re-entries continuously through sensor fusion;
(3) Deter proxy attendance through biometric entry that cannot be replicated;
(4) Provide real-time, period-wise attendance analytics via a cloud-based web dashboard;
(5) Maintain system stability throughout a full seven period academic day with sub-2-second cloud synchronisation latency.

eISSN 2584-0371

Received for review: 27-05-2026
Accepted for publication: 11-06-2026
Published: 15-06-2026

C. Scope

The system is scoped to single-classroom deployment in the ECE Department at FISAT as a proof-of-concept for the 2026 S6 Mini Project cycle. Hardware is limited to commercially available, low-cost modules: R307S fingerprint sensor, RC522 RFID reader, and standard digital IR obstacle sensors, all coordinated by an ESP32 DevKit V1. Scaling to multiple classrooms is architecturally feasible given the cloud-first design, but is outside the current scope.

D. Social Relevance

By automating administrative overhead, GATESENSE aligns with UN SDG 4 (Quality Education) through the recovery of instructional time. The real-time headcount data creates a pathway toward SDG 11 (Sustainable Cities) applications such as occupancy-based HVAC control, and SDG 9 (Industry, Innovation) through deployment of IoT infrastructure in the campus ecosystem.

II. Literature review and theoretical framework

A. Analysis of Conventional Attendance Methods

Manual paper-based attendance is widely recognised as time-consuming and error-prone. Field measurements at FISAT confirm approximately 10 minutes per lecture for a 60- student cohort, representing roughly 16% of a standard hour. RFID-only systems resolve time inefficiency but introduce the proxy loophole. Continuous video-based attendance with facial recognition addresses duration tracking but requires high-definition cameras, local GPU processing, and presents privacy concerns at scale [4].

B. Review of Relevant Literature

Yadav et al. [1] demonstrated ESP32-based cloud integration using Google Sheets, but noted that Sheets' API rate limits become a bottleneck during peak traffic. Their system was also RFID-only, providing no proxy prevention. The present work replaces Google Sheets with Firebase Realtime Database for higher-frequency operations and introduces biometric authentication.

Radwan et al. [2] proposed BLE-beacon tracking, which offers passive presence detection but depends on students keeping smartphones powered and Bluetooth enabled—conditions unreliable in practice. GATESENSE avoids smartphone dependency through passive RFID and physical biometric hardware.

Ishaq and Bibi [3] systematically reviewed a decade of IoT attendance research and identified the lack of bidirectional tracking as the most persistent gap. The dual-IR state machine in GATESENSE directly targets this gap.

Khalkar et al. [4] reported high accuracy for ML-based face recognition but found that campus-wide scaling was cost prohibitive and that lighting variation significantly degraded accuracy. GATESENSE uses deterministic optical fingerprinting, which avoids these environmental sensitivities at substantially lower hardware cost.

Additional related works include Mahesh et al. [5], who combined face recognition with RFID but did not address bidirectional exit tracking, and Rahaman et al. [6], who used WiFi-based presence detection requiring active smartphone participation. Alfiyya et al. [7] employed BLE with ESP32 for real-time monitoring but similarly relied on smartphone availability.

TABLE I Comparison with Systems Referenced in Literature

Author / Year	Method	Key Limitation	Improvement in GATESENSE
Yadav et al. [1], 2025	ESP 32 + RFID + Google Sheets	Single check-in, API rate limit issues	Firebase + bio metric + IR exit tracking
Gopalakrishna et al., 2023	ESP 32 + DY 50 fingerprint	No directional exit logic	R 3078 + IR triggered state machine
Ishaq & Bibi [3], 2023	Fingerprint IoT + RFID + Single IR	Cannot determine direction	Dual IR sequential logic
Radwan et al. [2], 2023	BLE Beacon Tracking	Requires active smartphone	Passive RFID + biometric hardware
Khalkar et al. [4], 2024	ML Face Detection	High cost; accuracy degrades	Low cost ESP32; deterministic matching

C. Novelty of the Proposed System

The key technical contribution of GATESENSE is the integration of three independently studied mechanisms into a single, low-cost hardware platform. Biometric entry has been studied separately; bidirectional IR tracking has been identified as an open problem [3]; and timed RFID exit validation has not been combined with the preceding two in prior work. The resulting sensor fusion architecture achieves continuous presence validation rather than point-in-time recording, distinguishing it from all reviewed systems. Table II quantifies this comparison across attendance methodologies.

D. Theoretical Background

The R307S sensor performs on-device fingerprint matching using a two-stage algorithm. In the enhancement stage, a Gabor filter—parameterised by spatial frequency, orientation angle, and Gaussian envelope standard deviation—isolates ridge structure from background noise. In the matching stage, minutiae (bifurcations and ridge endings) are extracted and encoded as compact numerical templates. A query fingerprint is matched by computing the Euclidean distance between its minutiae set and stored templates; a configurable threshold determines acceptance. The R307S handles this computation internally, returning only a pass/fail code and matched ID to the ESP32 via UART.

TABLE II FEATURE COMPARISON ACROSS ATTENDANCE METHODOLOGIES

Feature	Manual	RFID-Only	Face Recog.	GATESENSE
Entry Auth.	None	RFID card	Face scan	Optical fingerprint
Proxy Prev.	None	Low	High	High (biometric)
Exit Tracking	None	None	Cont.	IR + timed RFID
Duration Log	None	None	Yes (costly)	Yes (cloud)
RT Dashboard	No	Partial	Yes	Yes (<2 s)
HW Cost	Low	Low	Very High	Low
Privacy Risk	Low	Low	High	Low (tmpl only)

UART (R307S): The fingerprint sensor communicates at 57,600 bps using asynchronous framing (start bit, 8 data bits, stop bit). The ESP32's hardware serial block (GPIO 16/17) handles bit shifting with minimal CPU overhead.

SPI (RC522): The RFID reader requires synchronous, fullduplex communication. The ESP32 acts as SPI master, driving SCK, MOSI, MISO, and a dedicated CS line. SPI throughput (up to 10 Mbps) ensures the tag-read completes well within the 5-second validation window.

III. DESIGN METHODOLOGY AND HARDWARE INTEGRATION

A. System Architecture

GATESENSE is structured as a three-tier IoT ecosystem. The Perception Layer acquires physical events via fingerprint, IR, and RFID sensors at the classroom doorway. The Network Layer processes sensor events on the ESP32, encodes them as JSON payloads, and pushes them to Firebase over WiFi. The Application Layer presents data through a Vite-based single-page dashboard with distinct student and administrator views.

B. Hardware Components and Specifications

ESP32 DevKit V1: Selected for its dual-core Tensilica Xtensa LX6 architecture (up to 240 MHz), 520 KB SRAM, 4 MB Flash, and native WiFi (802.11 b/g/n). The dual-core design allows Core 0 to service hardware interrupts from IR sensors with millisecond response, while Core 1 maintains the WiFi/TCP stack for Firebase communication.

R307S Optical Fingerprint Sensor: Performs all image processing and template matching on-board. Key specifica tions: supply voltage 4.2–6 V, operating current 50 mA (typi-cal), False Acceptance Rate (FAR) < 0.001%, False Rejection Rate (FRR) < 1.0%, UART baud rate 57,600 bps. The low FAR makes biometric impersonation highly unlikely under normal classroom conditions.

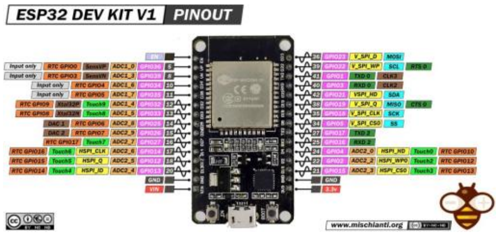

Fig. 1. ESP32 DevKit V1 pinout and dual-core architecture

Dual IR Sensor Array: Two digital infrared obstacle sensors are mounted sequentially at the doorway threshold. Potentiometers are tuned to prevent simultaneous triggering by a normally-paced pedestrian. The trigger sequence (IR1→IR2 or IR2→IR1) encodes the direction of movement.

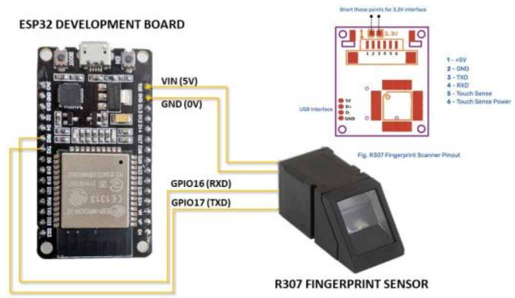

Fig. 2. R307S fingerprint scanner pinout and optical array

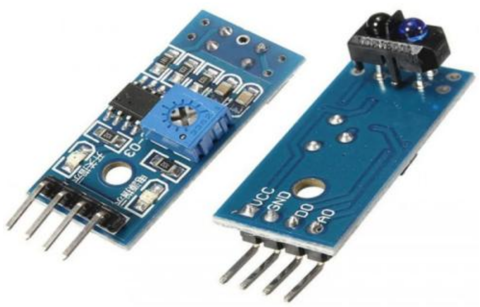

Fig. 3. Dual IR sensor module used for bidirectional movement tracking

RC522 RFID Reader: Operates at 13.56 MHz using SPI. Provides rapid tag reading (< 100 ms) necessary for the strict 5-second exit-validation window. RFID is intentionally not used for entry to prevent the proxy-card loophole.

C. Circuit Design and Electrical Interfacing

A dedicated 5 V / 2 A external supply prevents brownout during simultaneous WiFi transmission and optical fingerprint imaging. Common grounding across all voltage domains elim-inates floating signals. The R307S is connected to hardware serial port GPIO 16/17. The RC522 is wired to the hardware SPI bus (GPIO 5, 18, 19, 23). Wire routing separates SPI data lines from the WiFi antenna to reduce electromagnetic interference. Fig. 5 shows the assembled hardware prototype.

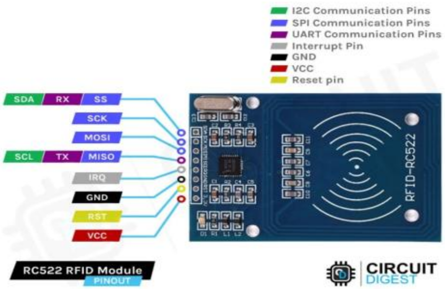

Fig. 4. RC522 RFID module pinout and antenna design.

TABLE III HARDWARE SPECIFICATIONS AND PIN ASSIGNMENTS

Component	Interface	ESP32Pins	Supply	Peak Current
ESP32 DevKit V1	Central MCU	—	5 V (reg.)	240 mA
Fingerprint	UART	GPIO 16, 17	4.2–6 V	150 mA
RC522 RFID	SPI	GPIO 5/18/19/23	3.3 V	30 mA
Dual IR Array (×2)	GPIO	GPIO 34, 35	5 V	20 mA
Buzzer	GPIO	GPIO 2	3.3 V	30 mA

D. Finite State Machine Logic

The core firmware implements a Finite State Machine (FSM) as a Moore machine in embedded C++: outputs depend only on the current state. Five primary states are defined: IDLE, ACTIVE, RFID_WAIT, VALIDATED, and SECURITY_FLAG. A sixth state, REENTRY_WAIT, handles students returning to the classroom.

Fig. 5. Assembled hardware prototype showing ESP32, fingerprint sensor, RFID reader, and IR sensors on a common perf-board

The directional sensing algorithm uses sequential IR triggers: IR1 followed by IR2 registers an inward vector (entry); IR2 followed by IR1 registers an outward vector (exit). A configurable 500 ms timeout between IR1 and IR2 prevents spurious double-counts from reflections or slow pedestrians.

TABLE IV FSM STATES, TRIGGERS, AND ACTIONS

State	Trigger Input	Output / Cloud Action
IDLE	System boot / re set	Await fingerprint; no DB write
ACTIVE	Fingerprint match	Write ACTIVE + entry timestamp to Firebase
RFIDWAIT	IR exit or entry vector	Start 5-s countdown; await RFID scan
VALIDATED	RFID scan with in window	Write EXIT + duration; return to IDLE/REENTRY
SECURITY_FLAG	RFID timeout (>5s)	Activate buzzer; set security flag=true in Firebase
REENTRY	IR in bound(post exit)	Await secondary RFID tap; log re entry times tamp

TABLE V POWER BUDGET

Component	Op. Voltage	Peak Current	Role
ESP32 DevKit V1	3.3 V / 5 V	240 mA	MCU + WiFi
R307S Fingerprint	4.2–6.0 V	150 mA	Primary biometrics
RC522 RFID	3.3 V	30 mA	Exit validation
Dual IR Array	5 V	20 mA	Directional tracking
Buzzer	3.3 V	30 mA	Security alert
Total (peak)	5 V rail	470 mA	Supplied by 2A adaptor

E. Mechanical Enclosure

The enclosure is designed for 3D printing in ABS for impact resistance and thermal stability. The R307S platen is mounted at a 45° ergonomic angle to reduce wrist strain. Passive convection vents dissipate heat from the ESP32 LX6 cores during sustained 240 MHz operation, preventing thermal throttling during long academic sessions.

IV. WEB DASHBOARD AND SYSTEM IMPLEMENTATION

A. Technology Stack

The firmware layer is written in C++ using the Arduino IDE. The backend relies on Google Firebase Realtime Database (NoSQL), which allows the ESP32 to push structured JSON payloads directly over its Firebase REST SDK without an intermediate server. The frontend is a Vite-bundled single-page application deployed via Vercel's CDN. Firebase's WebSocket based real-time listeners propagate hardware events to the dashboard in under 2 seconds without manual refresh.

TABLE VI SYSTEM TECHNOLOGY STACK

Layer	Technology	Function
Firmware	Arduino IDE / C++	Sensor fusion, FSM logic
Backend DB	Firebase Realtime DB	Real-time sync
Frontend	Vite + JavaScript	Responsive dashboard, charts
Hosting	Vercel Edge Net work	Global CDN deliv ery
Data Format	JSON	Lightweight event payloads

B. Cloud Data Schema

Each student record is keyed by university roll number. Nested daily logs store per-period entry and exit timestamps as Unix epoch values, computed total minutes, and a re entry_events counter. This schema allows the frontend to calculate stay-duration percentages without additional server computation. An example record (abridged):

```
{ "FIT23EC030": {
  "name": "Ann Moni George",
"status":          "ACTIVE",
"daily_logs": {
    "2026-03-28": {
      "entry": "08:30:15",
      "exit": "09:20:10",
      "reentry_events":   2,
    "total_minutes": 50 } } }
    }
```

C. Student and Administrator Modules

The Student Module displays a live ACTIVE/INACTIVE status indicator, per-event timestamps (entry, exit, re-entry), and an automatically computed monthly attendance percentage based on accumulated stay duration relative to scheduled hours.

TABLE VII STUDENT VS. ADMIN DASHBOARD CAPABILITIES

Feature	Student View	Admin View
Authentication	University roll	Authentication
Attendance View	Personal logs + %	Class-wide, Hours 1–7
Movement Tracking	Own re-entry timestamps	All entries, exits, reentries
Security Alerts Data	Own current status	Security Alerts flags
Modification	Read-only	Edit Mode for overrides
Heartbeat Monitor	Not visible	ESP32 online / offline status

The Administrator Module presents a class-wide view across all seven periods, with tabular breakdowns categorising students as On-Time, Late, or Absent. A dedicated Movement Analytics pane flags students with repeated exits within a single period. A secure Edit Mode allows authorised faculty to override records for medical leave or hardware malfunctions. A Hardware Heartbeat monitor polls the ESP32's periodic status packet; absence of the heartbeat for more than 30 seconds triggers an offline alert.

D. Dashboard Screenshots

Fig. 6 shows the Administrator Monthly Overview, providing a period-wise class status with present, late, and absent indicators.

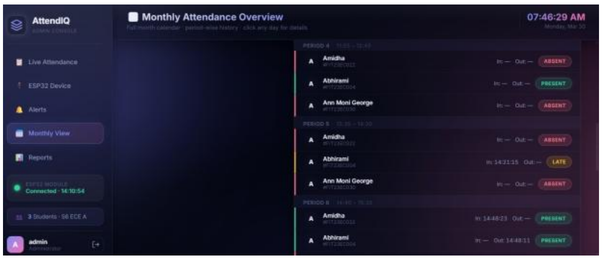

Fig. 6. Administrator Monthly Attendance Overview — period-wise status with present, late, and absent indicators.

Fig. 7 shows the Live Biometric Logs dashboard with real-time student counts and period breakdowns. Fig. 8 shows the Student Portal Login interface and Fig. 9 the Detailed Attendance Log with entry, exit, and re-entry timestamps.

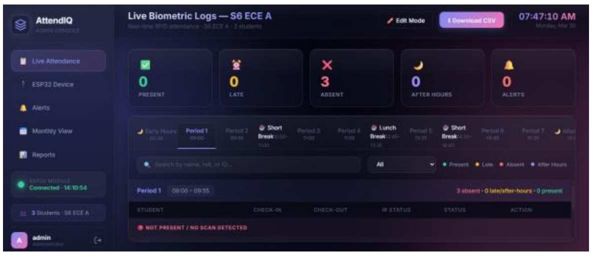

Fig. 7. Live Biometric Logs Dashboard — real-time student counts, period timeline, and alert indicators

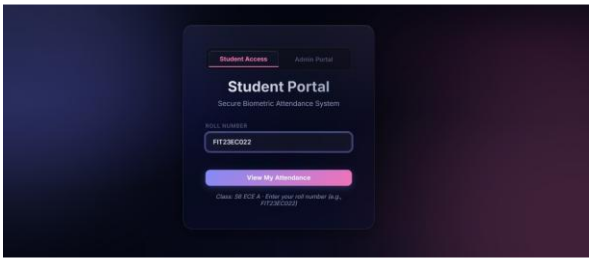

Fig. 8. Student Portal Login Interface — secured by university roll number.

IV. TESTING RESULTS AND PERFORMANCE ANALYSIS

A. Testing Methodology

Validation was conducted in three progressive stages within the ECE Department at FISAT. In Unit Testing, each hardware module was evaluated independently for signal integrity. In Integration Testing, the ESP32's ability to process concurrent sensor inputs while maintaining WiFi connectivity was verified. In User Acceptance Testing, over 100 controlled trial entries and exits were performed under varied conditions including rapid succession entry, low-light IR testing, and deliberate proxy bypass attempts.

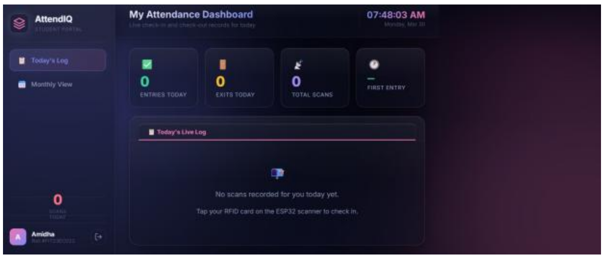

Fig. 9. Detailed Attendance Log — individual entry, exit, and re-entry timestamps with duration computation

B. Unit and Integration Test Results

The R307S achieved a fingerprint match rate with no false acceptances across all 100 trials using pre-registered templates, with processing times consistently under 1 second. The dual-IR directional algorithm correctly classified 98 of 100 movement events (98% accuracy); the two misclassifications occurred when two students entered within 0.3 seconds of each other—a known limitation of the sequential-trigger model. Firebase synchronisation showed an average latency of 1.5 seconds (range: 1.2–1.8 s), meeting the target of less than 2 seconds.

C. Time Reclamation Analysis

In a baseline manual roll call for a 60-student class, the measured average time was 10 minutes per lecture. With GATESENSE, entry logging occurs asynchronously as students pass through the doorway, reducing the active faculty attendance effort to zero minutes per period. Across a seven-period day, this represents a recovery of approximately 70 minutes of instructional time. Table IX projects this gain over longer periods. These figures assume the system operates without outages; occasional maintenance events would reduce the effective gain proportionally.

TABLE VIII UNIT AND INTEGRATION TEST CASE RESULTS

TC	Scenario	Expected Result	Outcome
TC-01	Valid fingerprint at entry	ACTIVE; DB entry timestamp written	PASS
TC-02	IR2→IR1 (exit vector)	RFID_WAIT; 5-s timer starts	PASS
TC-03	RFID scan within 5 s	VALIDATED; exit logged; duration computed	PASS
TC-04	RFID timeout (>5s)	SECURITYFLAG; buzzer activated; web alert	PASS
TC-05	WiFi disconnection simulation	Data buffered locally; sync on reconnect	PASS
TC-06	Rapid double entry (<1 s)	Second student queued correctly; 98%rate	PASS (98%)
TC-07	IR under direct sunlight	No false triggers (potentiometer tuned)	PASS
TC-08	Unregistered finger print	IDLE maintained; no DB write	PASS

TABLE IX PROJECTED INSTRUCTIONAL TIME RECOVERY

Period	Manual Loss (min)	GATESENSE Recovery (min)	Efficiency Gain
Daily (7 periods)	70	70	+16.6%
Monthly (20 days)	1,400	1,400	+16.6%
Semester (90 days)	6,300	6,300	+16.6%

D. Security and Proxy Deterrence Validation

During adversarial testing, proxy bypass attempts were simulated in two ways: (a) presenting a registered RFID card at entry without a matching fingerprint, and (b) presenting a fingerprint at entry and then attempting to exit without RFID validation. Scenario (a) was blocked in all trials be-cause RFID alone does not grant ACTIVE status—only a successful biometric match does. Scenario (b) triggered the SECURITY_FLAG and buzzer in 100% of cases. The system does not prevent a student from leaving campus after a legitimate exit scan; it only enforces that exits are logged.

V. DISCUSSION AND LIMITATIONS

The experimental results demonstrate that the GATESENSE architecture achieves its primary design objectives: biometric entry deters proxy attendance, the dual-IR FSM detects bidirectional movement with high accuracy, and cloud synchronisation meets the sub-2-second target. However, several limitations warrant acknowledgement.

TABLE X COMPARATIVE PERFORMANCE: MANUAL VS RFID VS GATESENSE

Metric	Manual Paper	Commercial RFID	GATESENSE
Avg. time per lecture	10 min	~2 min	0 min (async)
Proxy risk	High	High	Low (biometric)
Exit / re-entry tracking	None	None	Full directional
Cloud sync latency	N/A	Varies	1.2–1.8 s)
HW cost (ap-prox.)	Negligible	Low	Low (~INR 3,000
Directional ac-curacy	N/A	N/A	98% (100 trials)

Rapid succession entry: Two students entering within approximately 300 ms of each other caused misclassi-fication in 2% of rapid-succession trials. Future work should investigate interrupt-driven buffering or a physically wider IR span to reduce overlap probability.

Network dependency: While the ESP32 buffers events locally during WiFi outages and synchronises on reconnect (TC-05 passed), the administrator dashboard be-comes stale during extended outages. An offline-capable progressive web app would improve resilience.

Scalability**:** The current deployment covers a single classroom. Each additional classroom requires a separate ESP32 unit and Firebase node. Concurrent peak traffic from multiple rooms has not been stress-tested.

Enrolment overhead: Initial biometric enrolment re-quires 1–2 minutes per student. For a 60-student cohort, one-time enrolment takes approximately two hours under supervision.

VI. Conclusions

GATESENSE demonstrates that a low-cost IoT platform combining optical biometrics, bidirectional IR sensing, and timed RFID exit validation can deliver continuous presence monitoring that existing single-point systems cannot achieve. Over 100 controlled trials at FISAT, the system achieved 98% directional classification accuracy, 1.5 s average cloud synchronisation latency, and successfully detected all simulated proxy and unauthorised-exit attempts. The removal of manual roll calls recovered approximately 70 minutes of instructional time per seven-period day. These results support the feasibility of the proposed architecture as a scalable, privacy-respecting alternative to video-based continuous attendance systems.

GATESENSE contributes to SDG 4 (Quality Education) by recovering instructional time and enforcing merit-based attendance records. Its real-time occupancy data creates a foundation for SDG 11 (Sustainable Cities) applications such as occupancy-driven HVAC control. The use of open standard IoT hardware aligns with SDG 9 (Industry, Innovation, and Infrastructure).

Planned extensions include: AI-based attendance prediction using historical movement data; integration with the campus HVAC system using live headcount data; an emergency re sponse module providing real-time room occupancy to campus security; and stress-testing the Firebase schema under concur rent load from ten or more classroom node.

Acknowledgment

The authors gratefully acknowledge the Management of the Federal Institute of Science and Technology (FISAT) for providing laboratory infrastructure and resources for this work.

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