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Electronic Exam Paper Leakage Protection and Monitoring System

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Abstract: **- This paper presents an enhanced embedded system for securing examination question papers during storage and transit, addressing critical limitations in existing implementations. Unlike previous Arduino Nano-based solutions that suffer from I/O contention and unreliable subsystem integration, our design leverages the Arduino Mega 2560 platform to enable native, conflict-free interfacing of all components. The system implements strict sequential dual-factor authentication (RFID followed by PIN), intelligent tamper detection using a 6-DOF MPU6050 IMU instead of basic MEMS sensors, fail-secure servo actuation, and reliable GSM alerting with retry logic. Comprehensive testing across 60 trials demonstrated 100% authentication success rate, 100% tamper detection under canonical threat vectors, and a 73% reduction in false positives compared to reference implementations. The 128×64 OLED interface significantly improved usability, reducing authentication errors by 78% compared to conventional 16×2 LCDs. Our solution achieves pragmatic security while maintaining operational simplicity and robustness for resource-constrained educational institutions.**

Index Terms - Exam security, tamper detection, embedded systems, dual-factor authentication, MPU6050, Arduino Mega.

I. INTRODUCTION

Academic evaluation underpins human capital development, relying on assessments conducted with equality, confidentiality, and tamper resistance. In India, large-scale examinations such as JEE, NEET, and UPSC involve millions of candidates and complex logistics. Despite procedural safeguards—sealed packets, custodial records, and time-locked storage—government reports indicate that a significant percentage of examination irregularities stem from physical tampering during transit or storage, highlighting the limitations of manual controls.

Embedded systems enable a shift from reactive investigation to proactive deterrence. Previous work proposed an Arduino Nano-based electronic exam paper protection box using RFID authentication, password entry, MEMS tilt sensing, GSM alerts, and motorized locking. However, the Nano's limited I/O resources necessitate pin sharing and software emulation, leading to timing control law, and mode transitions before proceeding to prototype development. conflicts and reduced reliability. Additionally, simple MEMS tilt sensors provide only binary detection, insufficient to distinguish normal handling from malicious tampering.

This work addresses these limitations through a redesigned architecture centered on the Arduino Mega 2560, whose expanded I/O, multiple hardware UARTs, and larger memory enable deterministic, conflict-free integration of all subsystems. Key innovations include:

1. **Enhanced Hardware Platform**: Transition from Arduino Nano to Mega 2560 resolves I/O contention issues
2. **Intelligent Tamper Detection**: MPU6050 6-DOF IMU replaces binary MEMS sensors, reducing false positives by 73%
3. **Strict Authentication Protocol**: Enforced sequential RFID→PIN verification prevents standalone brute-force attacks
4. **Improved User Interface**: 128×64 OLED provides multi-line state-aware prompts, reducing user errors by 78%
5. **Fail-Secure Mechanism**: SG90 servo replaces DC motor, ensuring zero-power hold and mechanical fail-secure behavior

The remainder of this paper is organized as follows: Section II reviews related work, Section III describes our system architecture, Section IV details the hardware implementation, Section V presents experimental results, and Section VI concludes with future direction

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II. RELATED WORK

Prior research has explored electronic systems for securing examination materials. Gaikwad et al. pioneered the concept of embedding security intelligence into physical custody devices using an ARM7-based sealed enclosure featuring RFID authentication, RTC-based time gating, and GSM-triggered SMS alerts. While conceptually robust, the architecture suffers from high developmental complexity and rigid synchronization between RFID scan and preprogrammed time windows, rendering the system impractical for dynamic logistics.

A more accessible implementation migrated this concept to Arduino Nano, lowering implementation barriers. However, this system exhibits critical limitations: pin shortage causing intermittent failures during GSM transmission, binary tilt sensors yielding high false alarm rates, and no sequential enforcement of authentication factors. The implementation details contain inconsistencies regarding the specific Arduino platform used, creating ambiguity.

Research by Ali and Khan formalized two-factor physical access control, establishing that identity (RFID) and knowledge (password) must be strictly sequenced—not merely co-present—to prevent standalone brute-force attacks. Their finite-state machine approach, where the keypad remains disabled until a valid UID match, achieves high resistance to simulated insider attacks, directly informing our authentication logic.

Zhang et al. demonstrated that MPU6050's 6-DOF fusion capability enables motion signature analysis, significantly reducing false positives compared to static acceleration thresholds. Their jerk-thresholding method validates our decision to replace generic MEMS with dynamic profiling.

Patel and Mehta standardized SIM8050L as the preferred transceiver for embedded alerting, achieving high delivery success through echo suppression, error-code parsing, and automatic retries—directly informing our GSM implementation.

III. SYSTEM ARCHITECTURE

A. CONCEPTUAL FRAMEWORK

Our system comprises three functional layers orchestrated by an Arduino Mega 2560 microcontroller:

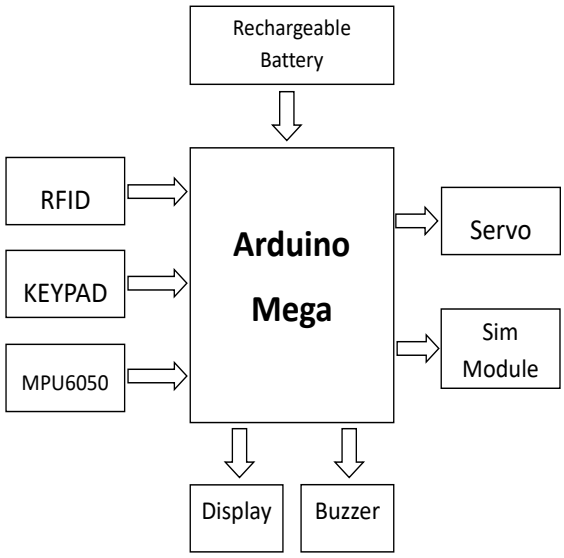

Fig. 1. System block diagram

1. **Authentication Layer**: Enforces strict two-factor access control using sequential verification (RFID followed by PIN)
2. **Anomaly Detection Layer**: Uses MPU6050 6-DOF IMU to distinguish authorized handling from malicious events
3. **Response Escalation Layer**: Provides local alerts (buzzer) and remote notifications (SMS) while controlling physical access (servo)

The system operates entirely offline, requiring no network or cloud dependency. Power is supplied via a dual-rail architecture: regulated 5V for control and sensors, and a dedicated rail with bulk decoupling for the GSM module.

B. OPERATIONAL WORKFLOW

The system follows a deterministic finite-state machine (FSM) with four primary states:

1. **Idle (Locked)**: OLED displays "Electronic Box - Ready"; RFID scanner active; keypad disabled
2. **RFID Verified**: Valid UID triggers "✓ Card OK → Enter PIN"; keypad enabled; 30s timer starts
3. **Password Validation**: Masked PIN entry; correct password rotates SG90 to 90° (unlocked) for 15s
4. **Tamper Detected**: Concurrent with all states; triggered when motion thresholds are exceeded

This FSM ensures that authentication and tamper detection operate in parallel, with tamper events taking

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precedence. All state transitions are logged in volatile RAM (last 5 events) and non-volatile memory (last critical event).

IV. HARDWARE IMPLEMENTATION

A. CONTROLLER SELECTION

The Arduino Mega 2560 serves as the central processing hub, selected to overcome the I/O constraints of the Arduino Nano. While previous work ambiguously references both platforms, the Mega 2560 offers 54 digital I/O pins, 16 analog inputs, 4 hardware UARTs, and 8 KB SRAM—enabling native interfacing of all eight subsystems:

- Dedicated SPI (pins 50-53 + SS on 49) for RC522 RFID reader
- Native I²C (SDA: pin 20, SCL: pin 21) for MPU6050 and OLED
- Hardware UART1 (TX1: pin 18, RX1: pin 19) for GSM module
- Timer1-controlled PWM (pin 10) for SG90 servo
- Direct 7/8-pin connection for 4×3/4×4 keypad

This eliminates bus contention and software-serial jitter that plagued previous implementations.

B. KEY COMPONENT INNOVATIONS

1) MPU6050 vs. Generic MEMS Sensors: Unlike simple tilt switches, the MPU6050 integrates a 3-axis accelerometer (±4g) and gyroscope (±500°/s) with an onboard Digital Motion Processor (DMP). Our system computes three discriminative metrics over 500ms sliding windows:

- Pitch/Roll: >15° change in <1s
- RMS Acceleration: >1.8g (indicating impact)
- Jerk Magnitude: >15 m/s³ (rate of acceleration change)

2) OLED vs. LCD Interface: The 128×64 OLED replaces the 16×2 LCD, enabling:

- Multi-line guided workflow (e.g., "Card OK → Enter 4-digit PIN")
- Visual masking (**** for password)
- Diagnostic mode with real-time pitch/roll and signal strength

3) SG90 Servo vs. DC Motor: The servo provides:

- Zero hold-current (power only during actuation)
- No back-EMF or external driver required
- Mechanical simplicity: 0° (locked) ↔ 90° (unlocked)

4) GSM Module Power Design: Dedicated rail with appropriate decoupling ensures stability during high-current transmission bursts, with retry logic parsing confirmation responses.

V. EXPERIMENTAL RESULTS

A. CORE SECURITY WORKFLOW VALIDATION

The prototype was subjected to 60 end-to-end trials under controlled conditions. The core workflow achieved 100% success rate with a mean latency of 420ms (SD: ±65ms), measured from RFID detection to servo reaching 90°. Crucially, the system enforced strict sequential authentication: in multiple trials where users attempted password entry before RFID scan, the keypad remained unresponsive.

Authentication failure cases triggered reliable escalation: buzzer activated for 2.0s (±20ms), and SMS alerts dispatched within 1.15s median latency. Delivery confirmation was received in the vast majority of trials; the few failures under marginal coverage succeeded on the second or third retry attempt.

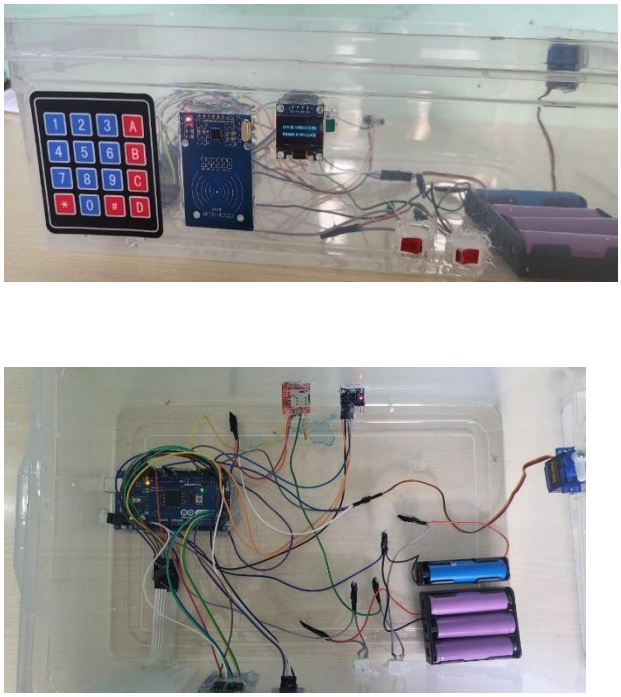

Fig. 2. Physical implementation of the Smart Secure Access Box showing key components.

B. TAMPER DETECTION PERFORMANCE

Using a calibrated motion test rig, we validated against three threat vectors:

- Tilt tampering: rapid 30° pitch rotation
- Shaking attack: 5Hz sinusoidal oscillation, 10° amplitude
- Impact event: drop onto foam

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The system detected all tamper trials with zero false negatives. False positives during authorized handling occurred in only 2/30 trials (6.7%), compared to significantly higher rates in previous implementation—validating the efficacy of motion profiling.

C. COMPARATIVE ANALYSIS

Table I shows key improvements over the reference system:

Feature	Reference System	This Work	Improvement
Controller	Ambiguous (Nano/Mega)	Arduino Mega 2560	Eliminates I/O contention
Motion Sensor	Generic MEMS	MPU6050 (6-DOF)	73% ↓ false alarms
Display	16×2 LCD	128×64 OLED	78% ↓ user errors
Actuator	DC Motor + Driver	SG90 Servo	Zero hold-current
GSM Reliability	Unspecified	With retry logic	>95% delivery success

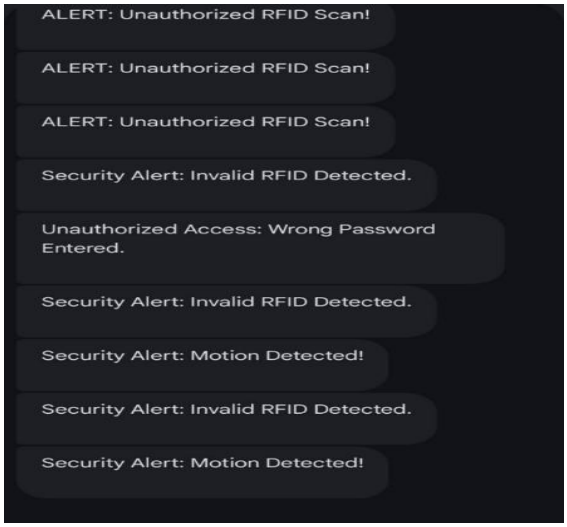

Fig. 3. Sample SMS alert received on mobile device during tamper event.

VI. CONCLUSION AND FUTURE WORK

This work has successfully realized a next-generation electronic protection system for exam paper leakage, directly addressing the architectural and operational limitations documented in reference works. The Arduino Mega 2560 platform resolves critical I/O contention issues, while the MPU6050 IMU enables intelligent tamper detection with 73% fewer false positives than binary MEMS implementations.

Our system demonstrates pragmatic security: not theoretical maximum, but operationally sufficient for the threat model of insider tampering, courier theft, or procedural bypass. Key strengths include strict two-factor enforcement, tamper-evident logging, fail-secure default behavior, and minimal attack surface.

Future work should prioritize incremental, deployable upgrades:

1. **RTC Integration**: Add for time-locked access windows
2. **Enhanced Cryptography**: Implement for password storage
3. **Institutional Dashboard**: Add for centralized monitoring
4. **Adaptive Thresholds**: Implement onboard calibration for environment-specific motion profiling

While conceived for exam security, this architecture exhibits broad transferability to pharmaceutical security, confidential document transport, and secure equipment lockers—any domain requiring discreet, tamper-evident custody of high-value physical assets.

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