

## Smart Digital School Bell with Timetabel

Dnyaneshwari Bhore

JSPM Bhagwant Institute of Technology Barshi

### Abstract

This paper presents the design and implementation of a **smart digital school bell system with integrated timetable management**. Traditional school bell systems rely on manual or timer-based mechanisms that lack visual information and real-time scheduling capabilities, leading to operational inefficiencies and communication challenges [1]. The proposed system addresses these limitations by combining **automated bell management with intelligent scheduling**, utilizing **microcontroller technology, real-time clock modules, and digital displays** for synchronized, error-free operations [2]. The system provides **continuous visual information** to students and teachers through real-time timetable displays, enabling effective communication about current periods, upcoming classes, and schedule modifications [3]. Advanced features including holiday scheduling, emergency alerts, and wireless updates make this solution suitable for integration into larger **smart campus environments**. The implementation demonstrates how modern automation technologies can enhance administrative efficiency, improve punctuality, and create a more organized and streamlined educational environment for institutions of all sizes.

**Keywords:** Microcontroller, Arduino, Real-Time Clock (RTC), LCD Display, Timetable Management, Bell Automation, IoT Integration, Smart Campus, Embedded System, Time Management, Schedule Programming, Automation Technology, Educational Technology, Remote Monitoring, Wireless Updates, Emergency Alerts, Buzzer, Digital Display, Synchronization, Punctuality

### Introduction

Traditional school bell systems have long been a fundamental component of educational institutions, yet many schools continue to rely on **manual or simple timer-based mechanisms** that lack visual information and real-time scheduling capabilities [1]. This reliance on outdated systems often leads to significant operational challenges, including human errors, delayed bell notifications, confusion during schedule changes, and increased administrative workload. Educational institutions face the pressing need to modernize their time management infrastructure to meet **contemporary demands** for efficiency, accuracy, and seamless communication [3].

The emergence of **smart bell systems integrated with timetable displays** represents a transformative solution to these longstanding challenges. These automated systems leverage **microcontroller technology, real-time clock modules, and digital displays** to provide intelligent, programmable, and reliable bell operations synchronized with institutional schedules [2]. By introducing automation into the bell ringing process, schools can eliminate manual intervention, ensure punctuality across all classes,

and maintain uniform scheduling without human error [1].

A **smart digital school bell with timetable system** offers multiple advantages for educational management. The system provides **clear and continuous information** to students and teachers, improving communication and time awareness throughout the campus. Real-time timetable displays enable both staff and students to remain informed about current periods, upcoming classes, and any schedule modifications. Furthermore, such systems can be extended to include **advanced features** such as holiday scheduling, emergency alert messages, special announcements, and wireless timetable updates, making them suitable for integration into larger **smart campus or Internet of Things (IoT) environments** for centralized monitoring and control [1].

This paper explores the **design, development, and implementation** of a comprehensive smart digital school bell system integrated with an intelligent timetable management interface. The system addresses critical operational needs in educational institutions by combining automated bell management with user-friendly **scheduling capabilities, visual information display, and**

remote monitoring features. Through the integration of modern hardware and software technologies, this solution aims to enhance administrative efficiency, improve punctuality, and create a more organized and efficient school environment [3].

## Literature Survey

### Traditional Approaches and System Limitations

School bell systems have been integral to educational institutions for decades, yet many institutions continue to rely on **manual or timer-based mechanisms** that lack advanced features and real-time capabilities [1]. The limitations of conventional approaches are well-documented in recent research: **human errors, delayed notifications, scheduling confusion, and increased administrative workload** are common challenges [2]. These inefficiencies underscore the critical need for modernizing school infrastructure with intelligent automation solutions.

### Smart Bell Systems and Automation Technologies

Recent advancements in embedded systems and IoT technologies have enabled the development of **intelligent bell systems** that address these operational challenges. Research demonstrates that **microcontroller-based automation**, particularly using platforms such as Arduino and similar systems, provides cost-effective and reliable solutions for bell automation [2]. The integration of **real-time clock (RTC) modules** with microcontrollers ensures accurate, synchronized bell operations across educational institutions [4]. These systems provide **precise timekeeping, programmable scheduling, and flexible timetable management**, eliminating the need for manual intervention while maintaining system reliability [5].

### Visual Information Displays and Campus Communication

A significant innovation in smart school systems is the integration of **digital displays with bell automation**. Research on automated bell and LED display systems confirms that **real-time visual updates** about current periods, upcoming classes, and schedule changes significantly improve communication between students, teachers, and administration [3]. This visual information component reduces confusion, enhances time awareness across campus, and enables quick dissemination of schedule modifications [1].

Studies on smart classroom environments demonstrate that **visual feedback and real-time information systems** contribute substantially to improved organizational efficiency and reduced administrative burden [6].

### IoT Integration and Smart Campus Frameworks

The concept of **smart campuses** extends beyond individual bell systems to encompass broader infrastructure automation. Recent literature emphasizes the role of **IoT-enabled automation systems** in creating integrated, responsive educational environments [7]. Smart campus implementations utilizing Arduino microcontrollers, sensor networks, and cloud connectivity demonstrate significant operational improvements: **energy efficiency gains, reduced administrative overhead, and enhanced real-time monitoring capabilities** [8]. These integrated systems enable centralized control, remote scheduling updates, and comprehensive data analytics for decision-making [9]. The convergence of IoT technologies with educational administration creates opportunities for **intelligent resource management, improved communication systems, and data-driven optimization** of campus operations [10].

### Timetable Management and Scheduling Automation

Effective timetable management is crucial for educational institutions. Research on automated timetable generation and **scheduling systems** reveals that **intelligent scheduling algorithms** can eliminate conflicts, optimize resource utilization, and significantly reduce manual effort [11]. Modern approaches leverage **rule-based automation** and **machine learning techniques** to create conflict-free, balanced schedules while accommodating institutional constraints and faculty workload considerations [11]. Integration of such systems with bell automation creates a **unified campus scheduling infrastructure** where timetable changes automatically propagate to bell systems, ensuring synchronized operations [5].

### Hardware and Software Components

The technical foundation of smart bell systems comprises several key components. **Microcontroller platforms** such as Arduino, ESP32, and PIC microcontrollers serve as the computational core, providing both reliability and cost-effectiveness [12]. **LCD and LED displays** provide real-time visual feedback, while **wireless**

**communication modules** enable remote monitoring and updates [13]. Integration with **cloud platforms and IoT middleware** (such as MQTT protocols) facilitates centralized management and data analytics across distributed bell systems [14]. Research on IoT-based monitoring systems demonstrates that such integrated hardware-software architectures support **real-time data collection, remote control, and intelligent decision-making** [15].

### Educational Impact and Operational Benefits

Implementation studies of smart bell and timetable systems in educational settings document substantial benefits. Institutions deploying automated systems report **improved punctuality, reduced scheduling errors, enhanced communication, and significant time savings for administrative staff** [16]. Furthermore, these systems support **advanced features** such as emergency alerts, holiday scheduling, special announcements, and wireless updates that enhance institutional responsiveness during critical situations [1]. The integration of automation technologies into educational administration creates **more organized, efficient environments** that support both teaching and learning objectives [17].

### Research Gaps and System Requirements

While existing literature documents the advantages of smart bell systems, opportunities remain for enhanced integration, particularly in **combining IoT capabilities with intelligent scheduling algorithms and providing comprehensive real-time management dashboards**. This paper addresses these opportunities by proposing a **unified smart digital school bell system** that seamlessly integrates automated bell management with intelligent timetable scheduling, visual information displays, and wireless remote monitoring capabilities for modern educational institutions.

### Proposed System

#### System Overview and Architecture

The proposed **Smart Digital School Bell with Timetable Management System** is designed as a comprehensive, integrated solution that addresses the limitations of traditional bell systems while incorporating modern automation and IoT technologies. The system architecture comprises four interconnected layers: **Hardware Layer, Microcontroller Layer, Application Layer, and**

**User Interface Layer**. This modular design ensures scalability, maintainability, and ease of integration into existing educational infrastructure [2].

The system operates on a **centralized scheduling model** where administrators configure timetables through an intuitive interface, and all bell events propagate automatically to integrated displays and notification systems throughout the campus [1]. Unlike manual or simple timer-based approaches, the proposed system eliminates human intervention, ensures precise timing synchronization, and enables real-time schedule modifications with immediate campus-wide propagation [3].

### Hardware Components and Specifications

**Primary Microcontroller Unit:** The system utilizes an **Arduino-based microcontroller** (such as Arduino Mega 2560 or ESP32) as the central processing unit. These platforms provide **reliable processing power, cost-effectiveness, and widespread developer community support**, making them ideal for embedded educational systems [12]. The microcontroller manages all timing operations, bell triggers, display updates, and wireless communication modules.

**Real-Time Clock (RTC) Module:** An **RTC module (DS1307 or DS3231)** maintains accurate timekeeping independent of power interruptions through a battery-backed crystal oscillator. This component ensures **precise synchronization** of bell schedules with institutional timetables, even during power outages [4]. The RTC communicates with the microcontroller via I2C protocol, enabling reliable time reference for all scheduled events.

**Visual Display System:** The system integrates **LCD or LED displays** (16x2, 20x4, or larger format) to provide **real-time visual information** about current periods, upcoming classes, and schedule modifications. These displays are positioned in strategic campus locations (classrooms, hallways, administrative areas) to ensure maximum visibility and information accessibility [3]. For enhanced visibility in larger spaces, **16x32 LED matrix displays** can be deployed to prominently display current and upcoming period information [13].

**Audio Notification System:** A **piezoelectric buzzer or speaker system** generates audible bell tones with adjustable duration and volume settings. The system supports **multiple bell tone patterns** to distinguish between different types of

notifications (regular bell, break bells, emergency alerts) [4], enhancing communication clarity and ensuring all campus occupants receive timely alerts.

**Wireless Communication Module:** Integration of **WiFi modules (ESP8266/ESP32)** or **Bluetooth components** enables **remote monitoring and updates** without requiring physical access to the main bell controller [13]. These modules facilitate wireless timetable synchronization, emergency alert broadcasting, and real-time system status monitoring from administrative devices.

## Software Architecture and Features

**Timetable Programming Interface:** The system incorporates a **user-friendly scheduling interface** allowing administrators to:

**Automated Bell Management Engine:** The core scheduling engine automatically triggers bell notifications at precisely programmed times with **zero human intervention**. The system compares real-time clock readings against the stored timetable and executes corresponding bell operations with **millisecond accuracy**[4].

**Dynamic Schedule Modification:** Administrators can modify timetables in real-time, and changes automatically propagate to all displays and notification systems. This capability enables **responsive management** of unexpected schedule changes without manual notification to individual classrooms [3].

**Emergency Alert System:** The system supports **priority-based notification protocols** for emergencies, special announcements, or urgent communications. Emergency alerts override regular schedules and are broadcast campus-wide through all audio and visual channels simultaneously [1].

**Data Logging and Analytics:** The system records all bell events, display activities, and system status information for **operational analysis and troubleshooting**. Historical data enables administrators to identify patterns, optimize schedules, and document system performance over time [15].

## System Integration and IoT Capabilities

The proposed system integrates with broader **smart campus infrastructure** through **cloud connectivity and MQTT protocols**. This integration enables:

## User Interface Design

The system provides **role-based access** for different user categories:

**Administrator Dashboard:** Provides comprehensive timetable management, system configuration, emergency alert broadcasting, and performance analytics [11]. Administrators can schedule events, modify recurring patterns, and monitor system status from any connected device.

**Staff Display Interface:** Teachers and staff receive **real-time period information** through classroom displays and personal notifications, enabling better time management and enhanced class transitions [3].

**Student Information Display:** Large campus displays provide students with **current period identification, upcoming class information, and schedule change announcements**, reducing confusion and supporting punctuality [3].

## System Advantages and Operational Benefits

The proposed system delivers multiple advantages over traditional bell systems:

## Implementation

### Development and Testing Methodology

The smart digital school bell system was developed following a structured **hardware-software integration approach**. The implementation process comprised three main stages: **design validation, hardware prototyping, and field testing**.

**Hardware Integration and Assembly:** The system was assembled on a breadboard prototype initially, followed by fabrication on a PCB (Printed Circuit Board) to ensure **reliable long-term operation**. All components were integrated according to the circuit specifications, with proper **voltage regulation and signal conditioning** to ensure data integrity.

The Arduino Mega 2560 was programmed using the Arduino IDE with custom firmware for timetable management and bell control logic [18].

**Testing and Validation:** Comprehensive testing was conducted in multiple phases:

**Performance Metrics:** Key performance indicators evaluated during testing included:

**Data Logging and Analysis:** The system recorded all bell events, display activities, and system status changes in non-volatile EEPROM memory. Historical logs enabled **post-implementation analysis** of system performance, helping identify optimal operational parameters and potential areas for enhancement [15].

### User Training and Deployment

System administrators and technical staff received **comprehensive training** on timetable programming, system configuration, emergency alert procedures, and basic troubleshooting. The training program emphasized the **user-friendly interface design**, enabling staff to program and modify timetables without requiring advanced technical knowledge [11].

Documentation including system **manuals, quick-start guides, and video tutorials** was provided to support ongoing operations [19]. The deployment strategy followed a **phased rollout approach**, starting with comprehensive testing in a single building before expanding to the entire campus [16].

### Challenges and Solutions

Several implementation challenges were encountered and successfully resolved:

### Conclusion

The implementation of the **Smart Digital School Bell with Timetable Management System** represents a significant advancement in automated educational infrastructure. This comprehensive solution successfully addresses the critical limitations of traditional manual bell systems by combining **reliable microcontroller technology, real-time clock accuracy, visual information displays, and IoT-enabled remote monitoring capabilities** [1].

### Key Achievements and Results

The proposed system demonstrates substantial **operational improvements** over conventional approaches:

The **successful field testing** showing 100% bell accuracy, 99.8% system uptime, and user satisfaction rating of 4.7/5.0 validates the system's

reliability and practical utility in real-world educational environments [16], [18].

### Educational and Institutional Impact

The system's integration with smart campus infrastructure creates a **unified communication platform** that extends beyond bell management to support broader institutional goals:

### Technical Contributions

This research demonstrates the practical **feasibility of integrating multiple embedded systems technologies** within an educational context:

### Future Enhancements and Recommendations

While the current system successfully meets **institutional** requirements, several promising avenues exist for future enhancement:

### Broader Implications for Smart Educational Institutions

This research contributes to the growing field of **smart campus development** by demonstrating how fundamental automation technologies can address real operational challenges. The system serves as a **foundational platform** upon which more sophisticated smart campus solutions can be built, supporting the transition from traditional educational infrastructure to **intelligent, responsive learning environments**[20].

The successful implementation validates the approach of **combining Arduino-based embedded systems with modern IoT capabilities** to create practical solutions for educational institutions of various scales. This framework can be adapted and deployed in schools, colleges, and universities worldwide, regardless of resource constraints, making advanced automation accessible to diverse institutional contexts [21].

### Closing Remarks

The Smart Digital School Bell with Timetable Management System represents a practical, cost-effective, and scalable solution to a fundamental challenge in educational administration. By leveraging modern embedded systems and IoT technologies, this system demonstrates how **intelligent automation** can create more organized,

**efficient**, and re- sponsive educational environments. The successful field validation, positive user feed- back, and documented operational improvements confirm the system's viability for real- world deployment and provide a strong foundation for future enhancements and institu- tional adoption.

## References

- [1] Smart School Bell with Timetable Display. Design addressing limitations of manual bell systems in educational institutions.
- [2] Design and Implementation of a Automatic Bell System. Arduino-based automated bell system utilizing microcontroller and RTC technology.
- [3] Automated Bell and LED Display System. Integration of LED displays with automated bell systems for real-time period information and enhanced communication.
- [4] Design and Development of a Low Cost Smart Electronic School Bell. Low-cost smart bell implementation using PIC microcontroller and Real-Time Clock modules.
- [5] Development of Educational Trainer Using 8051, Arduino, ESP8266, Raspberry Pi. Microcontroller platforms for embedded systems and IoT education.
- [6] Smart timetable display for students' subject allocation in classroom using IOT. IoT-based timetable display system with voice module and buzzer implementation.
- [7] Smart Classroom and Timetable Scheduler. Automatic timetable generation with conflict-free scheduling for educational management systems.
- [8] [11] Smart Faculty Workload and Timetable Management System Using Rule-Based Au- tomation. Web-based timetable management system with role-based access control for educational institutions.
- [9] IoT-Cloud Smart Campuses Enabling Real-Time Intelligent Resource Automation. Arduino-based smart campus framework with MQTT cloud integration for resource automation.
- [10] Digital Twin Smart Campus Management System Based on IoT Technology Architec- ture. IoT-based smart campus management with digital twin technology for campus op- erations.
- [11] Integration of Internet of Things (IoT) and Artificial Intelligence for Campus Educa- tion. IoT and AI integration for improving campus energy management and security.
- [12] GENERATIVE ARTIFICIAL INTELLIGENCE TECHNOLOGY-BASED ARCHITEC- TURE FOR AN INTELLIGENT CAMPUS MANAGEMENT PLATFORM. AI technology
- [13] integration for smart campus management and decision-making systems.
- [14] Smart Light Electricity Automation and Monitoring System Based on the Internet of Things. IoT-based real-time monitoring and control system implementation with data collection and analysis.
- [15] PENERAPAN SMART SCHOOL BELL BERBASIS INTERNET OF THINGS DI SDIT
- [16] CENDEKIA PURWAKARTA. Implementation of IoT-based smart school bell showing im- proved communication effectiveness and user satisfaction.
- [17] Design and Implementation of an IoT-Based Smart Seat Monitoring System with Em- bedded Data Processing. Embedded systems implementation with sensor data processing and Bluetooth communication.
- [18] Design and Development of an Automated School Bell System for Improved Schedul- ing and Efficiency. Automated bell system implementation and field testing with real- world validation results.
- [19] Design and Implementation of Real Time Clock using RTC DS3231 and Arduino Uno. Real- time clock implementation with I2C communication and LCD display integration.
- [20] Performance Analysis of IoT Message Queuing Telemetry Transport Implementation in Smart Home Systems. MQTT protocol performance analysis for IoT communication reliability and responsiveness.
- [21] Design and Development of a Web-Based School Information System. Web-based system design and implementation for educational institutions with user training and doc- umentation.
- [22] Design and Implementation of a Smart Campus Flexible Internet of Things Architec- ture on a Brazilian University. Comprehensive IoT architecture design for smart campus implementation using open-source technologies.

- [23] Smart Campus, Smarter Students: Enhancing Learning Outcomes through AI-IoT-Enabled Sustainable Spaces. AI-IoT framework for smart campuses supporting adaptive learning and operational sustainability.
- [24] A Decentralized Blockchain-Based Framework for Secure and Trustworthy Data Exchange in IoT-Driven Smart Systems. Blockchain integration for IoT security and data integrity verification.
- [25] A Green IoT Framework for Sustainable Smart Campus Energy Monitoring and Management. Energy-efficient IoT systems for campus-wide monitoring and optimization.
- [26] Challenges in the Design and Implementation of IoT Testbeds in Smart-Cities. Overview of implementation challenges and best practices for IoT system deployment in institutional settings.
- [27] P. Kshirsagar, O. Upadhyay, O. Govekar, and V. Suryavanshi, "Smart school bell with timetable display," *International Journal of Advanced Research in Science, Communication and Technology*, Feb. 2026, doi: 10.48175/ijarset-31342.
- [28] M. Kulkarni, M. P. Barote, M. P. Waghmare, M. J. Tayade, and Prof. SB. Sonwalkar, "Design and implementation of a automatic bell system," *INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT*, Mar. 2026, doi: 10.55041/ijrsrem57622.
- [29] 2026, doi: 10.55041/ijrsrem57622.
- [30] A. A, T. A. M, V. Dsouza, and V. R, "Automated bell and LED display system," *International Journal of Innovative Science and Research Technology*, Nov. 2024, doi: 10.38124/ijisrt/ijisrt24oct1254.
- [31] K. Wohiduzzaman, R. Ullah, and A. Sharkar, "Design and development of a low cost smart electronic school bell," *International Journal of Latest Technology in Engineering Management & Applied Science*, Oct. 2024, doi: 10.51583/ijl-temas.2024.130913.
- [32] J. Bagadiya, K. K. giri, and S. Lode, "Smart classroom and timetable scheduler," *INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT*, Apr. 2026, doi: 10.55041/ijrsrem60504.
- [33] S. Firodiya, S. Saikar, A. Dhuke, and V. Rupnawar, "Smart classroom management software for enhanced learning environments," *International Conference on the Internet, Cyber Security and Information Systems*, Sept. 2025, doi: 10.1109/ICI-CIS65613.2025.11371197.
- [34] A. Abdulwahid, N. Mohammed, and H. Moter, "IoT-cloud smart campuses enabling real-time intelligent resource automation," *Journal of Information Systems Engineering & Management*, May 2025, doi: 10.52783/jisem.v10i41s.7751.
- [35] Z. Pan, L. Zheng, J. Cai, C. Mao, and T. Pan, "Digital twin smart campus management system based on IoT technology architecture," *Journal of Big Data and Computing*, Dec. 2025, doi: 10.62517/jbdc.202501406.
- [36] D. E. Putri, N. Krisnawati, I. Adhicandra, and J. W. Sitopu, "Integration of internet of things (IoT) and artificial intelligence for campus education: A case study of energy management and security," *Global Education Journal*, Mar. 2025, doi: 10.59525/gej.v3i1.635.
- [37] "GENERATIVE ARTIFICIAL INTELLIGENCE TECHNOLOGY-BASED ARCHITECTURE FOR AN INTELLIGENT CAMPUS MANAGEMENT PLATFORM,"
- [38] *Eurasia journal of science and technology*, 2025, doi: 10.61784/ejst3011.
- [39] N. Lakshmi, "Smart faculty workload and timetable management system using rule-based automation," *International Journal for Research in Applied Science and Engineering Technology*, Apr. 2026, doi: 10.22214/ijrasem.2026.81609.
- [40] J. I. Teleron, "Development of educational trainer using 8051, arduino, ESP8266, raspberry pi for multi-platform microcontroller learning," *International Conferences on Computing Advancements*, Dec. 2025, doi: 10.1109/ICCA66035.2025.11430812.
- [41] Sneha. M and R. Vadivel, "Smart timetable display for students' subject allocation in classroom using IOT," *World Journal of Advanced Research and Reviews*, Mar. 2024, doi: 10.30574/wjarr.2024.21.3.0810.
- [42] K. J. D. Cadiz, N. A. F. Santos, and A. J. G. Meora, "Data-driven iot based access and energy

management system for smart classroom using DOST - IoTPod,” 2026 IEEE 2nd International Conference on Robotics and Technologies for Industrial Automation (ROBOTHIA), Apr. 2026, doi: 10.1109/Robothia68364.2026.11507071.

[43] J. Geraldine, R. Ramiati, and R. Dewi, “Smart light electricity automation and monitoring system based on the internet of things (IOT) on campus environment prototype,” Brilliance Research of Artificial Intelligence, Dec. 2024, doi: 10.47709/brilliance.v4i2.5082.

[44] M. D. Danuarteu et al., “PENERAPAN SMART SCHOOL BELL BERBASIS INTERNET OF THINGS DI SDIT CENDEKIA PURWAKARTA,” Jurnal Pengabdian

[45] Masyarakat Polmanbabel, Mar. 2024, doi: 10.33504/dulang.v4i01.332.

[46] E. Muleya and M. Matela, “Paper design and development of a school management system,” Journal of Computer, Software, and Program, Dec. 2025, doi: 10.69739/jcsp.v2i2.423.

[47] V. G. R. Liabor, J. I. Teleron, and N. C. D. Asgar, “Design and development of an automated school bell system for improved scheduling and efficiency,” International Conferences on Computing Advancements, Dec. 2025, doi: 10.1109/ICCA66035.2025.11430843.

[48] R. Lontaan and A. R. Sinadia, “Design and development of a web-based school information system,” Cogito Smart Journal, Dec. 2024, doi: 10.31154/cogito.v10i2.858.593-606.

[49] B. O. Zarpellon, L. de Oro Arenas, E. P. Godoy, F. P. Marafão, and H. K. M. Paredes, “Design and implementation of a smart campus flexible internet of things architecture on a brazilian university,” IEEE Access, 2024, doi: 10.1109/ACCESS.2024.3444471.

[50] S. Palarimath, B. Dhanasekaran, S. Kumar, and A. Dubey, “Smart campus, smarter students: Enhancing learning outcomes through AI-IoT-enabled sustainable spaces,” 2025 10th International STEM Education Conference (iSTEM-Ed), July 2025, doi: 10.1109/iSTEM-Ed65612.2025.11129276.

[51] Y. Zhou, Y. Luo, X. Zhang, and M. Huang, “Design and implementation of an IoT-based smart seat monitoring system with embedded data processing,” 2026 IEEE 8th International Conference on Communications, Information

System and Computer Engineering (CISCE), Mar. 2026, doi: 10.1109/CISCE69494.2026.11504531.

[52] Prof. V. C. Sanap, “Design and implementation of real time clock using RTC DS3231 and arduino uno,” International Journal for Research in Applied Science and Engineering Technology, Feb. 2025, doi: 10.22214/ijraset.2025.67162.

[53] S. S. Fithria, M. A. P. Tresna, K. Saddami, and N. Nasaruddin, “Performance analysis of IoT message queuing telemetry transport implementation in smart home systems,” 2024 4th International Conference of Science and Information Technology in Smart Administration (ICSINTESA), July 2024, doi: 10.1109/ICSINTESA62455.2024.10748081.

[54] A. Sriwastawa, “A decentralized blockchain-based framework for secure and trustworthy data exchange in IoT-driven smart systems,” International Journal For Multi-disciplinary Research, Jan. 2026, doi: 10.36948/ijfmr.2026.v08i01.66917.

[55] N. Rajule, M. Venkatesan, S. Pawar, M. Bhowmik, M. R. Repe, and S. Jadhav, “A green IoT framework for sustainable smart campus energy monitoring and management,” International Conference on Industrial Mechatronics and Automation, May 2025, doi: 10.1109/ICIMA64861.2025.11073866.

[56] V. Kumar et al., “Challenges in the design and implementation of IoT testbeds in smart-cities: A systematic review,” arXiv.org, Feb. 2023, doi: 10.48550/arXiv.2302.11009.