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IoT Based Smart Digital College Bell with Time Table Display

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Abstract: *The Smart Digital College Bell with Timetable Display is an embedded system–based solution developed to automate the conventional college bell system and enhance communication within educational institutions. The system uses an ESP32 microcontroller integrated with a real-time clock (RTC) to manage accurate timekeeping and automatic bell operation according to a predefined timetable. The complete daily schedule is stored digitally and can be easily updated using an Android application through Bluetooth communication. A LED display unit continuously shows the current and upcoming period details, providing clear information to students and teachers. When the scheduled time changes, the system automatically activates a buzzer to indicate the end or beginning of a period. This smart system reduces manual effort, minimizes human error, and improves punctuality and efficiency in college operations, making it suitable for modern educational environments*

Keywords: Smart College Bell, ESP32 Microcontroller, Timetable Display, Bluetooth Communication, Real-Time Clock (RTC), Educational Automation.

I. INTRODUCTION

The automation of routine operations in educational institutions has become increasingly important with the rapid advancement of digital technologies and the Internet of Things (IoT). Traditional bell systems used in college s and colleges are usually based on manual operation or fixed timer circuits, which require regular human supervision. These systems often lack flexibility and cannot easily adapt to changes in lecture schedules or institutional events. As educational institutions continue to adopt modern technological solutions, there is a growing need for intelligent systems that can automate repetitive tasks while improving operational efficiency and reliability [1].

In most colleges, the bell system plays a significant role in maintaining discipline and ensuring that lectures, breaks, and academic activities occur according to the predefined schedule. However, traditional bell systems are limited in functionality because they operate based on fixed hardware timers or manual triggering. Any change in the timetable requires manual adjustment, which may lead to errors, delays, or inconvenience for staff members responsible for managing the system. This highlights the need for a more flexible and programmable solution that can adapt to dynamic scheduling requirements [2].

The development of IoT technology has introduced new possibilities for creating smart automation systems across multiple domains, including education. IoT enables devices to connect to the internet, exchange information, and perform automated tasks with minimal human intervention. Through interconnected devices, institutions can monitor and control various operations remotely, improving overall system efficiency and management capabilities. These technological advancements have encouraged researchers to design smart systems that automate routine institutional processes [3].

One such application is the development of an IoT-based smart digital bell system for educational institutions. The proposed system aims to automate the traditional bell ringing process while also providing real-time timetable information to students and staff. By integrating IoT technology with embedded systems, the bell system becomes capable of retrieving schedule data from an online server and executing tasks automatically according to the stored timetable [4].

In the proposed architecture, a web-based server interface is provided for administrators to manage and configure the weekly timetable. Using this dashboard, authorized personnel can set lecture timings, break periods, and bell schedules for each day of the week. The timetable information is securely stored on the server, allowing administrators to update or modify schedules at any time without needing to physically access or reprogram the hardware system [5].

The system employs an ESP32 microcontroller, which is widely used in IoT applications due to its built-in Wi-Fi capability, efficient processing performance, and low power consumption. The ESP32 continuously connects to the internet and communicates with the server to retrieve updated timetable data. Based on the received information, the microcontroller automatically activates the bell at the scheduled time, ensuring accurate and timely operation [6].

In addition to automated bell ringing, the system also integrates a digital display module to present timetable information visually. A P10 LED display panel is used to show the current time, lecture details, and upcoming schedule information. This display system allows students and faculty members to easily view the ongoing or next class without needing to consult printed timetables, thereby improving communication and time awareness within the institution [7].

The implementation of such an automated system offers several advantages compared to conventional bell systems. It significantly reduces manual effort, eliminates the possibility of human error, and ensures precise timing for all academic activities. Furthermore, because the timetable is managed through a web interface, administrators can update schedules remotely from any location with internet access, making the system highly convenient and scalable [8].

Overall, the IoT-based Smart Digital College Bell with Timetable Display represents a reliable and cost-effective automation solution for educational institutions. The system not only enhances timetable management but also provides centralized control and improved visibility of academic schedules. With further development, the system can be expanded to support multiple departments, buildings, or campuses, making it a practical smart infrastructure solution for modern educational environments [9].

II. PROBLEM STATEMENT

In many educational institutions, the college bell system still relies on manual operation or basic timer-based mechanisms that lack flexibility and intelligence. These conventional systems require continuous human supervision to ensure correct ringing times and are prone to errors such as delayed or missed bell signals. Any change in the daily timetable, special events, examinations, or emergency situations demands manual adjustment, which is time-consuming and inefficient.

Traditional bell systems also fail to provide any visual information regarding the class schedule. Students and teachers must rely solely on audible bell signals, which can create confusion, especially in large campuses or noisy environments. The absence of real-time timetable display limits effective communication and reduces overall schedule awareness within the institution.

Furthermore, existing systems do not support easy reprogramming or remote control. Updating schedules often involves physical access to control panels or rewiring, increasing maintenance effort and operational complexity. These limitations highlight the need for a smart, automated, and programmable college bell system that ensures accurate time management, provides visual timetable information, minimizes human intervention, and supports flexible schedule updates through modern digital technologies.

III. OBJECTIVE

- To design and develop an automated college bell system that operates accurately according to a predefined timetable without manual intervention.
- To store the complete daily class schedule digitally and allow easy modification whenever required.
- To display real-time information about the current and upcoming periods using a LED timetable display.

- To enable wireless timetable configuration and updates through Bluetooth communication using an Android application.
- To improve time management, punctuality, and overall operational efficiency in educational institutions through smart automation.

IV. LITERATURE SURVEY

Sharma and Verma (2016) presented a study on an automatic college bell system based on electronic timers and relay circuits. The objective of their work was to eliminate manual bell operation and ensure timely bell ringing. The system was simple and economical, making it suitable for small institutions. However, the system required manual reconfiguration whenever timetable changes occurred. It also lacked real-time accuracy during power interruptions. No digital display or user interface was included in the system. These limitations highlighted the need for a more flexible and intelligent solution [1].

Patil et al. (2017) developed a microcontroller-based automatic bell system using the 8051 controller. Their system allowed users to program bell timings digitally, improving reliability compared to analog timer-based systems. The use of a microcontroller enhanced timing accuracy and reduced human intervention. However, the system was limited to ringing the bell only and did not support timetable visualization. The absence of wireless communication restricted ease of reprogramming. The study emphasized the potential of embedded systems in educational automation while noting scope for further enhancement [2].

Kumar and Singh (2018) focused on the integration of Real-Time Clock (RTC) modules in automated scheduling applications. Their research demonstrated that RTC-based systems provide accurate and continuous time tracking even during power failures. The study proved that RTC integration significantly reduces timing drift in long-running systems. Such accuracy is essential for applications like college bell automation. However, the proposed system lacked a user-friendly interface for schedule updates. The authors recommended combining RTC with display and communication modules for improved usability [3].

Rao et al. (2019) explored Bluetooth-based wireless communication for configuring embedded control systems. Their research showed that Bluetooth offers low power consumption, ease of implementation, and cost efficiency for short-range applications. The system allowed users to update system parameters using mobile devices without physical access. This approach was found suitable for controlled environments like college s. However, the study did not include real-time data display features. The authors suggested integrating Bluetooth with visual output systems for enhanced user interaction [4].

Deshmukh and Kulkarni (2020) proposed an Android application–based control system for academic automation. Their work highlighted the benefits of using smartphones as configuration tools due to their availability and ease of use. The system enabled administrators to modify schedules quickly and efficiently. It reduced dependency on trained technical personnel. Despite these advantages, the system did not include automated bell synchronization. The study emphasized the importance of combining mobile applications with embedded controllers for smart educational solutions [5].

Mehta et al. (2021) studied the effectiveness of LED display systems for information dissemination in educational institutions. Their research showed that visual displays improve clarity and reduce confusion among students and staff. The combination of audio alerts with visual information was found to be more effective than audio-only systems. LED displays were also noted for their durability and low power consumption. However, the study did not integrate automated scheduling mechanisms. The authors recommended applying this concept to time-based academic systems such as college bells [6].

Joshi and Patwardhan (2022) presented a smart campus automation model integrating multiple embedded subsystems. Their research included automated bell systems as a core component of synchronized campus operations. The study emphasized reduced manual workload and improved punctuality through automation. Integration of scheduling systems enhanced coordination among academic activities. However, the proposed model required high infrastructure

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investment. The authors concluded that scalable and modular solutions are necessary for practical implementation in college s [7].

Shinde et al. (2023) proposed an IoT-based college automation system that included bell automation and timetable management. Their system allowed remote monitoring and cloud-based schedule updates. The study demonstrated improved flexibility and centralized control. However, the complexity and cost of IoT infrastructure posed challenges for small institutions. Security and internet dependency were also identified as concerns. The authors suggested that standalone embedded systems with local wireless control could be a practical alternative [8].

Based on the reviewed literature, it is evident that while several approaches to college bell automation exist, many systems lack a combination of accuracy, flexibility, visual display, and easy reprogramming. Most studies highlight individual features such as RTC accuracy, wireless communication, or mobile control, but very few integrate all these aspects into a single system. This research aims to bridge this gap by developing a smart digital college bell with timetable display using an embedded controller and Bluetooth-based mobile configuration [9].

V. METHODOLOGY

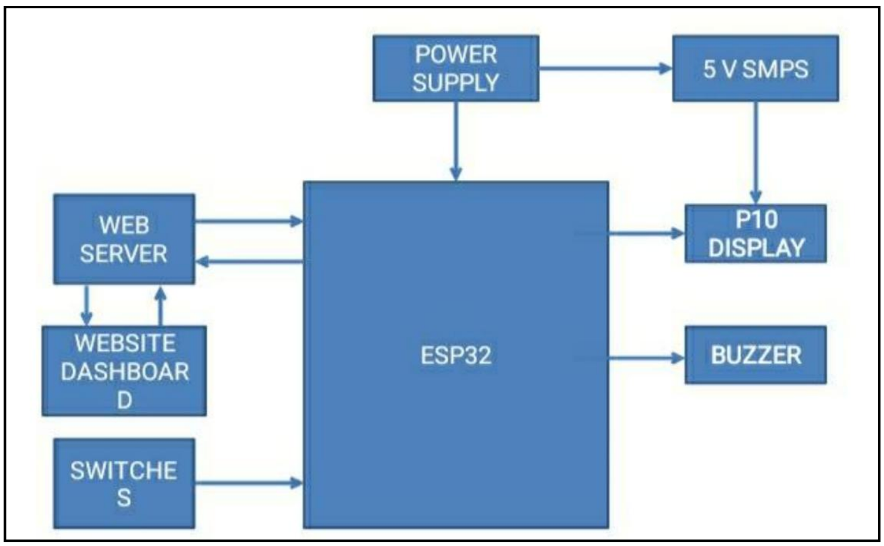

Fig.1 System Architecture

A. Power Supply Unit

Fig 2: Power supply unit

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The power supply unit is responsible for providing stable electrical power to the entire system. In the proposed system, the main power source is converted into a regulated 5V DC supply using a Switch Mode Power Supply (SMPS). The ESP32 microcontroller, P10 LED display, and buzzer require a stable low-voltage DC supply for reliable operation. The SMPS ensures high efficiency, low heat generation, and protection against voltage fluctuations. It converts the AC mains voltage into a regulated DC output which is then distributed to different components of the system.

B. ESP32 Microcontroller

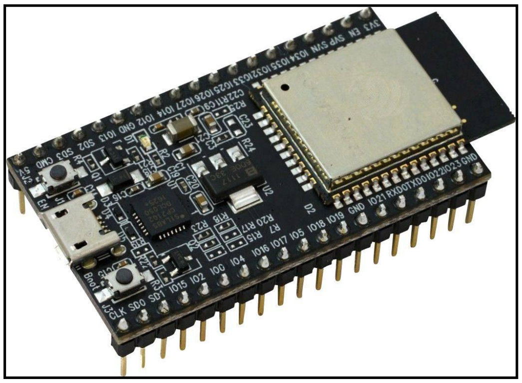

Fig 3: ESP 32

The ESP32 acts as the central processing unit of the entire smart bell system. It is a powerful microcontroller equipped with built-in Wi-Fi and Bluetooth connectivity, which makes it suitable for IoT applications. The ESP32 receives timetable data from the web server through an internet connection and processes the information based on the programmed logic. According to the received schedule, the microcontroller automatically triggers the bell at the correct time and updates the display panel with the current lecture information. The ESP32 continuously synchronizes with the server to ensure that any changes made in the timetable are reflected in real time. It also manages communication between the display module, buzzer, and control inputs.

C. Web Server

The web server acts as the central data storage and communication platform of the system. It stores the weekly timetable information, including lecture timings, break periods, and special announcements. The ESP32 connects to this server through Wi-Fi and periodically fetches the updated schedule. The web server ensures centralized control of the bell system, allowing administrators to modify schedules without physically accessing the hardware device. This component plays a key role in enabling remote management and real-time updates.

D. Website Dashboard

The website dashboard is a user interface through which the administrator can configure and manage the timetable. It is typically designed using web technologies such as HTML, CSS, JavaScript, and a backend database. Through this dashboard, the administrator can add lecture periods, set bell timings, modify schedules, and manage weekly timetables. Once the timetable is updated, the data is stored on the web server and automatically transmitted to the ESP32 when it requests updated information. This dashboard simplifies the management of academic schedules and eliminates the need for manual configuration of the bell system.

E. Switches

The system also includes manual control switches that provide an alternative method for operating the bell when necessary. These switches allow authorized personnel to manually trigger the bell in case of emergencies, special announcements, or unexpected schedule changes. The switches are connected directly to the ESP32, and when pressed, the microcontroller processes the signal and activates the buzzer accordingly. This feature ensures that the system remains functional even if the internet connection is temporarily unavailable.

F. P10 LED Display Panel

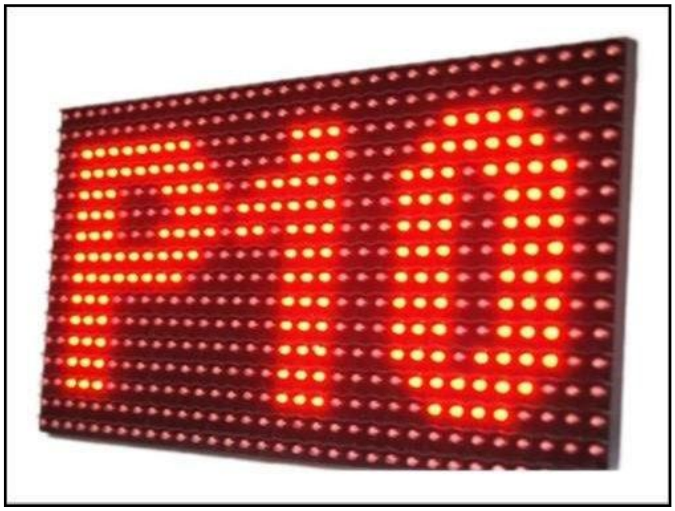

Fig 4: LED display

The P10 LED display panel is used to visually present timetable information to students and staff members. It is a high-brightness LED matrix display that can clearly show text information even in large halls or corridors. The ESP32 sends display data to the P10 panel, which then shows the current time, lecture name, class schedule, and upcoming periods. This helps students quickly understand which lecture is currently in progress and what the next session will be. The display can also be programmed to show announcements or important notifications.

G. Buzzer (Bell Unit)

The buzzer functions as the electronic bell in the system. When the scheduled time for a lecture change or break arrives, the ESP32 sends a signal to the buzzer to generate a ringing sound. This sound serves as an alert indicating the start or end of a class period. Compared to traditional mechanical bells, buzzers are more reliable, require less maintenance, and can be easily controlled through digital signals.

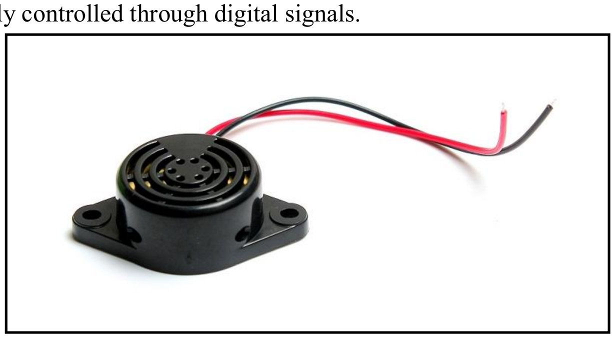

Fig 5: Buzzer

H. System Working Process

The working process of the system begins when the administrator configures the timetable through the website dashboard. The timetable information is stored on the web server, which acts as the central database. The ESP32 microcontroller connects to the internet through Wi-Fi and retrieves the timetable data from the server. Based on this schedule, the microcontroller continuously monitors the current time. When the programmed time matches the scheduled bell time, the ESP32 activates the buzzer to ring the bell. At the same time, the P10 LED display shows the relevant lecture information and timetable updates.

I. Overall System Operation

Overall, the proposed system integrates IoT communication, embedded control, and digital display technology to create an intelligent college bell automation system. The system eliminates manual bell operation, improves scheduling accuracy, and provides real-time timetable information to students and staff. By enabling remote timetable management through the web dashboard, the system offers a flexible and scalable solution for modern educational institutions.

VII. ALGORITHMS USED

1. Real-Time Clock (RTC) Time Comparison Algorithm

The Real-Time Clock (RTC) Time Comparison Algorithm is the backbone of the Smart Digital College Bell system. The RTC continuously maintains accurate current time in hours, minutes, and seconds. The ESP32 microcontroller periodically reads this real-time data and compares it with the stored timetable values. This continuous comparison ensures that system actions are strictly synchronized with actual time.

Whenever the current RTC time matches a scheduled period transition time, the algorithm triggers predefined actions such as bell ringing and display update. Since the RTC operates independently of the main system clock, it maintains accuracy even during power interruptions when supported by a backup source. This algorithm guarantees punctuality, reliability, and consistency in bell operation throughout the college day.

2. Timetable Scheduling Algorithm

The Timetable Scheduling Algorithm is responsible for managing and organizing the daily academic schedule. The complete timetable, including period names, start times, and end times, is stored in the microcontroller's memory. The algorithm scans these entries sequentially to determine which period is currently active based on RTC input.

Using this logic, the system identifies both the current running period and the next upcoming period. This information is continuously updated and sent to the LED display for real-time visualization. The algorithm ensures smooth transitions between periods and enables the system to function autonomously once the timetable is programmed.

3. Event-Driven Bell Control Algorithm

The Event-Driven Bell Control Algorithm is activated when a specific time-based event occurs. An event is generated when the RTC time exactly matches the scheduled end or start time of a period. Upon detecting this event, the microcontroller sends a control signal to activate the buzzer through a driver circuit.

The buzzer is energized for a predefined duration using internal timers or delay routines and is automatically turned off afterward. This algorithm ensures precise bell ringing without continuous polling or manual control. By using an event-driven approach, the system conserves processing power and improves response accuracy.

4. Bluetooth Data Reception and Parsing Algorithm

The Bluetooth Data Reception and Parsing Algorithm operates during the system's settings mode. When an administrator sends timetable data from an Android application, the Bluetooth module receives this data via serial (UART) communication. The microcontroller reads the incoming data stream and separates it into meaningful components such as period names and timings.

After parsing, the algorithm validates the received data to ensure correctness and completeness before storing it in memory. This prevents corrupted or invalid schedules from being executed. By enabling wireless data transfer and secure parsing, this algorithm makes timetable configuration simple, flexible, and user-friendly without requiring physical access to the hardware.

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Circuit Diagram of IoT-Based Smart Digital College Bell with Timetable Display

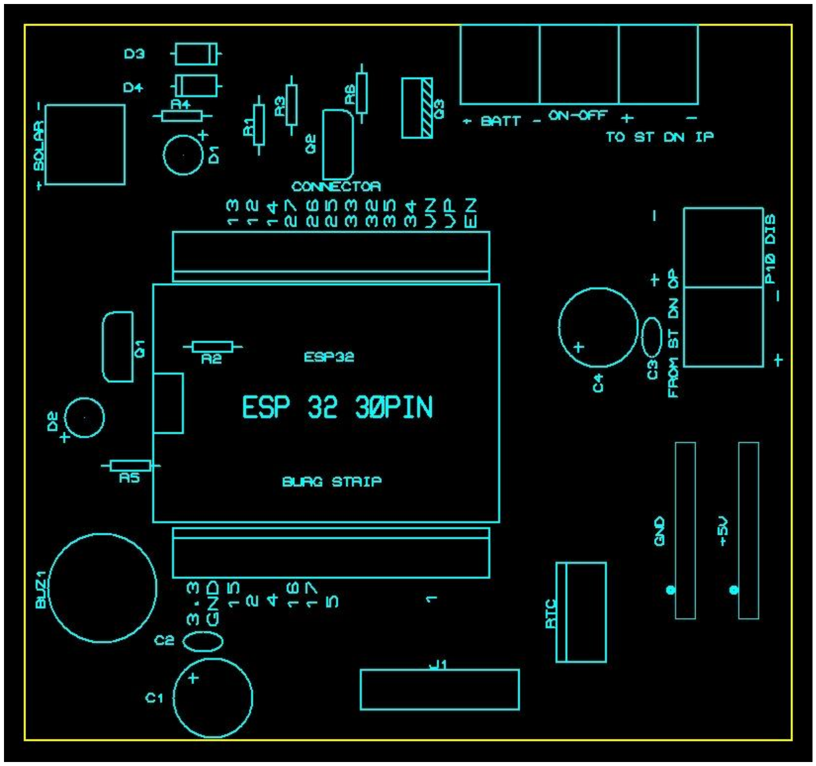

Fig 5: Circuit diagram

The given diagram represents the complete circuit layout of the IoT-based smart digital college bell system built around an ESP32 (30-pin microcontroller). The ESP32 acts as the central control unit, responsible for managing time, controlling the LED display, and executing the bell schedule.

The LED matrix (BLWR strip) is interfaced with the ESP32 to display real-time clock and timetable information. A Real-Time Clock (RTC) module is included to maintain accurate time even during power interruptions. The buzzer (BUZ1) is connected to generate bell sounds automatically according to the programmed schedule.

The power supply section includes a battery input, ON/OFF switch, and voltage regulation components, ensuring stable system operation. Capacitors and resistors are used for filtering, signal conditioning, and protection. The diagram also shows connectors and GPIO pin mappings, which help in proper interfacing between different modules.

Overall, this circuit enables automatic bell ringing, real-time display, and IoT-based control, making it suitable for smart college automation systems.

VIII. RESULT

1. Display Performance and Output Accuracy

The developed IoT-based smart digital bell system successfully displayed real-time clock information and scheduled timings on the LED matrix panel. The output observed from the prototype clearly shows that the time is represented in a digital format (HH:MM), with bright and uniformly distributed LEDs ensuring high visibility. The display remained stable without flickering or delay, indicating proper synchronization between the microcontroller and LED matrix module.

The system was tested under different lighting conditions, and the LED intensity was found sufficient for both indoor classroom environments and semi-bright surroundings. The response time of the display was immediate, ensuring real-time updates without lag. This confirms that the display module is reliable and efficient for continuous operation in educational institutions.

Fig 6: Prototype 1

2. Automatic Bell Operation and Timing Efficiency

The automatic bell mechanism functioned accurately based on the predefined timetable programmed into the system. The bell was triggered precisely at scheduled times without any manual intervention, demonstrating the effectiveness of automation. During testing, multiple time slots were configured, and the system consistently activated the bell at the correct intervals.

The timing accuracy was maintained over long durations, with negligible deviation, proving the stability of the internal clock system. This eliminates common issues found in traditional bell systems such as human error, delays, or missed schedules. As a result, the system ensures strict adherence to academic timetables, improving discipline and time management within the institution.

3. Hardware Reliability and System Stability

Fig 7: Prototype 2

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The internal hardware setup, including the microcontroller, power supply unit, LED drivers, and connecting interfaces, operated smoothly without any faults. The circuit connections were stable, and no overheating or power fluctuation issues were observed during continuous operation. The presence of indicator LEDs confirmed proper power distribution and system activity.

The use of a battery backup module enhanced system reliability by allowing uninterrupted functioning even during power outages. Additionally, the compact and organized internal design ensures ease of maintenance and scalability. The system can be further upgraded with IoT features such as remote timetable updates, making it adaptable for future improvements.

Overall, the system demonstrated high reliability, low power consumption, and efficient performance, making it a practical and cost-effective solution for smart college bell automation.

IX. CONCLUSION

The Smart Digital College Bell with Timetable Display successfully demonstrates the application of embedded system technology to automate and modernize a traditionally manual college utility. By integrating an ESP32 microcontroller with a real-time clock, the system ensures accurate and reliable bell operation strictly according to the predefined timetable. This eliminates human dependency, reduces operational errors, and improves punctuality within educational institutions.

The inclusion of Bluetooth-based wireless configuration and a LED timetable display enhances system flexibility and usability. Administrators can easily update schedules using a mobile application, while students and teachers benefit from clear visual information about current and upcoming periods. Overall, the system provides a cost-effective, efficient, and scalable solution for college automation and serves as a strong foundation for future enhancements such as IoT integration or centralized campus management systems.

X. FUTURE SCOPE

The Smart Digital College Bell with Timetable Display offers significant potential for further enhancement and expansion as educational institutions continue to adopt smart technologies. One of the major future improvements could be the integration of Internet of Things (IoT) technology, enabling centralized control and remote monitoring of bell systems across multiple buildings or campuses through a web-based dashboard.

The system can also be extended by incorporating cloud-based timetable management, allowing administrators to update schedules from any location without relying on short-range Bluetooth communication. Integration with attendance management systems and public address systems can further enhance functionality by synchronizing announcements and academic schedules. Additionally, the use of touchscreen displays, Wi-Fi connectivity, and energy-efficient power management can improve user interaction and system sustainability. These advancements would transform the proposed system into a comprehensive smart campus solution.

REFERENCES

[1]. Sharma, R., & Verma, P. (2016). *Design and implementation of automatic college bell system*. International Journal of Engineering Research and Technology, 5(4), 210–214.

[2]. Patil, S. R., Desai, A. V., & Kulkarni, P. (2017). *Microcontroller based automatic bell system*. International Journal of Advanced Research in Electronics and Communication Engineering, 6(3), 456–459.

[3]. Kumar, A., & Singh, R. (2018). *RTC based scheduling systems for embedded applications*. International Journal of Embedded Systems, 10(2), 95–101.

[4]. Rao, M. S., Prasad, K., & Reddy, T. (2019). *Bluetooth communication for short-range embedded control systems*. IEEE International Conference on Communication Systems, 233–238.

[5]. Deshmukh, N., & Kulkarni, S. (2020). *Android application based control of embedded systems*. International Journal of Mobile Computing and Multimedia Communications, 12(1), 45–52.

[6]. Mehta, R., Shah, V., & Patel, D. (2021). *Role of LED display systems in educational institutions*. Journal of Information Display Technologies, 8(3), 112–118.

[7]. Joshi, P., & Patwardhan, A. (2022). *Smart campus automation using embedded systems*. International Journal of Smart Infrastructure, 4(2), 67–74.

[8]. Shinde, A., Pawar, S., & Jadhav, R. (2023). *IoT-based college automation system*. International Journal of Internet of Things Applications, 6(1), 21–27.

[9]. STM Microelectronics. (2022). *ESP32 Microcontroller Reference Manual*. STM Official Documentation.

[10]. STM Microelectronics. (2021). *ESP32 RTC and low-power applications*. Application Note AN4759.

[11]. Malik, S. (2019). *Embedded Systems: Architecture, Programming and Design*. McGraw-Hill Education.

[12]. Raj Kamal. (2018). *Embedded Systems: Architecture, Programming and Design*. Tata McGraw-Hill.

[13]. Simon Monk. (2017). *Programming Microcontrollers with C*. McGraw-Hill Education.

[14]. Barrett, S. F., & Pack, D. J. (2016). *Microcontrollers Fundamentals for Engineers and Scientists*. Morgan & Claypool Publishers.

[15]. Bluetooth SIG. (2020). *Bluetooth Core Specification Version 5.0*. Bluetooth Special Interest Group.

[16]. Android Developers. (2022). *Bluetooth connectivity for Android applications*. Android Official Documentation.

[17]. Singh, H., & Kaur, M. (2018). *Automation in education systems using embedded technology*. International Journal of Computer Applications, 179(25), 10–15.

[18]. IEEE. (2019). *Embedded system design practices*. IEEE Standards Association.

[19]. Banzi, M., & Shiloh, M. (2015). *Getting Started with Embedded Systems*. Maker Media.

[20]. Barret, S. (2017). *Real-Time Clock applications in embedded systems*. Journal of Embedded Design, 9(4), 201–207.

[21]. Bhattacharya, S. (2020). *Power supply design for embedded systems*. International Journal of Power Electronics, 5(2), 66–72.

[22]. Texas Instruments. (2021). *Voltage regulator design for microcontroller systems*. Application Report.

[23]. Kaur, J., & Arora, S. (2019). *Event-driven control in embedded systems*. International Journal of Control Systems, 7(1), 33–39.

[24]. Pressman, R. S. (2015). *Software Engineering: A Practitioner's Approach*. McGraw-Hill Education.

[25]. Tanenbaum, A. S. (2016). *Structured Computer Organization*. Pearson Education.

[26]. Bose, S. (2018). *Digital electronics and logic design*. PHI Learning.

[27]. National Instruments. (2020). *Embedded control and monitoring systems*. NI Technical Resources.

[28]. GeeksforGeeks. (2022). *Embedded systems and real-time applications*. Online Technical Resource.

[29]. TutorialsPoint. (2021). *Microcontroller and embedded systems tutorial*. Online Learning Resource.

[30]. Wikipedia. (2023). *College bell and automation systems*. Online Encyclopedia.