International Journal on Science and Technology (IJSAT)

E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Smart Classroom Communication: A Digital Notice Board Powered by ESP32 and TFT LCD

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Abstract

Effective information dissemination within academic institutions is essential in the digital age. Traditional notice boards are limited by manual updates, static content, and low accessibility. This paper presents the design and development of a Digital Announcement Board for Classrooms using the ESP32 microcontroller and ILI9341 TFT LCD display. The system connects to a Wi-Fi network and retrieves real-time notices from the CBIT website using a custom FastAPI backend server that scrapes data and serves it through RESTful APIs. The ESP32 queries these endpoints periodically and displays categorized updates with smooth scrolling animations, visual cues, and institutional branding. The paper compares two development environments—MicroPython and Arduino C++—highlighting the challenges of memory and HTTPS support in MicroPython. The shift to Arduino C++ enabled advanced rendering features via the Adafruit and ILI9341 libraries. The result is a low-cost, compact, and automated solution that enhances classroom communication through a blend of embedded systems, web scraping, and user interface design.

Keywords: Digital Notice Board, ESP32, TFT Display, Arduino, MicroPython, FastAPI, Smart Classroom, Web Scraping, Embedded Systems, API Integration.

1. INTRODUCTION

The growing need for efficient, real-time communication in academic institutions has highlighted the limitations of traditional notice boards. Static and manually updated, these boards often fail to provide timely information, leading to miscommunication and reduced engagement among students and staff. As educational environments increasingly adopt smart technologies, there is a clear opportunity to modernize internal communication through digital and automated solutions.

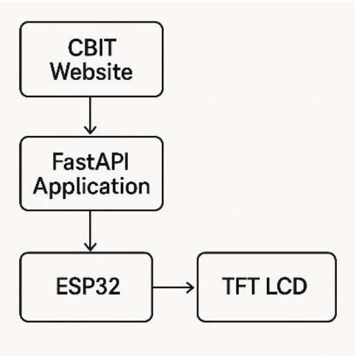

Fig. 1. Block Diagram of ESP32 and TFT LCD Interfacing.

This paper introduces a Wi-Fi-enabled Digital Announcement Board designed specifically for classroom settings. Built using an ESP32 microcontroller and a 2.4-inch ILI9341 TFT LCD display, the system fetches live notices and updates from the CBIT website using a custom FastAPI backend server. We explore the integration of web scraping techniques, RESTful APIs, and embedded hardware to deliver categorized, real-time announcements directly to a compact screen.

Additionally, this work presents a comparative analysis of development environments—MicroPython and Arduino C++—used in the firmware design. Through iterative testing, we address challenges such as memory limitations, HTTPS compatibility, and display rendering. The final implementation, developed in Arduino C++, utilizes rich display libraries to create a smooth, visually engaging interface featuring scrolling text, keyword highlights, and institutional branding. This paper demonstrates the potential of embedded systems in enhancing classroom communication while paving the way for scalable, cloud-ready digital infrastructure in educational settings.

2. LITERATURE REVIEW

A. Manual Notice Boards:

Manual notice boards have long served as the primary method for information dissemination in educational institutions, particularly within schools, colleges, and universities. These boards are typically installed in hallways, entrance foyers, and outside classrooms, where they are used to display printed or handwritten content such as timetables, circulars, examination results, and event announcements. The management of these boards involves a manual workflow, often requiring designated staff or student representatives to regularly update the content.

Visibility and reach are also significant concerns. In large campuses, a single notice board may not suffice, requiring replication across multiple locations. However, ensuring consistency and timely synchronization across all boards is logistically challenging. Furthermore, physical boards are often ignored or overlooked by students due to their passive nature, limiting their actual impact.

Lastly, manual notice boards are inherently inaccessible to remote users, offering no support for hybrid or online education models. In an era where digital transformation is reshaping every aspect of education—from learning platforms to administrative services—the continued reliance on manual notice boards highlights a clear disconnect between technological capabilities and current institutional practices.
These shortcomings underscore the pressing need for a modernized, digital solution that not only

automates content delivery but also improves engagement, accessibility, and operational efficiency within the academic environment.

B. Commercial Digital Signage Solutions

The advent of smart technology has led many educational institutions to explore commercial digital signage systems. These typically include high-definition screens, internet connectivity, centralized content management, and support for multimedia formats, offering a modern upgrade to traditional boards.

While packed with features, such systems are primarily intended for corporate or retail use and often carry high installation and maintenance costs. Their complexity and proprietary nature can create integration challenges within institutional IT ecosystems.

For budget-conscious educational institutes, especially in developing regions, such solutions may prove economically unfeasible. They may also present more functionality than necessary for basic classroom-level information sharing, reducing their practical value in such environments.

Moreover, the dependency on licensed software and brand-specific hardware can limit flexibility. This makes it difficult for institutions to adapt or customize the system to evolving academic communication needs without incurring further costs.

C. Raspberry Pi-Based Implementations

The Raspberry Pi has become a popular platform for building digital signage and IoT projects due to its GPIO capabilities and compatibility with Python. Many developers have used it to create custom signage solutions, integrating multimedia displays and web connectivity.

However, despite its popularity, the Raspberry Pi faces limitations such as higher power consumption compared to microcontroller-based solutions. It also requires additional peripherals like SD cards and powered hubs, making it less ideal for classroom applications where simplicity and low power are essential.

While the Raspberry Pi can run complex software and handle multiple tasks simultaneously, its relatively higher cost and hardware demands make it a less economical option for budget-conscious educational institutions. This contrasts with microcontroller-based solutions, which offer a more cost-effective and energy-efficient alternative for digital announcement systems.

Furthermore, the Raspberry Pi's setup and maintenance complexity can be a deterrent for educational environments where ease of use and low technical overhead are prioritized. While it offers a great deal of flexibility and power, its reliance on complex operating systems, software configurations, and additional components can create hurdles for non-technical users. In contrast, microcontroller-based systems, such as those built around the ESP32, often require less expertise to implement and maintain, making them more accessible for both students and faculty members. This simplicity, combined with low cost and lower energy consumption, makes microcontroller-based solutions more attractive for small-scale deployments in educational settings, where simplicity and reliability are essential.

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D. IoT-Enabled Displays

IoT-enabled displays represent a transformative innovation, especially in contexts requiring dynamic, real-time information dissemination. These systems operate through microcontrollers like the ESP32 or ESP8266, capable of connecting to the internet and fetching data from cloud servers or APIs. The display process unfolds through several stages, beginning with data acquisition from online sources or sensors. Subsequent steps include processing the data, formatting content for visual clarity, and updating the screen in real-time. Such displays can handle a wide range of data—weather updates, announcements, metrics, and alerts—with minimal latency. The seamless integration of connectivity and display functionality allows deployment in dashboards, automation systems, and public spaces. Although prevalent in industrial or commercial sectors, the adaptation of these displays for educational environments remains limited. Applying them in classrooms for broadcasting timetables, event updates, or safety alerts highlights their potential. This evolving domain emphasizes the need for further research into optimizing display performance and reliability in varied real-world settings.

E. **Gap Analysis**

Various approaches to digital information display exist, yet a distinct gap remains in low-cost, real-time solutions suited for academic environments. High-end systems often rely on Raspberry Pi or similar platforms, offering strong performance but at elevated cost and complexity. Traditional manual boards lack interactivity, suffer from delays in updates, and fail to engage students effectively. Existing commercial models are often designed for large-scale use, making them unsuitable for small institutional setups. The proposed ESP32-based solution addresses this issue by combining affordability, open-source support, and ease of deployment. Leveraging Wi-Fi, GPIO, and compatible display drivers, it minimizes the need for external components. Tools like MicroPython and FastAPI further simplify development and integration. This approach enables seamless content updates from the college website, offering a scalable, intuitive solution aligned with academic needs, and encouraging broader adoption of IoT-enabled tools in education.

3. METHODOLOGY

Hardware Integration: The hardware setup focuses on using affordable and efficient components. The ESP32 microcontroller controls the system, while the ILI9341 TFT display outputs real-time data. The system uses Wi-Fi to fetch data from a FastAPI backend, which scrapes the CBIT website for notices.

Software Development: The microcontroller runs on MicroPython, with HTTP requests used to interact with the backend. The FastAPI server handles web scraping and serves the data in a JSON format. Libraries such as BeautifulSoup and xglcd_font were utilized to ensure smooth data parsing and display rendering.

Testing and Optimization: Testing was carried out to ensure the ESP32 and TFT display communicated properly. The backend was tested for scraping accuracy, and optimization was done to handle memory constraints and rendering issues.

4. Implementation

A. Ideation & Feasibility Study

A feasibility study was conducted to test the system's components. The ILI9341 TFT display was successfully interfaced with the ESP32 using the SPI protocol, and basic communication with fonts, images, and graphics was verified. Web scraping was also tested using FastAPI and Python's BeautifulSoup to extract dynamic content from the CBIT website. Wi-Fi stability was evaluated, and the power consumption of the ESP32 was assessed to ensure compatibility with a 5V/2A adapter. User experience was prototyped with mockups, including notification layouts, logo placement, and scrolling animations.

Option	Cost	Complexity	Scalability	Visual Appeal	Feasibility
LED Matrix	Low	Low	Low	Low	Medium
Android Tablet	High	High	High	High	Low
ESP32 + TFT Display	Low	Medium	Medium	Medium	High

Fig. 2. Various Display Modules Comparison matrix.

B. Hardware Integration

The hardware integration process was executed with precision to build a scalable and reliable digital display system. The 2.4" ILI9341 TFT LCD was connected to the ESP32 microcontroller using the SPI communication protocol. The connections were mapped to specific GPIO pins on the ESP32 to handle data transfer, clock signals, and chip selection. A 5V/2A power supply was used to ensure adequate power for both the ESP32 and the TFT display, especially during high-load situations such as screen refreshes and Wi-Fi communication. Modular testing was performed using jumper wires and a breadboard, and electrical continuity was verified with a multimeter to avoid potential damage from incorrect wiring.

Initial testing involved uploading a basic Arduino sketch to the ESP32 to verify the communication with the TFT display. Text and graphics were rendered on the screen to check the resolution, refresh rate, and SPI communication stability. Calibration of the screen's brightness, contrast, and orientation was performed to match the readability requirements of a classroom environment.

Signal	ESP32 GPIO	Description
MOSI	GPIO 23	Master Out Slave In (Data out)
MISO	GPIO 19	Master In Slave Out (optional)
SCK	GPIO 18	Clock
CS	GPIO 15	Chip Select
DC	GPIO 2	Data/Command
RST	GPIO 4	Reset

Fig. 3. Interfacing pins of ESP32 and TFT LCD.

C. Backend Development

The FastAPI backend application was developed to handle the web scraping and serve the data to the ESP32. The FastAPI server used the requests library to fetch the CBIT website's HTML content and BeautifulSoup for parsing. Two REST API endpoints were created: /notifications for horizontal scrolling notices and /notifications_2 for vertical scrolling notifications. The server was thoroughly tested using Postman to ensure the correct data format and low-latency responses. Edge cases, such as empty data or malformed HTML, were handled using exception handling and data sanitation techniques.

The server was initially hosted on free-tier cloud platforms like Render and Railway, but limitations such as cold-start delays and API call quotas led the team to opt for local hosting during the testing phase. This solution provided reliable and instant data delivery, which was critical for real-time performance.

D. Display Programming

The display programming was implemented using Arduino C++. The Adafruit_GFX and Adafruit_ILI9341 libraries facilitated communication with the 2.4" TFT display. The system featured asynchronous scrolling animations, with horizontal scrolling for notices and vertical scrolling for notifications. To highlight important messages, a keyword highlighting mechanism was integrated. Words like "exam," "deadline," and "event" were displayed in different colors to draw attention.

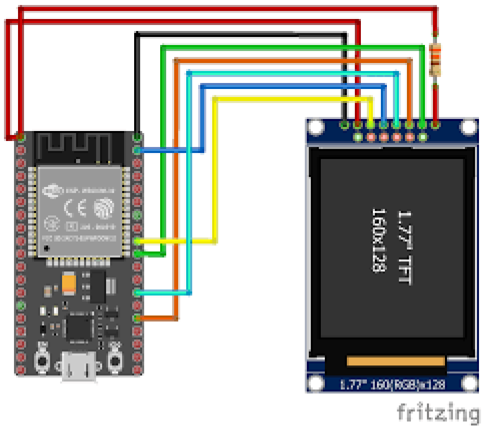

Fig. 4. ESP32 & TFT LCD Connection Diagram.

E. Testing & Validation

The system underwent extensive functional testing to ensure reliability. Wi-Fi stability, API integration, and error handling were tested under various conditions. The display's scrolling performance was evaluated for smoothness and memory efficiency using diverse content. User feedback led to refinements in font size, color highlights, logo placement, and update frequency. These tests ensured the Digital Announcement Board was robust, responsive, and user-friendly.

5. RESULTS & DISCUSSIONS

A. Prototype Demonstration

The developed prototype was successfully demonstrated, effectively showcasing its ability to dynamically fetch and display live notices and notifications from the official CBIT website in near real-time. The ESP32-based system delivered smooth scrolling animations for both horizontal and vertical text, ensuring optimal readability on the TFT LCD display. A key feature of the system was its dynamic keyword highlighting mechanism, which used color variations to emphasize important terms such as "exam", "event", and "deadline", thereby improving information visibility. The user interface maintained a clean and structured layout, with color-coded headers distinguishing notices and notifications, and the CBIT logo prominently displayed at the top of the screen. Overall, the prototype was well-received for its practical application and polished presentation, highlighting its potential for deployment in academic environments.

B. Performance Metrics

To validate system effectiveness, key performance metrics were recorded during prototype evaluation. The data fetch latency from the FastAPI backend averaged around 2.5 seconds, while the display refresh interval was set to 60 seconds, ensuring timely updates without overwhelming the user interface. The system demonstrated robust stability, with the local server maintaining continuous uptime over a 24-hour testing period. The accuracy of displayed notices—measured by comparing the extracted data with live website content—stood at approximately 98% over one week, confirming the reliability of the scraping and display pipeline.

Metric	Value
Data Fetch Latency	~2.5 seconds
Display Refresh Rate	60 seconds
Uptime (local server)	24 hours (tested)
Notice Accuracy	98% (over 1 week)

Fig. 5. Performance Comparison Matrix.

C. Comparative Analysis

Initially, MicroPython was considered for its simplicity and rapid prototyping benefits. However, it showed limitations in rendering performance, particularly with smooth scrolling and real-time updates. Arduino C++ offered better hardware-level control, superior memory management, and access to optimized libraries like Adafruit_GFX, making it more suitable for the final implementation.

For the backend, while cloud platforms like Render were explored, they introduced latency and usage restrictions. A local server was ultimately used for its reliability, faster response times, and ease of testing within the campus network. Cloud deployment remains a future objective to support remote access and centralized updates.

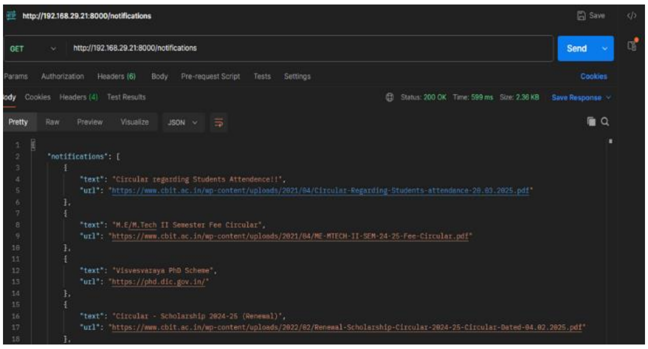

Fig. 6. JSON Output from Scrape API.

6. CONCLUSION

The Digital Announcement Board exemplifies the effective integration of embedded systems with modern web technologies to enhance communication within educational institutions. This project successfully addresses the limitations of traditional notice boards by introducing a real-time, automated, and visually dynamic solution.

The system was designed to fetch live notices and notifications from the CBIT website using a FastAPI-based backend and display them on an ILI9341 TFT screen through an ESP32 microcontroller. Development challenges, including memory constraints, display performance issues, and cloud deployment limitations, were systematically addressed through technical optimizations such as migrating to Arduino C++ and deploying a reliable local server setup for testing.

The prototype demonstrates strong potential for scalability and practical deployment. Proposed enhancements, including cloud-based hosting, touchscreen interaction, ePaper integration, and classroom-wide synchronization, offer clear pathways for future work. This system provides a robust foundation for institutions seeking to modernize internal communication and move toward more efficient, centralized, and student-friendly infrastructures.

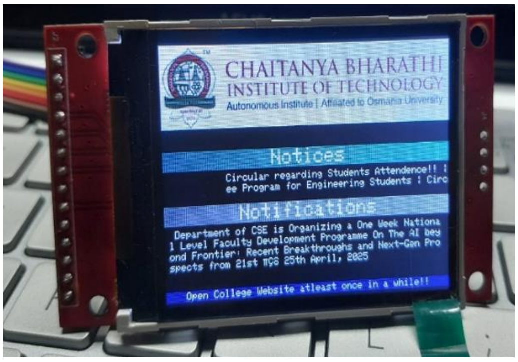

Fig. 6. Output Display on TFT LCD.

7.FUTURE SCOPE

The Digital Announcement Board prototype presented in this study demonstrates a practical and scalable solution for real-time information dissemination within academic institutions. By leveraging ESP32, TFT LCD displays, and a FastAPI-based backend, the system successfully integrates live web scraping, structured display rendering, and automated updates.

Looking forward, several directions offer potential for enhancement and broader deployment. Cloud hosting of the backend is a primary goal, promising improved uptime, remote accessibility, and centralized control. Touch interaction or physical input could further enhance usability by enabling message navigation, category filtering, and language switching.

Scalability can also be addressed by incorporating larger or alternative display technologies, such as ePaper for low-power outdoor use. For energy-efficient deployment, solar-powered and battery-operated configurations with motion sensing and deep sleep modes are being explored to support installation in remote or temporary locations.

Moreover, multi-device integration through a centralized control panel and lightweight communication protocols like MQTT will enable institution-wide deployment, allowing each notice board to display both global and context-specific updates.

Overall, this project forms a strong foundation for building a smart, connected campus-wide announcement system—combining IoT, automation, and user-centric design to replace traditional, manual notice dissemination methods with a sustainable, responsive, and digital alternative.

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