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Optimizing Energy-Efficient, Time-Scheduled Access-Enabled Attendance Tracking Using RFID and Cloud Logging

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Abstract: Traditional and conventional attendance systems are inefficient, leading to errors that may be vulnerable to fraud or make it possible to proxy attendance. Our motive in this paper is to introduce an optimized attendance system with time-constrained scanning. Our proposed model is embedded with various essential components like a scanner/reader, tags and mostly a time-based access control mechanism. This mechanism permits scanning only during assigned and designated periods (for example, 9-10 AM for entry schedule, 1-2 PM for lunch schedule, and 5-6 PM for exit schedule), which ensures a well-disciplined, energy-efficient attendance tracking pathway. This paper presents the design and implementation of the framework of an open-source software and hardware development environment in the field of keeping records of attendance and preparing a chart and sending alerts to users. Our solution system eliminates manual tracking and claims a strong recognition accuracy of 99.2%, along with very low alert latency and a simple frame capture of the user for future validation.

IndexTerms – Internet of Things (IoT), Attendance Tracking, Automated Attendance, RFID, RFID Attendance

I. INTRODUCTION

Manual attendance systems, such as roll calls or signing sheets or copies, are used not only in educational settings but also in various industries to track employee attendance. These traditional methods are often inefficient, taking up 5-10 minutes of valuable time per session in the classroom. The primary approach for monitoring or collecting student attendance in the classroom involves students manually signing an attendance sheet, which is typically then circulated throughout the whole classroom during the lecture. This system has several drawbacks. For example, lecturers with large classes may find the process of passing the attendance sheet around and having students sign it to be cumbersome [1-2]. These systems also take up more time in the workplace during shift changes or meetings. Both environments face similar challenges that make such manual systems susceptible to errors. These include proxy attendance, where students or employees identify others as present, meaning they themselves give the attendance of another employee, which leads to inaccurate records and potential compliance issues [3]. In recent years, most studies have showcased the potential to work on a contactless attendance keeping approach. A fundamental system using high-frequency/ultra-high-frequency Radio frequency Identification (RFID) technology with an integration of a microcontroller has been established [4]. Along with that, cloud integration has been successfully implemented through various cloud platforms [5]. However, most of the studies have not addressed two major aspects, one of which is continuous scanning (100% duty), which needs constant power, leading to wastage of energy, and the second is time-based access control to the system, which may lead to inefficiency in work within an industry or an institute.

Acknowledging the studies and constraints of the traditional attendance recording system, we design a solution that utilises an attendance tracking system powered by RFID technology. The core concept of our proposed system is to optimise the use of energy consumption and perform a time-based scanning mechanism. Our proposed system keeps student attendance in a semi-automated way. Users must present their identity card to the RFID scanner as they enter the organisation. This process allows our reader to immediately capture the unique ID, and subsequently, the data is transmitted to the online storage platform Google Sheets for documentation purposes [6]. We approach an automatic frame capture mechanism when a time-slotted scan occurs, which marks a validation pipeline. This is a serious challenge in optimizing power and time-based attendance that highlights the requirement for further innovative and unique solutions in attendance tracking system.

The following sections are organized in this manner: Section II provides a review of relevant literature to frame our approach and motive. In Section III, we elaborated system architecture and implementation of the system. Section IV demonstrates the whole methodology, and Section V showcases the experimental results and their analysis, followed by a discussion. Lastly, Section VI provides a wrap-up of the study, or to be specific, this section shares the conclusion portion of our study.

II. RELATED WORKS

This section states a full-fledged summary of the principles of whole attendance systems, including biometric technologies [7-15], face recognition [16-20], and RFID integration [21-24] in application development and deployment. The following section elaborates on the works referenced in this study. The progression of attendance tracking systems from manual methods to automated solutions reflects significant technological progress.

Biometric technologies are mostly used for surveillance and in controlling access [30]. Research on biometric technology includes exploring various areas such as algorithms, various system designs, different types of modalities and practical applications. Physical biometrics involves features of the human body like face, fingerprints, palm, iris scan, retina, and hand geometry. On the other hand, behavioral biometrics focuses on how people actually behave. Here, features are their voice, signature, walking style, typing habits or keystroke dynamics [31].

Initial RFID implementations focused on fundamental automation, such as the system created by Yuru et al. [25], which employed RFID tags and ARM series microcontrollers to track attendance but lacked real-time tracking or cloud involvement. With the use of Arduino series microcontroller, real-time clock (RTC) module, different LCDs, and web-based applications [21,24], the developed system reads the RFID card and verifies it with the dataset present in the microcontroller. Similarly, Kurniali [26] designed and developed a web-based RFID system for Indonesian universities, which reduces manual labor but faced technical deployment challenges like slow processing and scalability issues.

The amalgamation of the Internet of Things and cloud platforms marked a significant advancement. Yadav et al. [27] designed an RFID system with ESP32 microcontrollers and Google Sheets, enabling real-time attendance logging, cloud storage, and automated SMS notifications to parents. Extending this concept, Singh et al. [28] combined RFID with ESP32-CAM for laboratory environments, showcasing enhanced accuracy through IoT-enabled data synchronization and cloud analytics. Rjeib et al. [29] further enhanced functionality by embedding Arduino-based RFID with a web application.

Abdul Razak & Chuah [30] integrated CAPTCHA and audit trails into an RFID system designed for Malaysian universities, thereby reducing the risk of brute-force attacks and safeguarding data integrity.

The study by Santoso et al. [31] brings the technology of Arduino Uno R3, Ethernet shield, along with the R305 fingerprint sensor to process real-time attendance via fingerprint scanning and sending to the ThingSpeak cloud server. There is no power optimization.

In the domain of facial attendance systems, Patel et al. [32] introduced a solution using Raspberry Pi 3, OpenCV and the Haar cascade algorithm. This system will scan continuously for faces and dispatch email alerts. While accurate in identification accuracy, it lacks in the domain of energy efficiency due to the always-on nature of the camera.

Jain et al. [33] developed a cloud-integrated model using Arduino Nano, GT511C3 fingerprint sensor, and ESP8266 for Wi-Fi connectivity to connect ThingsBoard IoT platform. It didn't respond to energy efficiency and time-based scanning allowance.

We found a clear gap in studies in the domain of attendance tracking. Also, we analyzed no adjustment on scanning frequency based on timetable-aware schedules. There is enough scope to work on, and this is where our proposed system brings reliability and accurate identification.

III. SYSTEM ARCHITECTURE

Our proposed system is designed to enable seamless interaction between physical devices and the centralized intelligence layer. This section describes the blueprint of the architectural overview of the proposed system.

3.1 Components Overview

Our system is structured into three interconnected tiers: the Edge Layer or our perception layer, the Gateway Layer or the Network Layer, and the final tier is the Cloud Intelligence layer.

3.1.1 Edge Layer

Inside our Edge layer, we have a hardware background that includes all mainstream components.

ESP8266(NodeMCU): We employed the ESP8266 as the main controller to read RFID UID, connect to Wi-Fi, send data to Google Sheets, and trigger the ESP32-CAM for photo capture. It provides built-in Wi-Fi, GPIO pins for multiple sensors and peripherals, is easy to program, cost-effective, and works well with cloud-based applications.

ESP32-CAM: We used ESP32-CAM to capture the employee's photo when a valid RFID card is scanned. It uploads the image directly to Google Drive. It has a built-in camera module(2MP) and Wi-Fi. For this reason, the combination of a powerful microcontroller with camera functionality eliminates the need for a separate camera interface. It's compact, affordable, and perfect for real-time photo capture.

RFID Reader (RC522): We used the RC522 to scan to the RFID card and retrieve its unique UID for identification. it is simple to interface with ESP8266, affordable, and effective for card-based authentication. And the SPI interface makes it easy to use with microcontrollers like the ESP8266.

RFID Cards and Tags: Each employee was given an RFID tag or card, and we used these for user identification during attendance. RFID cards are reusable, secure, and each one has a globally unique ID. It's reliable and secure for individual identification.

LCD Display 16x2 with I2C Module: In this project, for displaying the message, we use the LCD. It shows messages like "Access Granted" or "Invalid Card" to give real-time feedback to users. The i2c module reduces pin usage, and the display provides immediate visual confirmation.

Buzzer: It provides us a clear and quick feedback, helping users know the scan status instantly. Like the buzzer to give sound alerts- a single beep on success and two beeps on failure, and also a three-beep sound will be produced when someone taps outside the given time.

Breadboard & Jumper Wires: This is used for connecting the various components during development and testing. It's allowed us to create and modify circuits easily without soldering

3.1.2 Gateway Layer

The Gateway Layer serves as the central node that interfaces the edge layer environment and the cloud intelligence infrastructure. In the proposed system, this critical role is performed by the ESP8266 NodeMCU microcontroller, which acts as both the processor and network communicator for data collected from the Edge Layer.

ESP8266 Wi-Fi Module: The Core computational unit and communication gateway of our system is ESP8266. It establishes the connection via a local Wi-Fi network to enable instantaneous communication.

Network Time Protocol (NTP): NTP eliminates the dependency on the internal Real Time Clock (RTC) module or external module to maintain no delay, along with minimal hardware integration. Time synchronization occurs with an NTP (Network Time Protocol) server with the help of the ESP8266 module.

3.1.3 Cloud Intelligence Layer

Our proposed system ends with a topmost layer, which is responsible for data storage, sending images, and storing them as a link inside the cloud platform. This layer has three software side integrations: Google Apps Scripts, Google Sheets, and Google Drive.

Google Apps Script: We employed custom scripts in Google Apps Script to build the cloud-side logic mechanism. This deployed side handles HTTP, GET and POST requests sent from our ESP8266/ESP32-CAM microcontroller to automate uploading captured images to Google Drive and logging data like Unique Identifier (UID), timestamp, and image URL into Google Sheets. It has a free and cloud-based scripting environment and allows secure access to Google Drive and Sheets APIs.

Google Drive: We used Google Drive to store the photos captured by the ESP32-CAM securely in the cloud. It offers free, reliable, and secure cloud storage. Seamlessly integrates with Google Apps Script, generates shareable links for saved images. It's used as a repository when a scan occurs at the edge.

Google Sheets: Google Sheets is an online, free database for storing data. For this usability, we used Google Sheets as our real-time cloud database to log UID, timestamp, time slot, like Entry, lunch, Exit, and the photo URL. We also create a sheet of mapping for storing the UID in this, so it's easy to access.

3.2 Combined Structural and Flow Diagram

At the core of our proposed system, we constructed the block diagram, which provides a hardware-centric overview of the system architecture. This block diagram marks the physical components used in our proposed system, meaning "what components exist?" and how they are interconnected via various protocols like Serial Peripheral Interface (SPI), Universal Asynchronous Receiver/Transmitter (UART), etc., as shown in Figure 1.

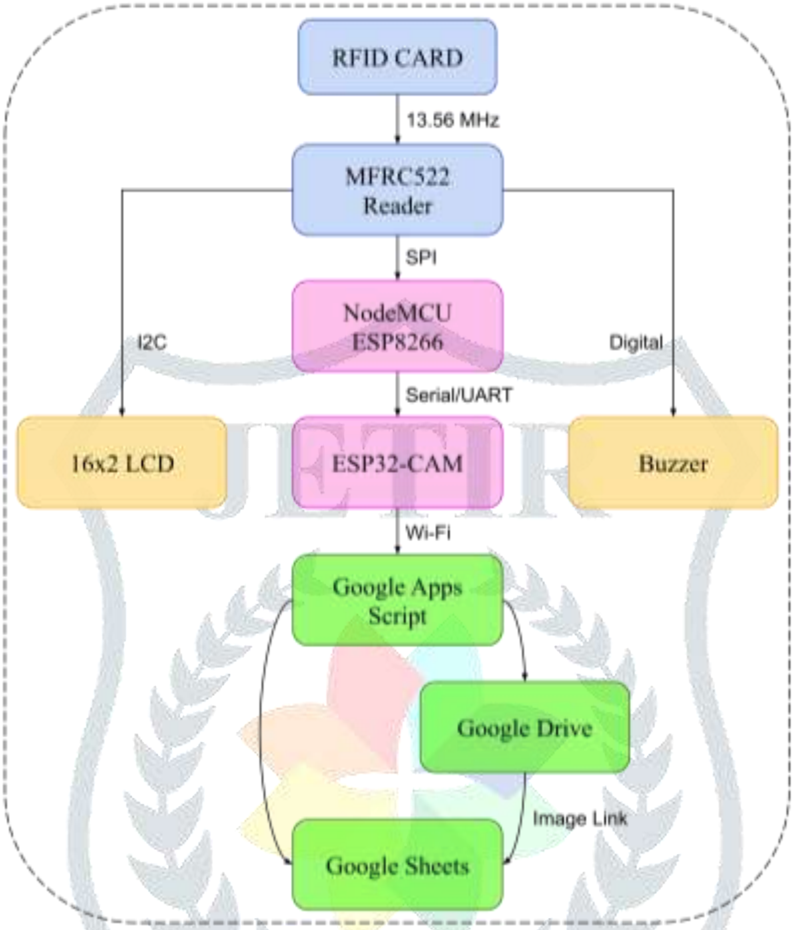

Fig. 1. Proposed block diagram of our attendance system

On the other hand, we present a more abstracted, software-centric view of our proposed system as shown in Figure 2, which actually traces the flow of data, or to be specific, signal through our system components. The flow of our system begins when a user scans their RFID card, which proceeds with a decision check, or to be specific, "Time Check Mechanism" performed by Network Time Protocol (NTP). This Mechanism serves two purposes in our system, one of which is that the system proceeds with the remaining tasks, like sending, fetching data, and the other of which is that the system directly sounds an abnormal sound and displays a message denying attendance. Upon successful identification, our system components ESP32-CAM module, capture an image upload it to Google Drive through a configured Google Apps Script. Now data flows to our cloud storage tier with a generated shareable image link along with a pack of UID and Timestamp as shown in Figure 2.

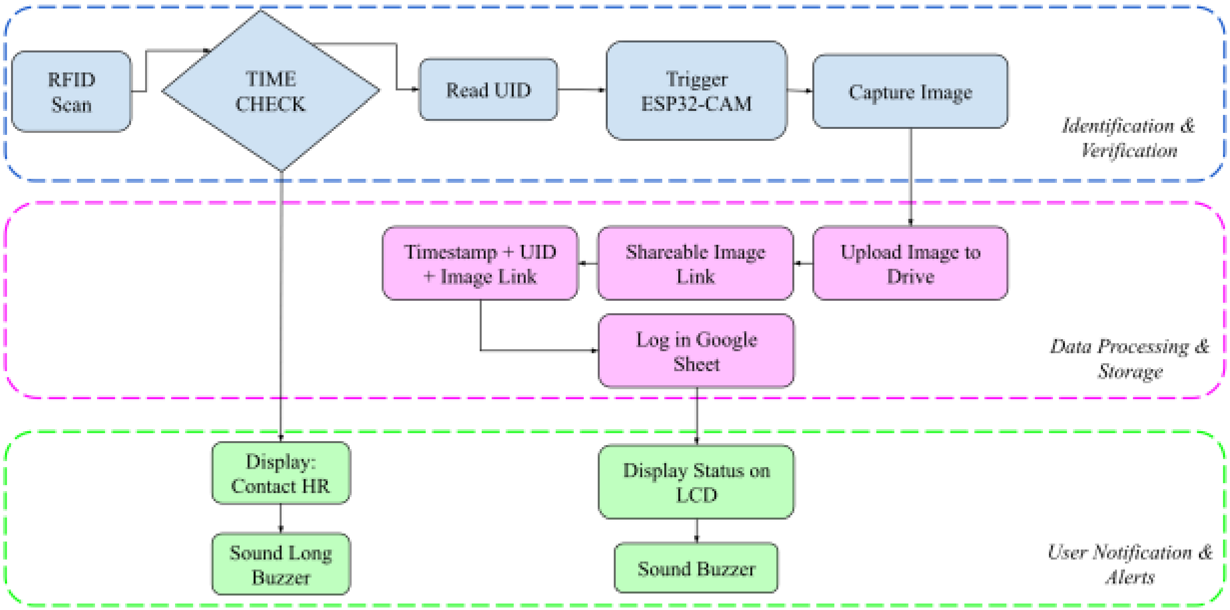

Fig. 2. Extended signal Flow diagram of our attendance system

To bring our logical design into a hardware prototype, we embedded a compact circuit as shown in Figure 3. We used the SPI protocol to interface the RC522 RFID reader with the NodeMCU, assigning standard GPIO pins for data and control. We break down the full, detailed pin-to-pin connection in the given Table 1.

Table 1. RC522 to ESP8266 SPI Pin Configuration and Functional Mapping

RC522 Pin	ESP8266 Pin
SDA	D4
SCK	D5
MOSI	D7
MISO	D6
RST	D3
GND	GND
3.3V	3.3V

To establish communication between the RC522 RFID reader and the ESP8266 NodeMCU, we used the duplex communication protocol, the SPI protocol, involving one master and one slave. The SDA pin of the reader connected to D4 on the ESP8266 acts as the Slave Select (SS) line. This pin is crucial for initiating and terminating communication, as it allows the microcontroller to select the RFID module when needed. The SCK (Serial Clock) line, connected to D5, performs a synchronized clock signal to coordinate real-time data transmission. The Master Out, Slave In (MOSI) line from D7 carries instructions and data from the ESP8266 to the RC522, such as commands to detect or authenticate RFID tags and the Master In, Slave Out line (MISO), connected to D6 of ESP8266, transmits data like the UID associated with the RC522 to the ESP8266. To manage hardware-level resets, we connected the RST pin of the RC522 to D3, and for stable power delivery, we connected the 3.3V pin of the RC522 to the ESP8266's onboard 3.3V output and the GND pin to the common system ground. We used an I2C interface for the LCD to reduce the number of GPIO pins required by the microcontroller and simplify wiring. The whole connection is listed in Table 2. In this configuration table, we connected the Serial data Line of the LCD module to the D2 pin of the microcontroller and the Serial clock Line to the D1 pin of our microcontroller.

Table 2. I²C LCD to ESP8266 Wiring and Communication Function

I2C Pin	NodeMCU Pin
SDA	D2
SCL	D1
VCC	3.3V
GND	GND

While keeping records, scanning cards we employed a camera to capture an image after every valid scan. To configure this we connected the GPIO 13 of ESP32-CAM with the D0 of ESP8266 pin along with an external power source.

Table 3. ESP8266 to ESP32-CAM Connection Mapping for Triggered Image Capture

ESP8266 Pin	ESP32-CAM Pin
D0 (GPIO16)	GPIO13
5V	5V
GND	GND

All the tabular configuration and wiring details are mentioned inside Tables 1, 2, and 3, and are visually represented as shown in Figure 3.

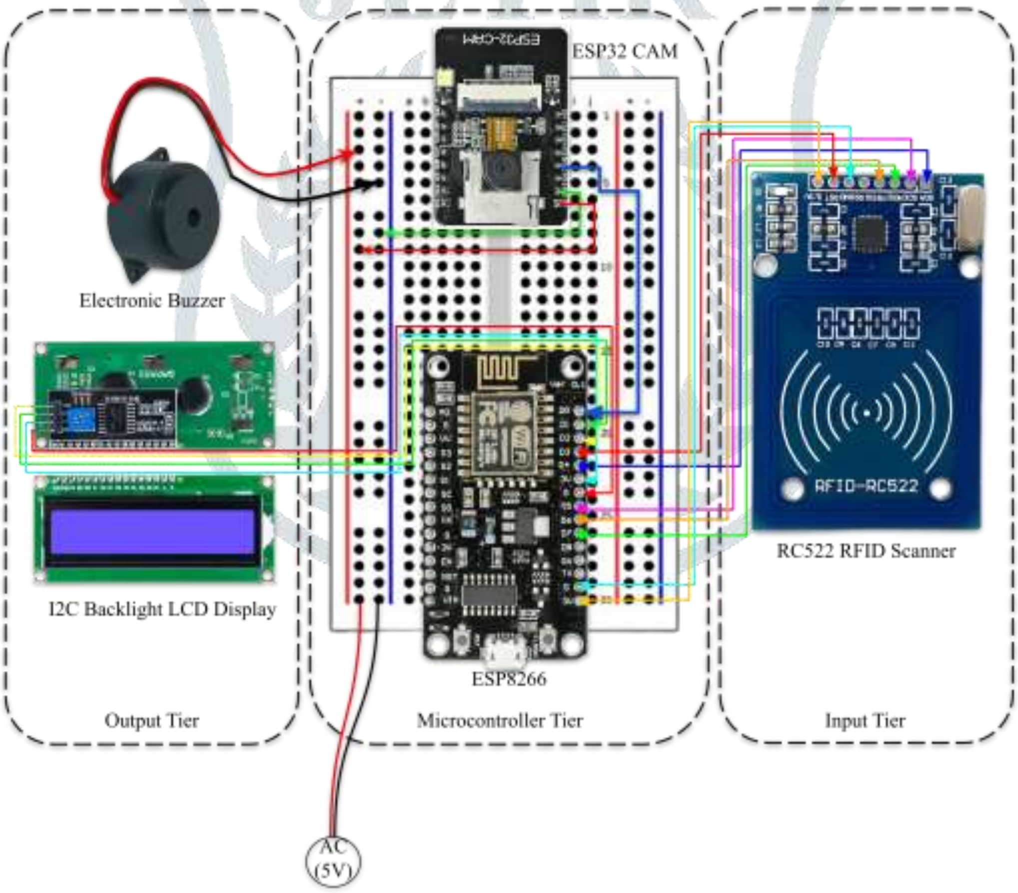

Fig. 3. Circuit diagrams of our attendance system

IV. Methodology

This section registers the extensive process employed in the system design, system development, and system deployment of our proposed attendance system. The methodology covers hardware prototyping, firmware development, and cloud stack integration to ensure a reliable attendance monitoring solution.

4.1 Hardware Prototyping

- We first assembled a breadboard prototype and built a connection map shown in Table 1 (RC522 ↔ ESP8266), Table 2 (I^2C LCD ↔ ESP8266) and the consolidated circuit diagram introduced in Figure 3.
- We positioned the ESP8266 NodeMCU at the center of the layout and wired the MFRC522 RFID reader over the SPI bus.
- A piezo-buzzer was tied to provide audible feedback, while an I^2C 16 × 2 LCD delivered on-site textual messages. Figure 4 demonstrates the overview of our hardware prototyping.

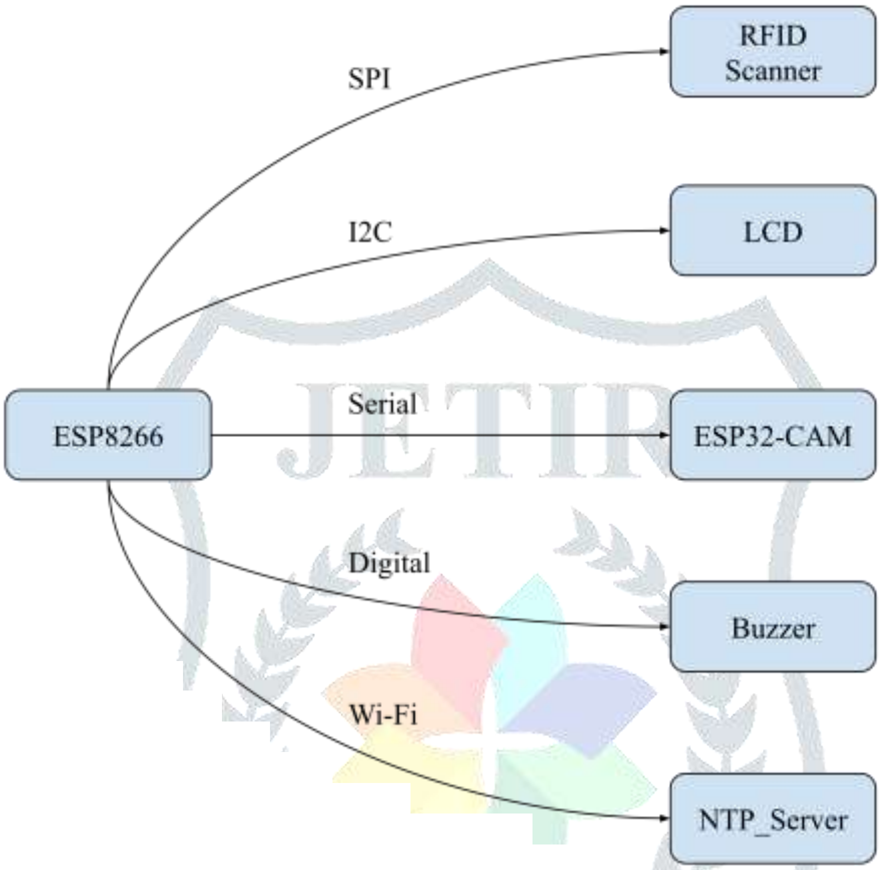

Fig. 4. Hardware Prototyping of our attendance system

4.2 Firmware Development

- We develop firmware using the Arduino IDE, with the following key libraries: ESP8266WiFi.h to manage Wi-Fi connectivity, and MFRC522.h to interface with the RFID module, NTPClient.h to sync system time using Network Time Protocol (NTP) and WiFiUDP.h and ESP8266HTTPClient.h to enable HTTP communication with cloud services.
- Now we encode the information onto the RFID cards and tags, ensuring the information is accurately programmed.
- After the development of firmware, the ESP8266 continuously scans for RFID tags.
- Upon card detection, the firmware reads and converts the RFID UID to a hexadecimal string. Fetches the current system time using the NTP protocol.
- Here comes our time-based scanning mechanism to evaluate whether the scan occurred within valid time intervals: We employed a scanning rule given in Table 4.
- Developed firmware checks if within a valid slot, an HTTP GET request is constructed with UID and slot parameters and sent to a Google Apps Script endpoint.
- Along with that, a frame is captured with the help of the ESP32-CAM board.
- Our visual tier displays feedback on the serial monitor based on the scan result and slot.
- We have developed the firmware this way, which detects unauthorized scans outside these time windows and prompts a message: "Contact HR/Principal – Invalid Time Slot".

Table 4. Time-bound access periods and corresponding system behavior

Period	Allowed Time	System Behavior
Morning	9:00 AM – 10:00 AM	Normal scanning enabled
Lunch	1:00 PM – 2:00 PM	Normal scanning enabled
Exit	5:00 PM – 6:00 PM	Normal scanning enabled
Outside Hours	Any other time	"Contact HR/Principal" message displayed

4.3 Cloud Stack Integration

Cloud stack involves Google App Script, Google Drive, and Google Sheets, which function collectively.

- Upon a successful RFID scan within a valid time slot, our microcontroller sends an HTTP GET request to our own configured Google Apps Script Web app endpoint.
- This request covers the UID of the scanned card along with the current date and time synchronized with an NTP server.
- This request also covers time-slotted label and, most importantly, a signal to trigger ESP32-CAM to capture the frame.
- We transferred the captured image via HTTP POST, uploaded it to Google Drive using Drive API functions. Now, a shareable link is generated and gets stored in the Google sheet again.

This is the whole pipeline on the cloud stack integration mechanism. We considered the dynamic approach to map UID-to-Name pairs. This is the most significant task from scanning an RFID card to store that unique UID along with the Unique name and details. We performed a cloud-based approach where we developed a dedicated "Mapping" sheet in Google Sheets that stores "UID-to-Name" pairs as shown in Figure 5. We prepared another sheet for the integration of the signal coming from the edge tier. This sheet has 5 columns, each of these have marked as a column header with a specific name as shown in Figure 6. Each row represents one day per employee, which reduces the overwrites for the same time slot.

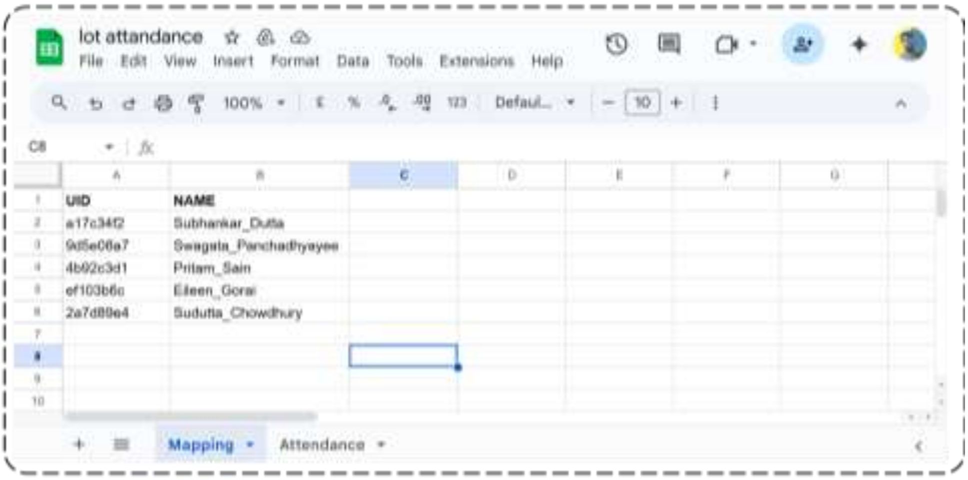

Fig. 5. UID-to-name mapping maintained for real-time identification

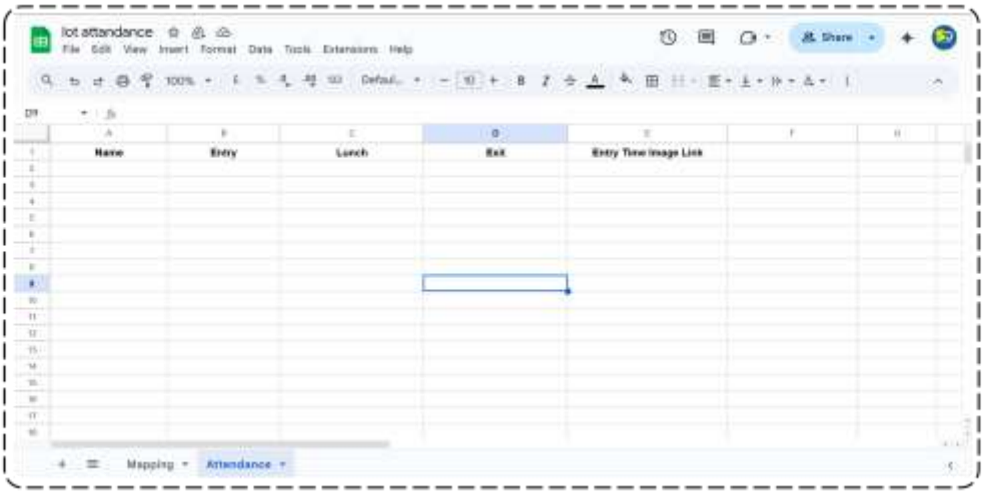

Fig. 6. Automated attendance record capturing required details

V. Experimental Setup and Results

We carried out the experiments. We followed the testing setup and testing rules. We conducted our experiments in a controlled office environment just to check the deployment scenario. We tested these experiments with five users, and each one is assigned with unique RFID card. To implement in a real-world deployment, we planned and assigned three specific time slots for user activity as mentioned in Table 3. To power our whole system, a standard AC connection with a 5-volt adapter. Both the ESP8266 and ESP32-CAM were connected to Wi-Fi to access internet services like NTP, Google Sheets, and Google Drive. We followed a stepwise routine to evaluate system functionality in detail.

1. We start with embedding several RFID cards and mapping their UIDs to user names in the sheet, as discussed in Section IV.
2. Each test user tapped their RFID card on the reader during various predefined time slots, like Entry, Lunch, and Exit.
2. The ESP8266 reads the UID and checks whether the card is authorized by checking the mapping sheet function.
3. If the card is valid and scanned within the slotted time, our proposed system presents the following responses:
    i. The LCD displayed the message based on the user's scanning time slot, such as “Welcome Subhankar- Happy Day”
    ii. The buzzer beeped once as an audio confirmation.
    iii. Our ESP8266 sent a GPIO request to the ESP32-CAM to capture a photo.
    iv. The photo was uploaded to Google Drive.
    v. The UID, timestamp, time slot, and Drive photo link were logged to Google Sheets on a real-time basis.
4. If the card is scanned outside the allowed time slot, our system delivers a few responses:
    i. Our system rejects the scanning attempt.
    ii. The LCD showed “Access Denied” or “Contact HR- Out of Slot”.
    iii. The buzzer beeped twice to signal rejection. This long beep stays for 3000ms.
    iv. Our firmware in this scenario doesn’t trigger the capture signal.
    v. So, no image is captured and no data is transferred to Google environments.

Our Proposed system displays different visuals at three scheduled times and outside of the scheduled time.

$$\text{Output}_{\text{scheduled time}} = \begin{cases} \text{1. Good Morning! Welcome to your shift} & (\text{At, Entry Start} \le T_{current} \le \text{Entry End}) \\ \text{2. Well done! Enjoy your break.} & (\text{At, Lunch Start} \le T_{current} \le \text{Lunch End}) \\ \text{3. Good Evening! See you next shift!} & (\text{At, Exit Start} \le T_{current} \le \text{Exit End}) \end{cases}$$

$$\text{Output}_{\text{Outside scheduled time}} = \begin{cases} \text{1. Access Denied! Contact HR} & \begin{array}{l} T_{current} < \text{Entry Start or} \\ (\text{Entry End} < T_{current} < \text{Lunch Start}) \text{ or} \\ (\text{Lunch End} < T_{current} < \text{Exit Start}) \text{ or} \\ T_{current} > \text{Exit End} \end{array} \end{cases}$$

Where,

- $T_{current}$ is the current system time
- Entry Start = 09:00 AM (In our Proposed System)
- Entry End = 10:00 AM (In our Proposed System)
- Lunch Start = 13:00 PM (In our Proposed System)
- Lunch End = 14:00 PM (In our Proposed System)
- Exit Start = 17:30 PM (In our Proposed System)
- Exit End = 18:30 PM (In our Proposed System)

We repeated the system test across various conditions to ensure reliability. We perform operations with multiple users tapping with valid cards, also during the correct time. On the other hand, we tested under the conditions like the same users outside of their time slot and completely unauthorized RFID cards. In Figure 7, we showcased the entire attendance tracking sheet, which keeps maps UIDs against the names of users and keeps records of entry time, lunch time, exit time, along with the entry time image link.

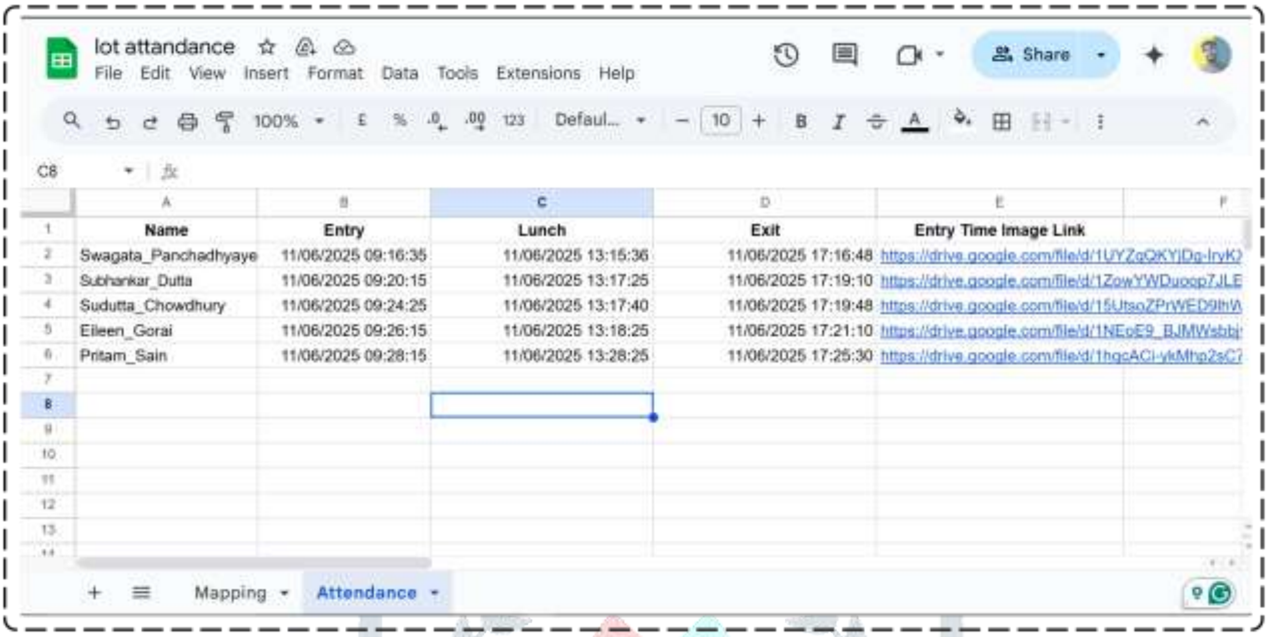

Fig. 7. Live attendance data sheet gathered from our proposed system

Most importantly, we worked on three separate error-handling and emergency power management techniques. During development, we worked on three errors such a network instability, cloud server downtime, and camera failure. We added a display message to warn users about Wi-Fi instability. In this scenario, our system shows "Wi-Fi Error! Retrying" along with a reconnect action after every 10 seconds. Whereas our main microcontroller, ESP8266, stores data locally if there is any server error. Along with these, we attached a bypass mechanism when there is any camera failure, our firmware stores logs without the image. To further ensure uninterrupted function for an emergency service when there is a power cut, we have an option to connect with a Li-ion battery 2000mAh as a backup power source. The following table 5 states the amount of current drawn by our proposed prototype.

Table 5. Estimated power requirements for each hardware component used in our proposed system

Component	Qty	Power Requirement
Nodemcu Esp8266	1	5v 500ma
Esp32-Cam Module	1	5V 1A (Peak)
Mfrc522 Rfid	1	3.3v 150ma
16x2 I²C Lcd	1	5v 20ma
Active Buzzer	1	5v 30ma
Total		5v 2a

Over a 30-day period of evaluation with 10 RFID cards scanned three times a day, is analysed for system accuracy calculation. We found total 900 scans using 10 cards, three times a day, during 30 days' time duration. Our accuracy evaluation metrics indicates i) Total Scans, ii) Number of failures mentioned in Table 6, iii) Successful scans. We used standard formula to compute accuracy of our system over the records as mentioned in equation 1.

$$\text{Accuracy} = [(\text{Total Scans} - \text{Number of Failures}) / \text{Total Scans}] \times 100 \quad (1)$$

Our experimental values state the value observed by the parameter of finding accuracy of our proposed system. We found

$$\text{Total Scans} = 10 \text{ cards} \times 3 \text{ scans/day} \times 30 \text{ days} = 900$$
$$\text{Number of Failures} = 7$$
$$\text{Successful Scans} = 900 - 7 = 893$$
$$\text{Accuracy} = (893 / 900) \times 100 = 99.222...\%$$

Table 6. Illustration of error type along with the percentage of occurrence

Error Type	Percentage of occurrence	Test Simulation
Distance Error	43% of failures	3/7
Angle Error	29% of failures	2/7
Signal Interference	18% of failures	1/7
User Error (Reader Timeout)	12% of failures	1/7

At final stage our system is ready to be deployed for real world usage after resolving all dilute error shown in figure 8. The system operates on AC connection with 5 Volt adapter.

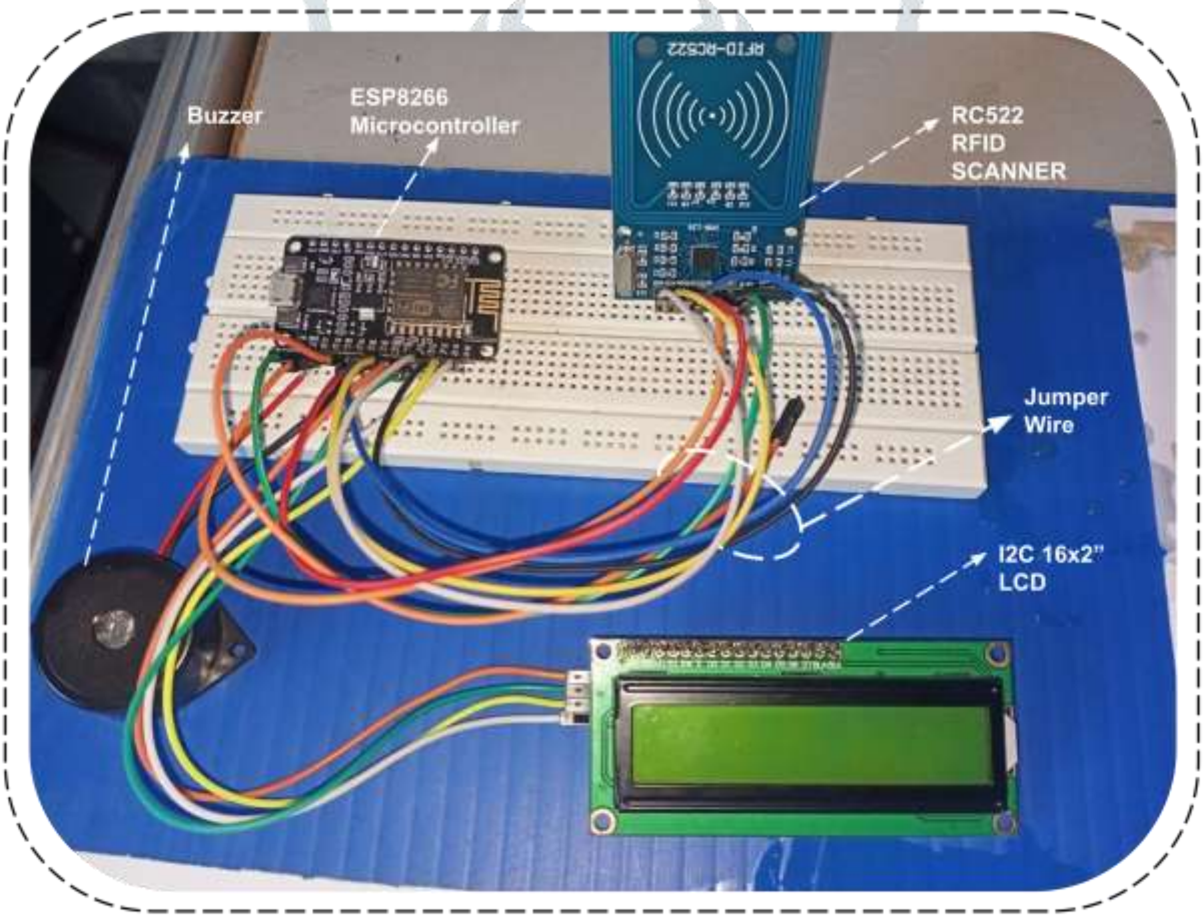

Fig. 7. Physical model of our proposed system

VI. Conclusion

The conventional method of manually recording and tracking attendance could be improved for greater efficiency. The attendance tracking system utilizing RFID authentication has the potential to simplify and enhance the entire process. A portable RFID attendance system based on the combined framework of Internet of Things (IoT) and Cloud Computing can offer significant benefits to educational institutions and industries, as it demonstrates high levels of efficiency and optimization in power consumption. Our research presents a robust IoT-based RFID attendance system that successfully follows the time-restricted logic. This system works on time-based scanning; it also works on optimization of energy consumption. Our proposed system ensures strict time-based attendance with visual verification, which is our main objective while optimizing power consumption during off-hours. Implemented dual-layer validation of our prototype (device + cloud) to prevent false recordings of attendance. We achieved 99.2% accuracy on recognition accuracy along with 100% reliability with time windows.

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