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Original Article

DESIGN, INTEGRATION, AND BATTERY ENERGY DEPLETION ANALYSIS OF AN RFID-BASED ATTENDANCE SYSTEM

Ernest Jude Terna[1], and Oluwaseun Adeyeye [1,*]

[1] Department of Mathematics, Physics and Computer Science, Caleb University, Imota, Lagos, Nigeria.

*Corresponding author, E-mail: oluwaseun.adeyeye@calebuniversity.edu.ng (Tel: +234-8036610964)

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ABSTRACT

The need for an automated attendance management system has evolved from the limitations of traditional approaches, such as buddy punching and the time-consuming process of covering many participants. This article presents the design and integration of an RFID-based device for recording and tracking students' attendance. The gadget is linked with Google Sheets for cloud data storage. It is fabricated using an ESP32 microcontroller, Radio Frequency Identification (RFID), and feedback mechanisms such as an LED, an LCD, a buzzer, and a push button. The push button aids dynamic switching between multiple Google Sheets. A portable power station can power the device; hence, a differential equation model was developed to observe its battery energy depletion over various usage patterns. The results obtained using Euler's numerical method give insights into optimizing battery life and improving the device's performance.

KEYWORDS: Portable power source, Euler method, Attendance, RFID, Energy optimisation.

1. INTRODUCTION

Institutions recently need accurate and efficient attendance management systems to ensure that operations are carried out clearly and that attendance is accounted for. Attendance is an essential part of education and determines whether a student is eligible to write exams, and traditional methods of recording attendance, such as roll-calling or logbooks, are time-consuming. They are prone to errors and are inefficient, particularly in a busy environment. Radio Frequency Identification (RFID) technology has become a reliable, contactless solution to mitigate these limitations. Working with cloud services, RFID enables scalable, automated attendance tracking.

Various studies have sought to eliminate traditional attendance recording methods by developing RFID-based devices. Fahad (2023) created an ESP8266 RFID attendance system with Google Sheets integration. The device uses the ESP8266 Wi-Fi and PN532 RFID modules to log real-time attendance in Google Sheets. Its features included real-time updates to Google Sheets, multi-sheet functionality, and basic attendance analytics, but it lacked dynamic multi-sheet switching within a single system interface. The author designed an attendance system using RFID and Google App Script. The system logs attendance using Arduino, Ethernet, and the push box API. Its features include real-time logging, LED, and buzzer feedback for user interaction. However, it had no wireless functionality and no dynamic spreadsheet switching. Embedotronics (2019) developed an Internet of Things (IoT)- enabled attendance system using an Intel Edison to log data in Google Sheets. Although the IoT-enabled remote monitoring, the device was limited to a single attendance sheet and lacked advanced analytics and user-friendliness. Salunkhe *et al.* (2025) conducted a review that explored the architecture, functionality, and technological evolution of RFID-based smart attendance systems, emphasizing their capacity to enhance record management through automation and real-time processing. Hasman and Ahmad (2022) designed a system that goes beyond only RFID detection attendance but also displays if a user is early or late to the class while noting if such student has an acceptable body temperature to attend the class.

Other related studies include Alam (2016), Saddam (2015), Koppikar *et al.* (2019), Awotunde *et al.* (2022), and Rozlan *et al.* (2023). For example, Alam (2016) designed a system that logs attendance using an 8051 microcontroller and sends data to Google Sheets via Wi-Fi. It is low-cost and includes a buzzer and LED feedback.

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However, it does not have analytics or multi-sheet integration. Saddam (2015), on the other hand, developed an RFID-baslacksed authentication system using an Arduino Microcontroller. It uses Arduino Uno and the EM-1 module to log attendance data in the Arduino IDE serial monitor. Its limitation was that it had no wireless capabilities, LCD feedback, or multi-sheet integration. Also, Koppikar *et al.* (2019) created a system that combines RFID with IoT for attendance monitoring and data display on an analytics dashboard, while Awotunde *et al.* (2022) and Rozlan *et al.* (2023) developed the system with hardware and software components such as RFID cards, an RFID reader model RC522, a buzzer, and an LED. It had real-time synchronisation and analytics for attendance trends. In addition, Shrivastava *et al.* (2025) developed an IoT-based RFID attendance monitoring system for students in a defined area using Arduino ESP8266 and Adafruit.io. Their development focused on analytics but lacks interactive user feedback, such as LCD displays or alert systems.

A standard limitation among most systems is the absence of dynamic multi-sheet integration, which prevents them from being usable in instances where multiple attendance circumstances exist, such as different classes or events. Additionally, most projects lack real-time response or feedback mechanisms like LCDs and fail to use advanced logic in pattern analysis for attendance. Some systems rely on expensive and old or outdated hardware, limiting them from broader applications due to cost-effectiveness and accessibility. In addition, the energy depletion was not analysed in any of these devices to optimise energy use.

Due to the developed system's use of a portable power source, a concern that comes to mind is how to monitor power usage while ensuring that the gadget lasts a long time in use. Various models can be used to observe this dynamics, and differential equations are valuable and applicable (Pankaj, 2024). Studies such as Tamilselvi *et al.* (2021), Morimoto *et al.* (2021), and Pepe *et al.* (2022) have shown that ordinary differential equation (ODE) models can provide information on battery durability and usage. The authors in the former conducted research where an ODE model was developed for the numerical simulation of batteries where the distance of the anode to cathode is small, with a merge in the diffusion layers at both electrode surfaces. Hence, the latter developed neural ODEs to forecast the state of health of batteries and predict their end-of-life. Therefore, in addition to the differential equation battery depletion model developed in this article, the gadget resolves the limitations mentioned earlier by integrating features such as dynamic multi-sheet switching, real-time LCD feedback, and advanced analytics for attendance patterns. The ESP32 microcontroller, with its power efficiency and flexibility, ensures a scalable, cost-effective, and user-friendly solution; these upgrades make the proposed design the best for academic institutions and other organisations needing comprehensive attendance management.

2. MATERIALS AND METHODS

System Overview:

This system's architecture consists of hardware and software components working together to record real-time attendance data. The hardware includes:

- ESP WROOM32 microcontroller used for core processing and offers Wi-Fi connectivity.
- The RFID-RC522 module reads signals from RFID cards/tags.
- LEDs, LCD, and buzzer provide real-time feedback on attendance status.
- Push-Button interface allows switching between multiple Google Sheets for different classes.

Figure 1 below shows the compilation of these components.

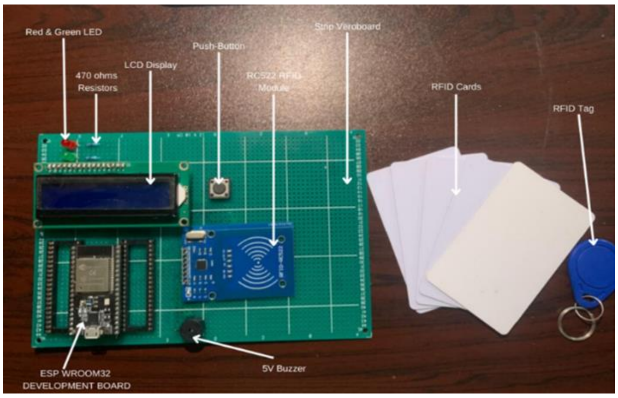


Figure 1: Layout of the system component.

On the other hand, the software entails coding the firmware in C/C++ for the ESP32 and Google Apps Scripts to link it with Google Sheets. It also uses timestamps, student names, matriculation numbers, attendance status, and behavioural patterns. Figure 2 shows how hardware and software are combined to work accurately.

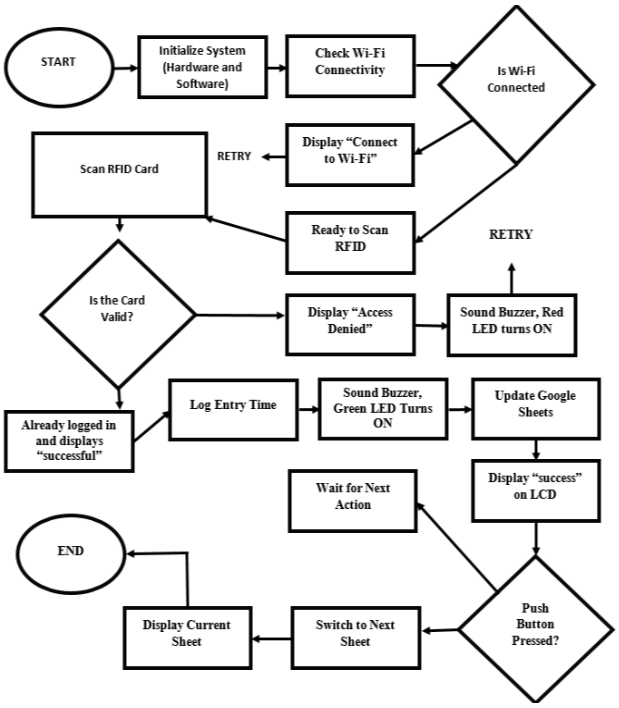


Figure 2: Workflow of the RFID-based attendance system.

The digital devices utilised are discussed as follows:

A. RFID Tag and Reader:

The RFID system uses passive tags operating at 13.56 MHz. These tags communicate with the RC522 reader using frequencies, sending the tags' data to the ESP32. In this system, each RFID tag is registered with a student ID. Figure 3 gives a sample image of the reader and tag.

Figure 3: RFID-RC522 Reader and RFID Card/Tag.

B. Microcontroller (ESP WROM32):

The ESP32 controls the whole system. It gets data from the RFID reader, handles attendance logic processes, communicates with cloud-based services, and manages real-time user feedback via LEDs, LCDs, and a buzzer.

Figure 4: ESP32 WROOM microcontroller.

An essential part of this project is the pin configuration and connection between its various components and the microcontroller. Table 1 below provides a detailed description of each pin used.

Table 1: Pin Allocation of Corresponding Component-Pin.

Component	ESP32 Pin	Purpose
RFID Reader (MFRC522)		
SDA	GPIO 21	Select a line for SPI communication
SCK	GPIO 18	SPI Clock
MOSI	GPIO 23	Master Out, Slave In
MISO	GPIO 19	Master In, Slave Out
RST	GPIO 22	Reset line
GND	GND	Ground
3.3V	3.3V	Power supply for the RFID module
LCD Display (I2C)		
SDA	GPIO 32	Data line for I2C communication
SCL	GPIO 33	Clock line for I2C communication
VCC	5V	Power supply
GND	GND	Ground
Buzzer		
BUZZER	GPIO 15	Digital output to control the buzzer
LEDs		
RED LED	GPIO 13	Digital output for the red LED
GREEN LED	GPIO 14	Digital output for the green LED
Push Button		
Button Input Pin	GPIO 12	Reads the button state for switching sheets
GND	GND	Connects one terminal of the button to ground
Power Supply		
ESP32 Vin or Micro-USB	5V	Power source for the ESP32

C. Display and Feedback Mechanisms:
A 16x2 I2C LCD displays the message “successful” or “Failed,” depending on whether the tag scanned is valid. LED (green and red) and a buzzer ensure that attendance is recorded, and the status is visually and audibly confirmed.

Figure 5:16x2 IC2 LCD.

Figure 6: Green and red LED.

Figure 7: Buzzer.

D. Cloud Integration through Google Sheets:

Attendance records are uploaded in real time to Google Sheets using HTTP requests and Google App Scripts. Each record includes:

- ✓ Student ID/ matriculation number
- ✓ Name
- ✓ Timestamp (WAT zone)
- ✓ Date
- ✓ Attendance status
- ✓ Class or session tag

The administrator can switch between multiple Google Sheets using a push button, allowing record-keeping for different groups.

Figure 8: Push button.

E. Software Workflow:

The software consists of modules for:

a. User authentication (via RFID tag)
b. Attendance validation
c. Google Sheets update via API
d. LCD output and buzzer actuation
e. Push button sheets switching

The system ensures no duplicates or unauthorised entries by validating tags against a predefined list in the cloud database.

Implementation:

When the system was complete, it was assembled and tested in a university setting. The system was evaluated through a controlled pilot test involving five undergraduate students to validate functional correctness, data integrity, and real-time performance. As the RFID tag was scanned and read successfully, the student's data was uploaded to Google Sheets. Feedback was provided immediately via LCD, LEDS, and a buzzer. The system performance was carefully evaluated using the following metrics: accuracy, responsiveness, scalability, and user satisfaction.

Pilot implementation showed:

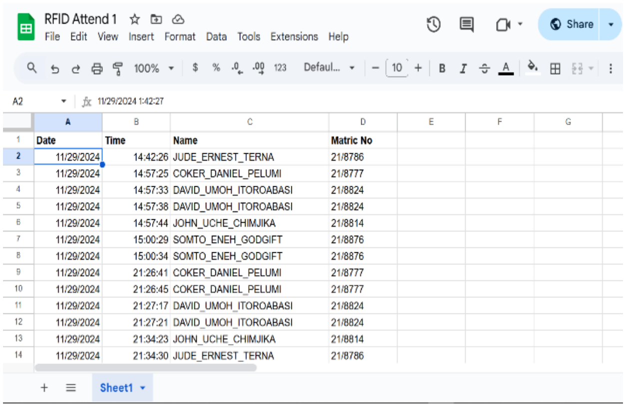
1. 98% accuracy in reading valid tags,
2. Real-time synchronisation under 2 seconds,
3. Easy usability for students and staff,
4. Positive feedback from administrators and students regarding different performances.

To obtain users' feedback on the system, a survey was carried out. Questions about ease of use, LCD feedback clarity, push button efficiency, and behavioural analysis were asked. The findings are presented in Table 2.

Table 2: User Feedback on Different Performance Metrics During Pilot Test.

Parameter	Positive Feedback (%)	Negative Feedback (%)
Ease of Use	97%	3%
LCD Feedback Clarity	95%	5%
Push Button Efficiency	95%	5%
Behavioural analysis	100%	0%

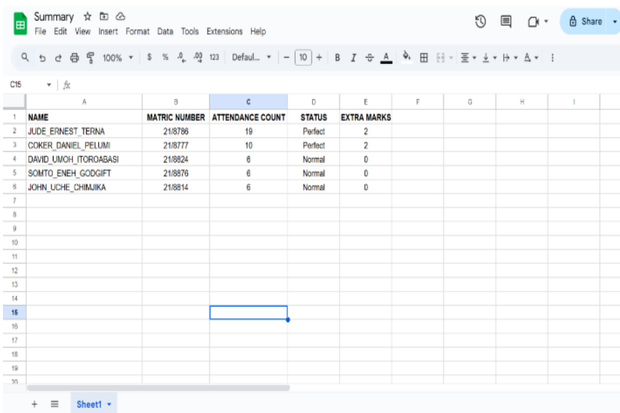
Figure 9 below displays a sample Google Sheet record tracking student attendance. This window makes it easy to identify absent students. Also, an administrator analyses attendance, which is tracked and recorded. The administrator can tell a student's behavioural pattern from attendance, as shown in Figure 10.



RFID Attend 1

Date	Time	Name	Matric No
11/29/2024	14:42:26	JUDE_ERNEST_TERNA	21/8786
11/29/2024	14:57:25	COKER_DANIEL_PELUMI	21/8777
11/29/2024	14:57:33	DAVID_UMOH_ITOROABASI	21/8824
11/29/2024	14:57:38	DAVID_UMOH_ITOROABASI	21/8824
11/29/2024	14:57:44	JOHN_UCHE_CHIMJIKA	21/8814
11/29/2024	15:00:29	SOMTO_ENEH_GODGIFT	21/8876
11/29/2024	15:00:34	SOMTO_ENEH_GODGIFT	21/8876
11/29/2024	21:26:41	COKER_DANIEL_PELUMI	21/8777
11/29/2024	21:26:45	COKER_DANIEL_PELUMI	21/8777
11/29/2024	21:27:17	DAVID_UMOH_ITOROABASI	21/8824
11/29/2024	21:27:21	DAVID_UMOH_ITOROABASI	21/8824
11/29/2024	21:34:23	JOHN_UCHE_CHIMJIKA	21/8814
11/29/2024	21:34:30	JUDE_ERNEST_TERNA	21/8786

Figure 9: Sample Tracking Record in Google Sheets During Pilot Test.



Summary

NAME	MATRIC NUMBER	ATTENDANCE COUNT	STATUS	EXTRA MARKS
JUDE_ERNEST_TERNA	21/8786	19	Perfect	2
COKER_DANIEL_PELUMI	21/8777	10	Perfect	2
DAVID_UMOH_ITOROABASI	21/8824	6	Normal	0
SOMTO_ENEH_GODGIFT	21/8876	6	Normal	0
JOHN_UCHE_CHIMJIKA	21/8814	6	Normal	0

Figure 10: Summary Sheet of Pilot Test Candidates.

BATTERY ENERGY DEPLETION MODEL:

To ensure that the deployed RFID attendance device is energy efficient, a mathematical model is developed using ODE. The aim is to monitor, record, and track the battery usage and eventual depletion over different usage conditions, that is, active-scan mode and low-power idle mode. A first-order ODE is defined with the remaining energy of the battery in watt-hours (Wh) at the time t denoted as $E(t)$.

Also, instantaneous power consumption is denoted as $P(t)$. The rate of change of energy is given as:

$$\frac{dE}{dt} = -P(t),\ E(0) = 7.4Wh \quad (1)$$

with the rate of change of the energy remaining in the battery $\left(\frac{dE}{dt}\right)$ having a negative value because energy decreases as the battery is used. This implies that the more power the device consumes, the faster the energy is depleted. Figure 11 gives a visual description of the behaviour of the ODE model.

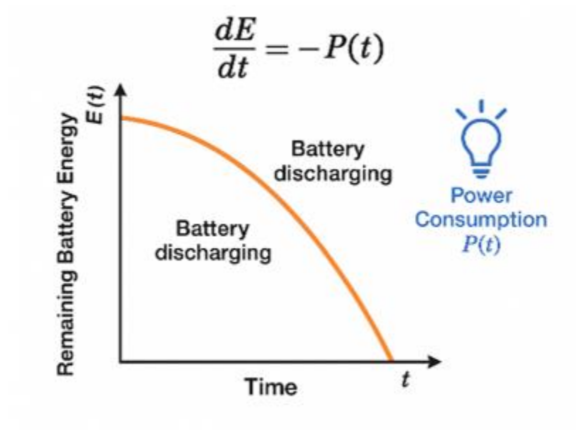


Figure 11: Visual description of the ODE model.

The initial condition of $E(0) = 7.4Wh$ in Equation (1) is calculated using the initial battery energy of the portable power source, which uses a 3.7V, 2000 mAh battery. Thus, the product of both values gives the value of the initial condition $E(0)$.

Note that the device works in two modes. The first mode is when attendance is scanned using the RFID tag (active-scan mode) and when no scanning is done (idle mode). It is assumed that during the active-scan mode, the system draws a $P(t) = 0.5W$ within the 2-second time as mentioned in the implementation phase above, and $P(t) = 0.05W$ during the idle mode. If scanning occurs at the rate of one scan per minute (60 seconds), the power function is thus defined as a periodic step function.

$$P(t) = \begin{cases} 0.5, & t \bmod 60 < 2 \\ 0.05, & otherwise \end{cases}. \qquad (2)$$

Combining the initial value problem in Equation (1) and the step function in Equation (2), the rigour of obtaining an exact solution is bypassed by a numerical method. Euler's method, $y_{n+1} = y_n + hf_n$ is coded in Python to simulate the battery energy over time (See Appendix).

The results obtained for the estimated battery life in days are given below:

1. If the scan interval is 30 seconds, the battery life is 3.9 days,
2. If the scan interval is 60 seconds, the battery life is 4.7 days, and
3. If the scan interval is 120 seconds, the battery life is 5.4 days.

Figure 12 below shows the graphical result.

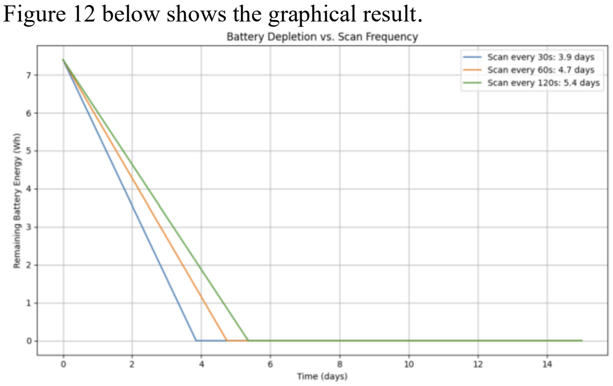


Figure 12: Battery energy simulation graph.

The operational granularity and power conservation can be visualised from the graph. It is seen that there is a nonlinear relationship between frequent scanning and energy usage. This conclusion is drawn because when the scanning frequency is doubled, the battery life is not automatically halved, and this is due to the disproportionately higher active mode power draw.

CONCLUSION

This paper offers a scalable RFID attendance system integrated with cloud services for an educational environment. The system effectively mitigates the standard limitations of traditional and digital attendance methods by leveraging ESP32-based wireless communication, real-time response, and cloud services. This study introduces a system that uses the ESP WROOM32 microcontroller with the RFID-RC522 module and Google Sheets. This RFID attendance system stores attendance data and provides real-time feedback via LEDs, LCDs, and buzzers. It also supports a push button that allows dynamic switching between multiple logs. Compared to other standalone RFID solutions, this system provides remote monitoring and behavioural analysis via cloud-based records, making it suitable for educational institutions to manage attendance for hundreds of students across multiple classes. In addition to hardware fabrication, this article provides insight into the energy depletion of the portable power source attached to the device. The ODE model estimated the duration over which the device's battery would be depleted under specific usage modes. The results show that the device will be operational for 5 to 6 days when running at full charge, assuming one scan is performed per minute. The introduction of ODE and its numerical solution on the hardware allows the user to make informed decisions about the efficient energy use of this novel RFID-based fabrication in attendance systems.

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Ethical Statement:

The study did not require ethical approval, as it did not involve human participants or animal subjects.

Author Contributions:

T. E. J. developed the design and coupling of the RFID-based attendance system. A. O. developed and analysed the energy depletion model of the RFID-based attendance system. Both authors contributed to the drafting and revising of the manuscript, read and approved the final manuscript.

Conflict of Interest:

The authors declare no conflict of interest.

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Appendix

```
import numpy as np
import matplotlib.pyplot as plt
# Initial energy: 2000mAh * 3.7V = 7.4 Wh
E0 = 7.4  # Wh
dt = 1  # time step in seconds
max_time = 15 * 24 * 3600  # simulate up to 15 days
scan_intervals = [30, 60, 120]  # in seconds
active_duration = 2  # active scan duration in seconds
P_active = 0.5  # power in active mode (W)
P_idle = 0.05  # power in idle mode (W)
battery_life_days = []
plt.figure(figsize=(10, 6))
for interval in scan_intervals:
  time = np.arange(0, max_time, dt)
  E = np.zeros_like(time, dtype=float)
  E[0] = E0
  for i in range(1, len(time)):
    t_mod = time[i] % interval
    P = P_active if t_mod < active_duration else P_idle
    E[i] = E[i-1] - P * dt / 3600  # Convert W·s to Wh
    if E[i] <= 0:
      E[i:] = 0
      break
  depletion_index = np.argmax(E == 0)
  battery_life = time[depletion_index] / (3600 * 24) if
depletion_index > 0 else max_time / (3600 * 24)
  battery_life_days.append(battery_life)
  plt.plot(time / 3600 / 24, E, label=f'Scan every
{interval}s: {battery_life:.1f} days')
# Plot setup
plt.xlabel('Time (days)')
plt.ylabel('Remaining Battery Energy (Wh)')
plt.title('Battery Depletion vs. Scan Frequency')
plt.grid(True)
plt.legend()
plt.tight_layout()
plt.show()
# Display the results
print("Estimated Battery Life (Days):")
for interval, life in zip(scan_intervals, battery_life_days):
  print(f"Scan Interval: {interval}s => Battery Life: {life:.1f}
days")
```