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RFID-Based Smart Library Management System Using ESP32

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A B S T R A C T

Libraries require reliable ways to identify borrowers and maintain accurate circulation records. Manual issue and return procedures can take time and may lead to recording errors. This paper presents the design of a low-cost prototype for a smart library management system using an ESP32 microcontroller and an MFRC522 RFID reader. A registered student RFID card is scanned first to identify the borrower, followed by the RFID tag attached to a library book. The ESP32 processes the scanned identifiers and checks the corresponding borrower and book records before an issue or return operation is accepted. The prototype is intended to demonstrate a simple RFID-based circulation workflow using commonly available components. This paper describes the proposed architecture, hardware, software, operating sequence, and functional tests of the prototype. At a read distance of 2 cm, 9 of 10 scans were recognised and the average response time was 0.94 s.

Keywords: RFID, ESP32, MFRC522, smart library, book circulation, embedded system.

1. Introduction

Libraries manage collections of books and borrower information. In a conventional circulation process, staff may need to search for a book record, verify a borrower, and manually update issue or return details. These repeated tasks can increase transaction time and create opportunities for human error [1], [2]. Radio Frequency Identification (RFID) provides a way to identify tagged objects without requiring direct optical alignment, making it useful for library circulation applications [1]–[3]. A microcontroller-based system can read RFID identifiers and apply simple rules to maintain book status.

This project proposes a compact library circulation prototype using an ESP32 development board [4] and an MFRC522 RFID reader [5]. The system identifies a student card and a book tag in sequence. The prototype focuses on the basic issue and return workflow rather than claiming to replace a complete commercial library platform.

2. Problem statement

Manual library issue and return procedures may involve repeated data entry and manual record checking. Such processes can be time-consuming and may result in incorrect or outdated availability records. A low-cost method is therefore required to identify a borrower and a book, verify their status, and update circulation information with fewer manual steps.

3. Objectives

The main objectives are: (1) to identify registered students using RFID cards; (2) to identify library books using RFID tags; (3) to validate student and book records; (4) to support issue and return operations; and (5) to demonstrate a low-cost embedded prototype using ESP32 and MFRC522.

4. Related work

Previous studies have examined RFID use in libraries, including circulation processes, user acceptance, and system design. Gannamraju et al. [1] built a smart library system from an RFID reader, an ESP8266 and a back-end database, with a portal that shows book transactions and fine details. Devi et al. [2] proposed an RFID-based system in which a microcontroller detects the user and the books and updates the database automatically. Mukund et al. [3] added a PyQt web portal with analytics and fine calculation to an intelligent RFID library system.

Several studies use the ESP32 platform. Wijaya et al. [6] reported the development and testing of an RFID circulation system based on ESP32 and MySQL, and Musale et al. [7] designed an ESP32-based smart library with real-time data transmission and cloud monitoring. Performance has also been studied: Achary [8] proposed an architecture that links the library network to the Internet and cloud servers and analysed the parameters that degrade

RFID performance, while Suhaimi et al. [12] found that reader angle and placement strongly affect read performance. Other work has added artificial intelligence with Raspberry Pi [9], biometric authentication [10], and RFID-based authorization for computer systems in smart library environments [11].

These works provide a basis for using RFID identifiers to automate book tracking and borrower identification. The present prototype narrows the scope to a small, low-cost implementation based on an ESP32 board and one MFRC522 reader, with a simple sequential workflow of student card first and book tag second, and without cloud, biometric or analytics components.

5. Proposed system

The proposed system consists of student RFID cards, RFID tags attached to books, an MFRC522 reader, an ESP32 controller, and a record store. The reader obtains the card or tag identifier and transfers it to the ESP32 through the SPI interface. The controller checks whether the scanned identifier is registered and whether the requested circulation operation is valid. A single reader is used sequentially: first the student card is scanned, then the book tag is scanned.

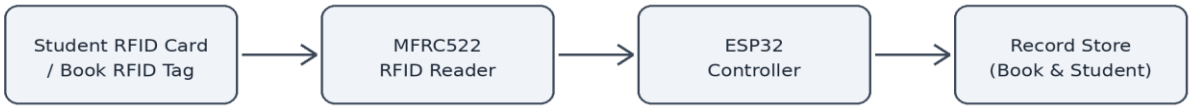


Fig. 1 - High-level architecture of the proposed RFID-based library prototype.

6.1 Hardware and software requirements

The components and tools used in the prototype are listed in Table 1.

Table 1 - Hardware and software requirements.

Component	Purpose
ESP32 DevKit V1 (ESP-WROOM-32)	Reads RFID data and controls the circulation logic.
MFRC522 RFID reader	Reads 13.56 MHz compatible RFID cards and tags.
MIFARE RFID student card	Stores a unique identifier associated with a registered borrower.
MIFARE RFID book tags	Identifies individual library books.
Breadboard and jumper wires	Provide temporary circuit connections.
Arduino IDE and MFRC522 library	Used to write, upload, and test the ESP32 program.

7. System methodology

7.1 Student registration

The UID of each approved student card is associated with a student record. Only registered identifiers are accepted by the circulation program.

7.2 Book registration

Each book tag UID is associated with a book identifier, title, and availability status. The record must be added before circulation testing.

7.3 Book issue

The user scans a registered student card and then scans the required book tag. The ESP32 checks both records. If the student is valid and the book is available, the system marks the book as issued and associates it with the student. Otherwise, it displays an appropriate rejection message.

7.4 Book return

The return workflow identifies the book tag and checks whether it is currently issued. If the record is valid, the system changes the book status to available and clears the active borrower association.

8. Algorithm

1) Initialise the ESP32, RFID reader, and record store. 2) Wait for an RFID card or tag. 3) Read its UID. 4) If the system is waiting for a student, validate the student UID and store the active student. 5) Otherwise, identify the book UID. 6) For an issue request, verify that the book is available and update its status to issued. 7) For a return request, verify that the book is issued and update its status to available. 8) Display the result and return to the scan-ready state.

9. Results and discussion

9.1 Functional test plan

The functional tests used to check the circulation workflow are given in Table 2.

Table 2 - Functional test plan.

Test	Test condition	Expected behaviour	Observed result
T1	Scan registered student card	Student record is identified	Student identified
T2	Scan unregistered card	Access is rejected	Invalid student
T3	Scan available book after valid student	Book is issued and linked to student	Book issued successfully
T4	Attempt to issue an already-issued book	Duplicate issue is rejected	Issue rejected
T5	Return a currently issued book	Book status changes to available	Book returned successfully
T6	Attempt return of an available book	Invalid return is reported	Invalid return
T7	Repeat scans at different distances/orientations	Read reliability is recorded	9 of 10 scans read at 2 cm (recognition rate 90%); average response time 0.94 s

9.2 Read reliability and response time

Read reliability (test T7) is evaluated using the recognition rate in Eq. (1), and the response time is measured from the moment a card or tag is presented to the moment the result is displayed, averaged as in Eq. (2). At a read distance of 2 cm, 9 of 10 scans were read successfully, giving a recognition rate of 90%. The response times over 10 trials were 0.7, 0.8, 0.9, 1.0, 1.0, 1.1, 0.8, 0.9, 1.0 and 1.2 s, giving an average of 0.94 s (range 0.7 to 1.2 s). These results come from a small sample at a single distance and should not be generalised to other distances or orientations.

Recognition rate (%) = (Number of successful reads / Total scan attempts) × 100

(9/10)*100=90% (1)

Average response time = Sum of measured response times / Number of completed trials

9.4/10=0.94 seconds (2)

9.3 Discussion

The functional tests in Table 2 cover valid and invalid issue and return operations, and show that a low-cost ESP32 and MFRC522 arrangement can support basic borrower identification and book circulation. The use of one reader reduces hardware cost but requires student and book scans to be performed in a defined sequence. The system's reliability may be affected by tag orientation, distance, nearby metal, wiring quality, power stability, and duplicate or unregistered identifiers [8], [12]. The prototype should be regarded as a small-scale demonstration, since it has not been evaluated with a larger library dataset.

10. Limitations

The prototype is intended for a limited number of registered cards and books. A single RFID reader requires sequential scanning. The MFRC522 has a short read range and is sensitive to tag placement. If records are stored only in ESP32 local memory, data management and backup are limited compared with a networked database. The current design does not by itself provide a complete web dashboard, multi-branch synchronisation, or enterprise-level security.

11. Future enhancements

Future work may include a web-based librarian dashboard, cloud or database integration, automatic due-date calculation, overdue notifications, a larger test dataset, improved enclosure design, and evaluation of read success across different distances and orientations. Authentication and data backup should also be strengthened before deployment in a real library.

12. Conclusion

This paper described a low-cost RFID-based library circulation prototype using an ESP32 microcontroller and an MFRC522 reader. The workflow uses a student RFID card and a book RFID tag to support borrower identification, book issue, and book return, and the functional tests in Table 2 cover valid and invalid operations. At 2 cm, 9 of 10 scans were read successfully with an average response time of 0.94 s. The design provides a practical educational demonstration of embedded systems and RFID-based identification. Future work will add persistent database storage, a librarian dashboard, and evaluation with a larger set of books and borrowers.

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