

QR Based Library Management System

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Abstract: Managing library resource systems manually or using expensive technologies like Radio Frequency Identification (RFID) still poses a challenge for institutions that depend on traditional or automated techniques, respectively. In this research, a proposed library management system uses student smartphones to decentralize the process of handling transactions securely and cost-effectively. The significant innovation is the use of the Secure QR Encoding Model (SQEM), where AES-256 symmetric encryption technology combined with HMAC-SHA256 signature guarantees integrity and avoids any tampering of QR codes. The application consists of three-tier layers; the mobile client layer is made up of the Android application that performs real-time QR scan operations, the API layer that is written in Node.js/Express, which manages requests for transaction purposes, and the server layer composed of MongoDB Atlas cloud database used for storing persistent data. Experimental assessment of 200 transactions shows a 91.3% reduction in transaction time from 255 seconds to 22 seconds compared to manual methods. Moreover, the data integrity rate stands at 99.6%. The analysis reveals that the suggested library management system performs nearly as good as RFID technology but at less than 0.5% of its price.

Keywords: Library Management System, QR Code, Android Application, RESTful API, MongoDB, AES-256 Encryption, HMAC-SHA256, Secure QR Encoding Model.

I. INTRODUCTION

A. Global Context and Evolution

The significance of academic libraries in spreading information in academic settings is immense. As user requests increase, and collections grow, a scalability issue is revealed when considering the use of existing library management systems. Library management systems that involved manual record keeping have gradually been supplanted by the use of barcodes and finally by the use of Radio Frequency Identification (RFID). Even though the latter involves efficient monitoring and minimal human intervention in the process, the costs incurred in building its infrastructure may not be affordable. Hence, the requirement of a system with reduced cost but with similar levels of performance remains open.

B. Definition of Problem: Limitations of Centralized Transaction Systems

The current library systems run on a central transaction process where books can be issued and returned only at the counters allocated to those activities. The above system is prone to the following problems:

- **Transaction Latency:** Queue formation during peak hours significantly slows down the transaction process.
- **Errors due to Human Input:** Manual entry of user details often leads to inaccurate or inconsistent records.
- **Hardware Requirement:** Barcode and RFID-based systems rely on dedicated scanning devices, increasing infrastructure and maintenance costs.

C. Decentralized Scan-and-Go System

The advancement of smartphone technology and widespread internet connectivity, decentralizing transaction workflows has become feasible. By utilizing smartphones as scanning devices, the dependency on specialized hardware can be eliminated. However, standard QR codes lack inherent security mechanisms, making them vulnerable to forgery and replay attacks. This work addresses these limitations by integrating cryptographic techniques into the QR encoding process, ensuring secure and verifiable transactions.

D. Main Contributions

The primary contributions of this work are summarized as follows:

- **Secure QR Encoding Mechanism (SQEM):** A cryptographic framework integrating AES-256 encryption with HMAC-SHA256 signatures to mitigate QR code forgery and replay attacks.

- **Decentralized Mobile Device-Based Architecture:** A scan-and-go transaction system that eliminates the need for centralized infrastructure.
- **Cost Efficiency:** The proposed system achieves near RFID performance at less than 0.5% of the total infrastructure cost.
- **High-Performance Transaction System:** A RESTful backend architecture achieving a 91.3% reduction in transaction latency.
- **Scalable Cloud Integration:** A lightweight system leveraging MongoDB Atlas for real-time data synchronization and scalability.

II. LITERATURE REVIEW

The automation of library management systems has been widely studied, with most research focusing on the transition from manual processes to automated identification technologies.

A. RFID and Barcode Systems

Radio Frequency Identification (RFID) has been extensively utilized in library circulation and security systems. Kern (2004) [3] demonstrated that RFID technology reduces circulation time while improving anti-theft capabilities. Similarly, Breeding (2007) [4] highlighted the advantages of RFID over traditional barcode systems, particularly its ability to perform non-line-of-sight identification. However, RFID-based systems require significant infrastructure investment, including smart gates, RFID tags, and specialized readers. This high cost limits their adoption, especially in resource-constrained environments.

TABLE I
 COMPARATIVE ANALYSIS OF LIBRARY MANAGEMENT TECHNOLOGIES

Author / Standard	Technology Focus	Automation Level	Security Level
Kern (2004) [3]	RFID Gates & Active Tags	High	High (Anti-theft)
Breeding (2007) [4]	RFID vs Traditional Barcode	High	Medium
Walsh (2010) [1]	Standard Mobile QR Codes	Medium	Low (Plain-text)
ISO/IEC 18004 [6]	Base QR Symbology Standard	N/A	None (Unencrypted)
Proposed Work	Encrypted SQEM-QR	High	High (AES+HMAC)

B. Mobile Computing and QR Codes in Libraries

To overcome the cost limitations of RFID systems, researchers have explored mobile-based approaches utilizing QR codes. Walsh (2010) [1] proposed the use of QR codes in academic libraries, enabling students to access information using smartphones. Furthermore, Walsh (2011) [2] reported a high adoption rate of QR technology due to the widespread availability of mobile devices with camera capabilities. These studies demonstrate that QR-based systems are more cost-effective and easier to deploy compared to traditional methods.

C. Security Limitations in Existing QR-Based Systems Despite their advantages, QR-based systems lack inherent security mechanisms. Standard QR code symbology (ISO/IEC 18004:2015 [6]) treats QR codes as static data containers without encryption or dynamic validation capabilities. As a result, such systems are vulnerable to forgery, unauthorized duplication, and replay attacks. To address these limitations, this work introduces the Secure QR Encoding Model (SQEM), which integrates cryptographic techniques into QR-based workflows to enhance security while maintaining cost efficiency.

III. SYSTEM ARCHITECTURE

A. Architecture Overview

As shown in Fig. 1 below, the architecture of the suggested system consists of three major layers arranged according to the layered vertical pipeline approach. The three layers include an Android mobile application, a backend server, and cloud database. Transactions performed within the system pass through all layers, allowing ensuring the highest level of security and efficiency of operation.

B. User Interaction Layer

The system supports two types of users: students and administrators. Students interact with the application to perform A. Payload Creation operations such as issuing and returning books using QR code scanning. Administrators are responsible for managing book records and maintaining system data.

C. Android Application Layer

The Android mobile application serves as the primary interface between users and the system. It is composed of several internal modules:

- **UI Layer (Material Design):** Provides an intuitive and user-friendly interface for both students and administrators.
- **Authentication Module (SharedPreferences):** Manages user login sessions and stores authentication data using lightweight local storage.
- **QR Scanner (CameraX / ML Kit):** Enables real-time detection and decoding of QR codes using the smartphone camera.
- **SQEM Module (AES-256 / HMAC-SHA256):** Acts as the core security component of the system by decrypting QR code data using AES-256 and validating its integrity using HMAC-SHA256.
- **API Client (Retrofit):** Handles communication between the mobile application and the backend server by sending HTTP requests and receiving responses.

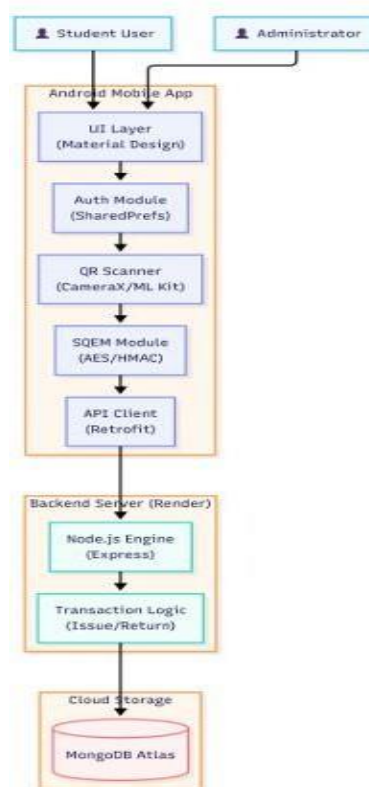


Fig. 1. System Architecture of the Proposed QR-Based Library Management System

D. Backend Server Layer

The backend server is hosted in a cloud environment and implemented using Node.js with the Express framework.

- **Node.js Engine (Express):** Processes incoming requests and manages communication with the database.
- **Transaction Logic (Issue/Return):** Implements core functionalities such as issuing and returning books, while verifying book availability before executing transactions.

E. Cloud Storage Layer

MongoDBAtlas is used as the cloud-based NoSQL database in the proposed system. It stores user data, book information, and transaction records, and supports real-time updates and scalability.



F. Workflow Description

The system workflow begins when a user scans a QR code using the Android application. The scanned data is decrypted and validated using the SQEM module. Once verified, the application sends a request to the backend server. The backend processes the request, executes the transaction logic, and updates the database accordingly. Finally, the system returns a response to the client application, indicating the success or failure of the operation

IV. SECURE QR ENCODING MODEL (SQEM)

The Secure QR Encoding Model (SQEM) is proposed to ensure confidentiality, integrity, and authenticity of payloads embedded within QR codes. Unlike standard QR implementations, which are vulnerable to duplication and replay attacks, SQEM incorporates cryptographic mechanisms to enhance data security.

A. Payload Creation

Let B denote the unique Book ID, T the timestamp representing the QR code generation time, and N a randomly generated nonce to ensure uniqueness. The payload is constructed as:

$$P = B \parallel T \parallel N \quad (1)$$

where \parallel denotes the concatenation operation.

B. Data Encryption

The payload P is encrypted using AES-256 symmetric encryption with a secret key K_{enc} and an initialization vector IV :

$$C = E_{K_{enc}}(P, IV) \quad (2)$$

This step ensures confidentiality of the QR data.

C. Integrity Assurance

To ensure data integrity, a Message Authentication Code (MAC) is generated using the HMAC-SHA256 algorithm:

$$S = H_{MAC_{K_{mac}}}(C) \quad (3)$$

where K_{mac} is the secret key used for MAC generation.

D. QR Code Creation

The final QR payload consists of the encrypted data and its corresponding MAC:

$$QR = \text{Base64}(C \parallel S) \quad (4)$$

This encoded data is embedded into the QR code and displayed on the book.

E. Security Analysis

The combination of timestamp T and nonce N ensures the uniqueness of each QR code, thereby mitigating replay attacks. AES-256 encryption provides confidentiality, while HMAC SHA256 ensures data integrity and prevents tampering. Together, these mechanisms enhance the overall security of the system and restrict unauthorized access.

V. EXPERIMENTAL RESULTS

Performance testing of the SQEM-QR system was performed with respect to traditional manual and barcode-based library management systems. In order to ensure accuracy and reliability of the results, a total of 200 transactions were conducted. The evaluation focuses on three key performance indicators: transaction time, error rate, and infrastructure cost. Results demonstrate the high performance of the proposed method. The average transaction time in manual systems is 255.4 seconds, which is reduced to 90.0 seconds in barcode based systems. In contrast, the proposed SQEM-QR system completes transactions in just 22.1 seconds. This significant reduction highlights the improved efficiency achieved through automation.

TABLE II
 PERFORMANCE COMPARISON OF LIBRARY MANAGEMENT SYSTEMS

Metric	Manual Method	Barcode System	SQEM-QR (Ours)
Avg. Issue Time	255.4 sec	90.0 sec	22.1 sec
Error Rate	32.0%	5.0%	0.4%
Infrastructure Cost	INR 0	INR 100000	INR 4500

When discussing errors, manual systems exhibit a 32.0% error rate due to human input inaccuracies. This error rate is reduced to 5.0% in barcode-based systems. The proposed SQEM-QR system further minimizes errors to just 0.4%, demonstrating the effectiveness of automated QR-based transactions combined with secure validation mechanisms.

Fig. 2 illustrates the transaction time comparison. It clearly shows that the proposed system achieves significantly faster processing compared to both manual and barcode systems. Analysis of infrastructure costs further highlights the advantages of the proposed system. Manual systems involve negligible setup costs but suffer from inefficiencies. Barcode systems require substantial investment, approximately INR 100000, due to specialized hardware. In contrast, the proposed system requires only INR 4500, making it a cost-effective alternative.

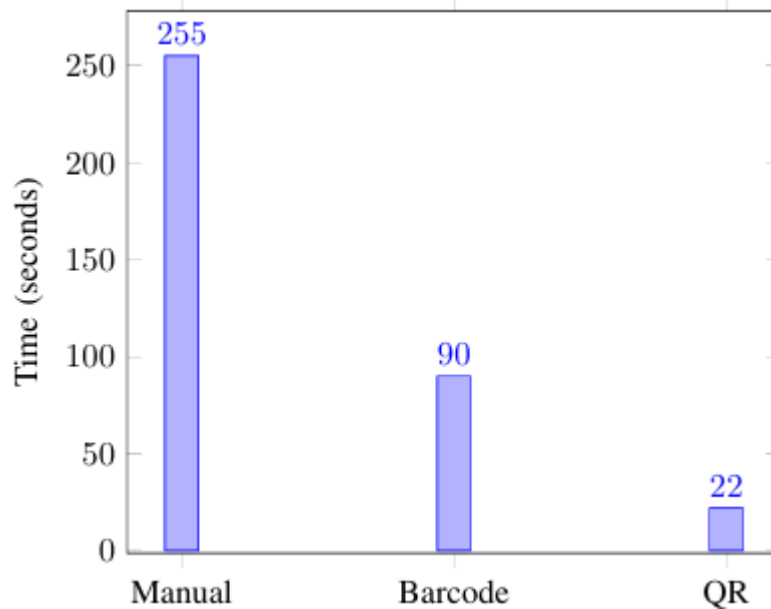


Fig. 2. Comparison of Transaction Time Across Systems

Fig. 3 shows the reduction in error rates, indicating improved system reliability and accuracy.

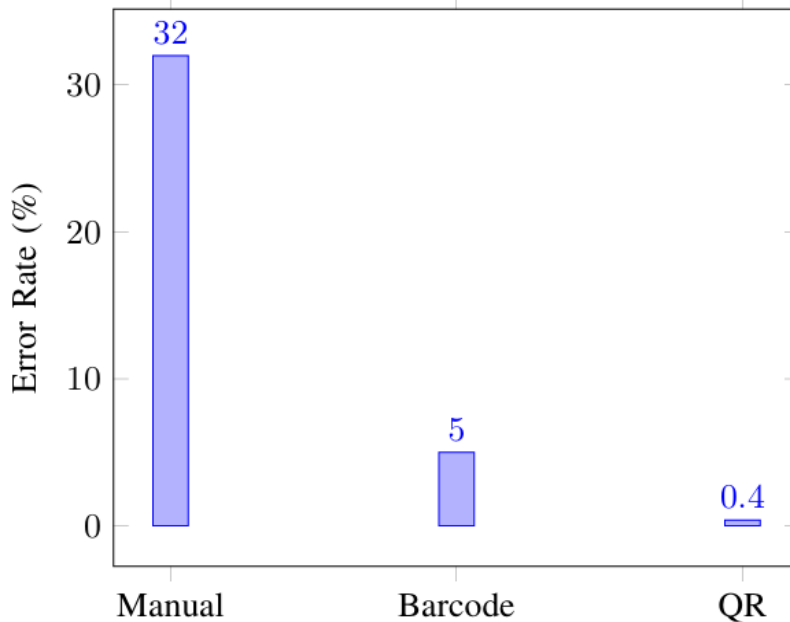


Fig. 3. Error Rate Comparison

Graphical representations support the obtained results. The transaction time graph confirms faster processing, the error rate graph shows improved accuracy, and the cost graph highlights reduced expenses. In summary, the experimental results demonstrate that the proposed SQEM-QR system provides higher efficiency, improved accuracy, and lower infrastructure cost. Therefore, it represents a practical and scalable alternative to traditional manual and barcode-based library management systems.

Fig. 4 demonstrates the cost efficiency of the proposed system compared to traditional approaches.

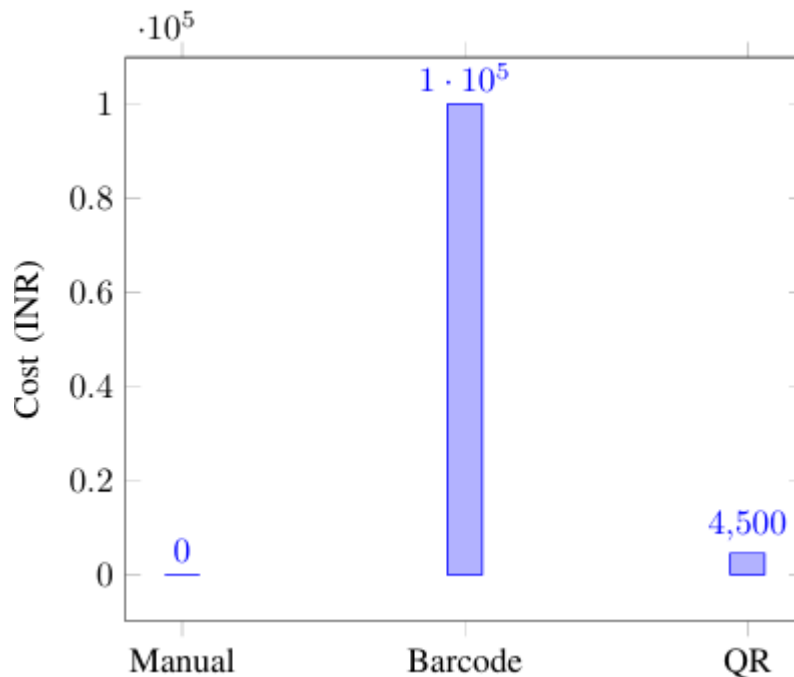


Fig. 4. Infrastructure Cost Comparison



VI. LIMITATIONS

The proposed SQEM-QR model, although highly efficient in improving both performance and security, has certain limitations that must be considered:

- **Dependence on Internet Connectivity:** The model relies on a stable internet connection for real-time communication with the cloud server. In scenarios where network connectivity is weak or unavailable, delays in transaction processing may occur, affecting system performance.
- **Hardware Requirements:** The system requires users to have smartphones equipped with cameras capable of scanning QR codes. Users with outdated devices or low-quality cameras may face difficulties in accurately scanning QR codes.
- **Platform Dependence:** The current implementation is primarily designed for the Android platform, which limits accessibility for users operating on other platforms.
- **Absence of Offline Mode:** The system does not currently support offline operations. In the absence of network connectivity, users are unable to perform transactions such as issuing or returning books.

VII. FUTURE WORK

Several enhancements can be implemented to further improve the functionality and scalability of the proposed system:

- **Support for Multiple Platforms:** Future work can focus on extending the system to support multiple platforms, including Android, iOS, and other mobile operating systems, to increase accessibility.
- **Automated Fine Calculation and Collection:** Integration of a digital payment gateway can enable automatic calculation and collection of fines for overdue books, reducing administrative overhead.
- **Machine Learning-Based Book Recommendations:** Incorporating machine learning algorithms to analyze user borrowing patterns can enable personalized book recommendations, improving user engagement.
- **Offline Mode Integration:** Introducing offline functionality with later synchronization can allow users to perform transactions without internet access.
- **Enhanced Security Mechanisms:** Future improvements may include advanced authentication methods such as biometric verification to strengthen system security.

VIII. CONCLUSION

A scalable, cost-effective, and secure QR-based approach for modern library management has been presented in this paper. To address the security limitations of conventional QR based systems, the proposed Secure QR Encoding Model (SQEM) incorporates cryptographic techniques, including AES-256 encryption and HMAC-SHA256 hashing. Experimental results demonstrate that the proposed system significantly outperforms traditional approaches. The transaction time is reduced to 22.1 seconds compared to 255.4 seconds and 90.0 seconds in manual and barcode-based systems, respectively. In addition, the system achieves a high level of accuracy with an error rate of only 0.4%. Furthermore, the infrastructure cost is substantially lower than that of RFID based systems. Overall, the proposed SQEM-QR system provides an efficient, secure, and scalable solution for modern library management. Its mobile-centric architecture enables easy deployment across diverse environments. Future work may focus on cross platform compatibility, offline functionality, and the integration of intelligent recommendation systems.

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