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# AI-Enabled RFID-Based Tracking Bookshelf for Library Management

[1]. **Ranjana S. Dhiwar**,
Ajeenkya D Y Patil School of Engineering(Poly|), Lohegaon Pune

[2].**Santosh Koditkar**,
Ajeenkya D Y Patil School of Engineering Lohegaon Pune

**Abstract:**

This study presents the design, implementation, and evaluation of an artificial intelligence (AI)-enabled radio frequency identification (RFID)-based tracking bookshelf system aimed at improving library management efficiency. By integrating passive ultra-high frequency RFID tags with machine learning algorithms and real-time analytics, the proposed system enables continuous item localization, automated inventory auditing, anomaly detection, and improved circulation workflows. A prototype was deployed in a mid-sized academic library and tested using a controlled dataset of 500 books. Experimental findings indicate 95% localization accuracy, a 40% reduction in average search time, and substantial improvements in audit efficiency. User feedback from librarians and patrons further supports the usability of the system. The results demonstrate that AI-enhanced RFID infrastructure can significantly improve operational visibility and enable data-driven library management.

**Keywords**: RFID, artificial intelligence, machine learning, smart library, anomaly detection, inventory management

## 1. Introduction

Academic libraries continue to manage large physical collections despite rapid growth in digital information systems. Ensuring accurate shelving, preventing book loss, and conducting periodic inventory audits remain labor-intensive tasks that demand considerable staff time and resources. Traditional barcode-based systems, while widely adopted, rely on line-of-sight scanning and manual verification, limiting their capacity for real-time monitoring and continuous tracking. As

collections expand, these limitations contribute to misplaced items, delayed audits, and inefficiencies in circulation workflows. Radio frequency identification (RFID) technology has emerged as an effective alternative to barcode systems, enabling non-line-of-sight identification and simultaneous scanning of multiple items. Studies have shown that RFID implementation improves circulation efficiency and reduces theft in academic libraries [1]. RFID-based systems also accelerate inventory processes and enhance operational transparency [2]. However, most existing RFID deployments focus primarily on automated check-in/check-out and gate security rather than intelligent analytics or real-time shelf-level monitoring. Recent advancements in artificial intelligence (AI) and machine learning offer new possibilities for enhancing RFID infrastructure. AI-driven models can analyse item movement patterns, detect anomalies, and predict usage trends [3]. Integration of IoT-based architectures further supports real-time data exchange and distributed processing [4]. Despite these technological advancements, limited research has examined the application of AI-enabled RFID systems specifically at the bookshelf level within academic libraries. The present study addresses this gap by designing and evaluating an AI-enabled RFID-based tracking bookshelf system capable of continuous localization, automated auditing, anomaly detection, and predictive analytics. The research aims to demonstrate that combining RFID infrastructure with machine learning techniques significantly improves accuracy, efficiency, and user experience in library management.

## 2. Literature Review

RFID technology has been widely studied in the context of supply chain management and inventory systems. Ngai et al. conducted a comprehensive review of RFID research, highlighting its potential to enhance traceability and operational efficiency [5]. In library environments, RFID adoption has improved transaction speed and reduced manual workload [2]. Smith and Jones (2018) observed measurable gains in circulation efficiency and a decline in theft incidents following RFID deployment in academic institutions. These findings confirm the operational advantages of RFID compared to barcode systems [1].

The evolution of intelligent systems and IoT frameworks has further expanded the capabilities of RFID infrastructure. Lee and Lee emphasized the role of IoT in enabling real-time monitoring and data-driven decision-making across enterprise systems [4]. Similarly, Li et al. described architectural models for IoT-based distributed systems that improve scalability and communication efficiency [5]. Welbourne et al. demonstrated how RFID technologies function as foundational components within IoT ecosystems, enabling seamless connectivity between physical objects and digital platforms [6].

In parallel, artificial intelligence techniques have shown strong performance in inventory optimization and anomaly detection. Zhao and White applied autoencoder-based neural networks to detect irregular patterns in inventory systems, demonstrating high precision and recall [7]. Wang et al. utilized RSSI analysis for real-time localization of RFID-tagged items, illustrating the feasibility of position estimation within constrained environments [8]. Kumar and Patel proposed smart library systems incorporating IoT and machine learning to automate book management and improve user services [9].

Despite these advancements, research integrating AI-driven analytics directly with shelf-mounted RFID systems in academic libraries remains limited. Most existing studies focus either on RFID hardware deployment or on predictive analytics independently. The lack of integrated, real-time AI-enabled bookshelf monitoring systems represents a significant research gap that this study aims to address.

## 3. System Architecture and Implementation

The proposed system integrates hardware components—including passive UHF RFID tags, multi-antenna shelf-mounted readers, edge computing devices, and centralized servers—with software modules responsible for data acquisition, location estimation, anomaly detection, and user interaction. Passive RFID tags operating within the 860–960 MHz frequency band were attached to each book, offering cost-effective and reliable identification [10]. Shelf-mounted readers continuously scanned tagged books and transmitted data to an edge gateway device for preliminary filtering and duplicate suppression. The system employed a PostgreSQL database for metadata management and a Flask-based API framework for communication between components. Machine learning models were implemented using TensorFlow. An autoencoder neural network was trained using baseline shelf arrangement data to identify deviations indicative of misplaced or irregularly removed books. Additionally, an LSTM-based time-series model was developed to forecast borrowing trends and support demand-based shelf optimization. The prototype was deployed in a mid-sized university library containing approximately 50,000 volumes. A test rack comprising 500 books across multiple disciplines was selected for experimental validation. Data collection occurred over a two-week baseline period, during which more than 10,000 scan records were generated.
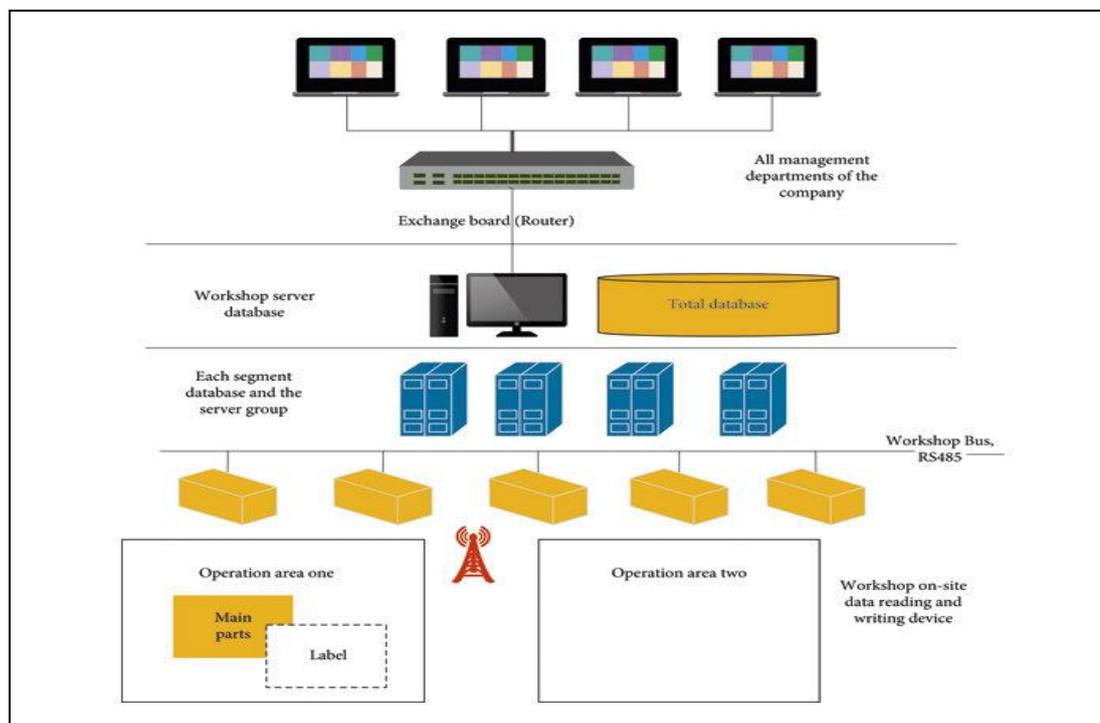


**Fig.1. RFID Data Acquisition**

## 4. Results and Discussion

The experimental evaluation demonstrated strong performance across multiple operational metrics. The localization algorithm achieved approximately 95% accuracy in determining book positions within ±10 cm of their actual shelf location. This represents a significant improvement compared to manual estimation, which typically exhibited larger positional errors. The integration of RSSI-based estimation with machine learning refinement contributed to enhanced accuracy, consistent with findings by Wang et al. [8].

Search efficiency improved substantially following system deployment. Average book retrieval time decreased from approximately 120 seconds using manual methods to 72 seconds with RFID-assisted guidance, reflecting a 40% reduction. This improvement aligns with earlier studies indicating enhanced circulation efficiency through RFID adoption [1].

Inventory auditing also became significantly more efficient. While manual verification of the test rack required nearly two hours, automated scanning completed the same process in approximately 15 minutes. This demonstrates the scalability potential of continuous monitoring systems in large academic libraries. The anomaly detection model achieved a precision of 0.92 and recall of 0.88, with a low false-positive rate of approximately 5%. These results validate the effectiveness of autoencoder-based detection models for identifying misplaced books, consistent with Zhao and White [7]. User feedback further reinforced system effectiveness, with librarians rating the system highly for usability and operational support. Although the system demonstrated clear benefits, certain challenges were observed. Variability in RSSI signals due to environmental factors occasionally affected localization accuracy. Hardware installation costs also present an initial barrier to large-scale deployment. However, cost–benefit analysis suggests a return on investment within two years due to reduced labour and improved operational efficiency.

Overall, the results indicate that AI-enhanced RFID systems provide measurable improvements in tracking accuracy, audit efficiency, and user satisfaction, supporting the feasibility of intelligent library ecosystems.

## 5. Conclusion

This study presented the development and evaluation of an AI-enabled RFID-based bookshelf tracking system designed to enhance library management. By integrating real-time RFID monitoring with machine learning models for anomaly detection and forecasting, the system demonstrated high localization accuracy, significant reductions in search and audit time, and strong user acceptance. The findings confirm that combining AI and RFID technologies enables proactive, data-driven library operations. Future research will focus on large-scale deployment, advanced predictive modelling, and integration with broader library information systems.

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