An IoT-Based Smart Library Framework for Enhancing User Experience in Malaysian Higher Education

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ABSTRACT

The increasing adoption of digital technologies in higher education has accelerated the transformation of conventional libraries into smart learning environments that enhance operational efficiency and user experience. However, many academic libraries continue to face challenges such as misplaced books, limited visibility of study seat availability, and the inability to monitor in-library reading activities, resulting in inefficient resource management and increased staff workload. This study presents an Internet of Things (IoT)-based Smart Library Management System that integrates an ESP32 microcontroller, RFID RC522 modules, FSR402 pressure sensors, cloud computing, and a web-based dashboard to enable real-time monitoring and automation of library operations. RFID technology is employed to verify book locations and detect misplaced items, while pressure sensors monitor seat occupancy to provide users with real-time availability information. In addition, the system records the duration that books remain off the shelves to identify in-library reading activities, providing valuable insights into resource utilisation. Sensor data are transmitted via Wi-Fi to a cloud platform, enabling centralized monitoring of book status, seat occupancy, and library usage through an interactive dashboard. Prototype evaluation demonstrated reliable system integration with an average data transmission latency of approximately 180 ms, while the total prototype cost of RM121.54 demonstrates the feasibility of implementing a cost-effective smart library solution. To complement the technical evaluation, a user acceptance and usability survey involving 70 respondents indicated strong support for the proposed smart library features, particularly real-time seat occupancy monitoring and automated misplaced-book detection. Overall, the proposed framework provides a practical, scalable, and user-centred solution that supports Smart Campus initiatives by improving library services, enhancing operational decision-making, and promoting more efficient resource management in higher education institutions.

Keywords: Internet of Things (IoT), Smart Library, RFID, ESP32, Smart Campus, Library Management, Real-Time Monitoring.

INTRODUCTION

Academic libraries play a fundamental role in supporting teaching, learning, and research by providing equitable access to academic resources, collaborative learning spaces, and digital information services. As higher education institutions continue to undergo digital transformation, libraries are expected to evolve beyond their traditional role as repositories of printed materials into intelligent learning environments that support efficient resource management and enhanced user experiences. This transformation is closely aligned with Smart Campus initiatives, where Internet of Things (IoT) technologies, cloud computing, and data-driven decision-making are increasingly adopted to improve institutional services and operational efficiency [1], [2].

Despite these developments, many academic libraries continue to rely on conventional library management systems that primarily record borrowing and returning transactions. While Online Public Access Catalog (OPAC) systems enable users to search for library collections, they generally cannot verify the actual physical location of books on library shelves. Consequently, books that are incorrectly returned to the wrong location may still appear as "available" in the digital catalogue even though they cannot be located physically. This phenomenon, commonly referred to as the phantom book problem, reduces service quality, increases the time users spend searching for materials, and creates additional workload for library staff responsible for manual shelf inspections [3], [4].

In terms of inventory management challenges, academic libraries also face increasing pressure to optimise the utilisation of study spaces. During peak periods, students often spend considerable time searching for available seats because occupancy information is not monitored or updated in real time. Furthermore, most conventional library management systems record only borrowing transactions and do not capture books that are temporarily removed from shelves for in-library reading. Consequently, library administrators have limited information regarding actual resource utilisation, reading behaviour, and space usage, restricting their ability to make informed decisions on collection management and facility planning [5], [6].

Recent advances in IoT technology have created new opportunities to modernise library operations through the integration of RFID systems, embedded devices, wireless communication, cloud computing, and web-based monitoring platforms. RFID technology has been widely recognised as an effective solution for automatic identification and inventory tracking because it enables contactless detection, reduces manual processing, and improves inventory accuracy compared with conventional barcode systems [4], [7]. Similarly, cloud-enabled smart library platforms provide continuous synchronisation between sensing devices and management dashboards, allowing administrators to monitor library resources remotely and respond more efficiently to operational issues [8], [9].

Although previous studies have demonstrated the potential of IoT-enabled library management systems, most existing solutions address only specific operational functions. Some studies focus primarily on RFID-based inventory management, while others concentrate on seat occupancy monitoring or automated circulation services. Few systems integrate these functions into a unified platform capable of simultaneously monitoring book placement, study space availability, and in-library resource utilisation. In addition, existing systems rarely distinguish between borrowed books and books that remain within the library for reference purposes, resulting in incomplete information on user behaviour and resource usage [3], [5], [8].

To address these limitations, this study proposes an Internet of Things (IoT)-based Smart Library Management System that integrates RFID technology, FSR402 pressure sensors, an ESP32 microcontroller, cloud-based communication, and a web-based dashboard into a unified monitoring platform. The proposed system automatically verifies book placement, detects misplaced books, records in-library reading activities based on book removal duration, and monitors seat occupancy in real time. Sensor data are transmitted through Wi-Fi to a cloud database, enabling library administrators to access current operational information through a centralized dashboard.

Compared with existing smart library solutions, the proposed framework offers a more comprehensive approach by integrating resource tracking, occupancy monitoring, and usage analytics within a unified IoT ecosystem. Besides improving operational efficiency through automated monitoring and real-time analytics, the proposed framework was designed based on identified operational challenges and user requirements collected through a survey involving potential library users. Incorporating user perspectives during the system design process ensures that the proposed features address actual operational needs rather than purely technical requirements. Furthermore, the use of affordable and commercially available hardware components demonstrates that smart library technologies can be implemented cost-effectively, making the framework suitable for higher education institutions seeking to support Smart Campus initiatives and accelerate digital transformation [2], [8], [10].

Accordingly, this study aims to design, develop, and evaluate an IoT-based Smart Library Management System capable of improving library operations through real-time monitoring and automation. Specifically, the proposed system seeks to enhance the accuracy of book tracking, automate the detection of misplaced books, monitor seat occupancy, and provide analytical information on in-library resource utilisation. In addition to evaluating the technical performance of the developed prototype, this study also examines user acceptance and perceived usefulness through a user acceptance and usability survey involving 70 respondents comprising students, public users, and library personnel. The findings are expected to contribute to the development of more efficient, accessible, and user-centred library services while supporting the broader digital transformation agenda of Malaysian higher education institutions.

Related Works

The integration of Internet of Things (IoT) technologies into library management has received increasing attention in recent years as academic libraries seek to improve operational efficiency, resource accessibility, and user experience. The emergence of smart libraries has shifted the focus of library management from conventional circulation systems toward intelligent environments that integrate RFID technology, cloud computing, embedded systems, and real-time analytics to support evidence-based decision-making and digital transformation [4], [5].

One major area of research has focused on RFID-enabled inventory management. RFID technology has been widely adopted because it enables automatic identification of library materials without requiring direct line-of-sight scanning, thereby improving inventory accuracy and reducing manual workload. Arfan [1] reported that RFID significantly enhances library management efficiency by simplifying book identification and tracking processes while reducing human errors associated with conventional barcode systems. Similarly, Suhaimi et al. [7] demonstrated that RFID-based library systems improve inventory management by automating resource tracking and minimizing manual shelf inspections. Nevertheless, both studies primarily concentrated on inventory management and did not integrate real-time occupancy monitoring or cloud-based analytical functions.

Recent studies have extended RFID applications through the integration of IoT technologies. Poornima et al. [5] developed an IoT-enabled smart bookshelf capable of automatically monitoring book placement and synchronizing inventory information with a cloud platform. Their findings demonstrated that real-time synchronization reduces the need for manual shelf inspections and improves the accuracy of inventory records. Likewise, Apeksha et al. [2] proposed an IoT-based library management framework that combined embedded systems with centralized database management to automate library operations. Although these studies demonstrated the benefits of IoT integration, their systems mainly focused on inventory automation and provided limited support for detecting misplaced books or analysing in-library resource utilisation.

Another important research direction involves the development of smart library infrastructures within Smart Campus ecosystems. Sungkur et al. [6] demonstrated that IoT-enabled library services can improve information accessibility and facilitate centralized monitoring across university campuses. Similarly, Zhou [9] proposed a smart library architecture that integrates IoT devices with Software Defined Networking (SDN) to improve communication efficiency and scalability. These studies highlight the importance of integrating intelligent technologies into library management; however, they provide limited discussion on practical mechanisms for validating book placement, monitoring user activities, or supporting operational decision-making through integrated analytics.

In addition to inventory management, several researchers have investigated intelligent monitoring of library facilities. Xu et al. [8] developed a smart seat management system capable of providing real-time occupancy information, enabling users to locate available study spaces more efficiently. While the system successfully improved space utilization, it operated independently of library inventory management and therefore could not provide a comprehensive view of library operations. Consequently, administrators were still required to rely on separate systems to manage physical resources and facility utilisation.

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The literature also indicates a growing emphasis on cloud computing and real-time monitoring for educational environments. Cloud-based architectures enable continuous synchronization between sensing devices and management dashboards, allowing administrators to monitor library conditions remotely while supporting data-driven decision-making [9], [10]. Nevertheless, existing implementations generally focus on individual operational components, such as inventory management, circulation services, or occupancy monitoring, rather than integrating these functions within a unified platform.

Overall, previous studies demonstrate that IoT technologies have significantly improved library management through RFID-based automation, cloud communication, and intelligent monitoring. However, three important research gaps remain. First, most existing systems focus on either inventory management or occupancy monitoring without integrating both functions into a single platform. Second, limited attention has been given to detecting misplaced books through continuous shelf validation, despite the operational impact of the phantom book problem. Third, existing systems rarely capture books used within the library without formal borrowing transactions, resulting in incomplete information on resource utilisation and user behaviour. Table 1 summarize the comparison of selected existing smart library systems.

Table 1. Comparison of Existing Smart Library Systems

Reference	**Main Technology**	**Key Contribution**	**Research Gap**
Arfan [1]	RFID	Improved book identification and inventory tracking	No occupancy monitoring or analytics
Apeksha *et al.* [2]	IoT, Database	Barcode-based book issuing and automated library management	Not RFID-based shelf monitoring And no misplaced-book detection
Poornima *et al.* [5]	RFID, IoT, Cloud	Smart bookshelf with real-time synchronization	No seat monitoring or reading analytics
Sungkur *et al.* [6]	RFID, IoT, Cloud	Centralized campus-wide library monitoring	Limited misplaced-book detection
Suhaimi *et al.* [7]	RFID	Evaluate RFID reader angle, reader performance, and reading accuracy	No reading analytics and occupancy monitoring
Xu *et al.* [8]	Smart Seating	Real-time seat occupancy monitoring	Not integrated with inventory management
Zhou [9]	IoT, SDN	Smart library architecture for scalable communication	Limited operational analytics and resource tracking

To address these limitations, this study proposes an integrated IoT-based Smart Library Management System that combines RFID-enabled book validation, real-time seat occupancy monitoring, cloud-based dashboard visualization, and reading activity analytics within a single platform. Unlike previous studies, the proposed framework simultaneously supports inventory management, facility monitoring, and usage analytics, providing library administrators with comprehensive operational insights while contributing to the development of smarter learning environments in Malaysian higher education institutions.

METHODOLOGY

This study employed a prototype-based design and development approach combined with a user-centred evaluation to develop and assess an Internet of Things (IoT)-based Smart Library Management System for improving resource management and service delivery in academic libraries. The research consisted of two complementary phases. The first phase focused on the design, development, and functional validation of the proposed IoT prototype integrating RFID technology, FSR402 pressure sensors, embedded computing, cloud communication, and a web-based dashboard. The second phase involved a user acceptance and usability survey to identify operational challenges, assess perceived usefulness, and evaluate users' acceptance of the proposed smart library features. Combining prototype development with user evaluation provides both technical validation and practical evidence regarding the suitability of the proposed framework for implementation in Malaysian higher education libraries [11], [12].

The overall research methodology consisted of five major stages: (i) User requirements and problem identification, (ii) System architecture design, (iii) Hardware and embedded system development, (iv) Cloud-based data management, and (v) System integration, functional testing, and user acceptance evaluation. These stages ensured that the proposed framework was developed based on actual user requirements while simultaneously validating the technical functionality and perceived usefulness of the system.

User Requirements Survey

Prior to the prototype implementation, a user acceptance and usability survey was conducted to identify the operational challenges experienced by academic library users and to determine the desired functionalities of a smart library system. A structured questionnaire was distributed online using Google Forms, and a total of 70 respondents comprising students, public users, and library personnel participated in the survey. The questionnaire covered six aspects, namely respondent background, misplaced book issues, in-library reading behaviour, study space management, proposed IoT features, and overall user feedback. The collected responses were analysed using descriptive statistics and were subsequently used to guide the design priorities and feature integration of the proposed Smart Library Management System.

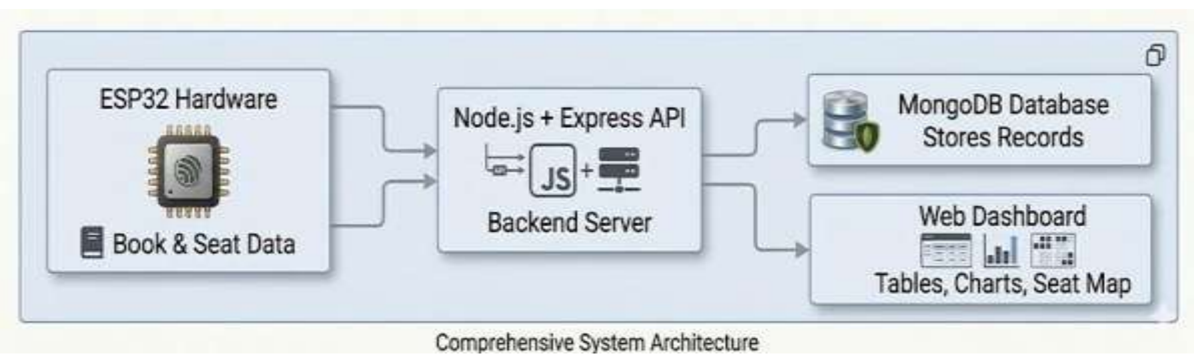
System Architecture

The overall architecture of the proposed Smart Library Management System shown in Figure 1. It adopts a layered IoT architecture consisting of four interconnected components: the sensing layer, communication layer, cloud platform, and application layer. Such an architecture is widely adopted in IoT-based monitoring systems because it enables efficient acquisition, transmission, storage, and visualization of real-time information [9], [11].

At the sensing layer, RFID RC522 readers continuously monitor the presence and location of books, while FSR402 force-sensitive resistors detect seat occupancy. An ESP32 microcontroller functions as the edge computing device, collecting sensor data and transmitting the information through a wireless network.

The communication layer transfers sensor data to a backend server developed using Node.js and Express.js. The backend processes incoming requests before storing validated information in a MongoDB database. Finally, the application layer consists of a web-based dashboard that provides administrators with real-time information on book locations, misplaced books, seat occupancy, and reading activity statistics. This architecture supports centralized monitoring while minimizing manual intervention in daily library operations [6], [9].

Figure 1. Overall architecture of the proposed Smart Library Management System.



Hardware Development

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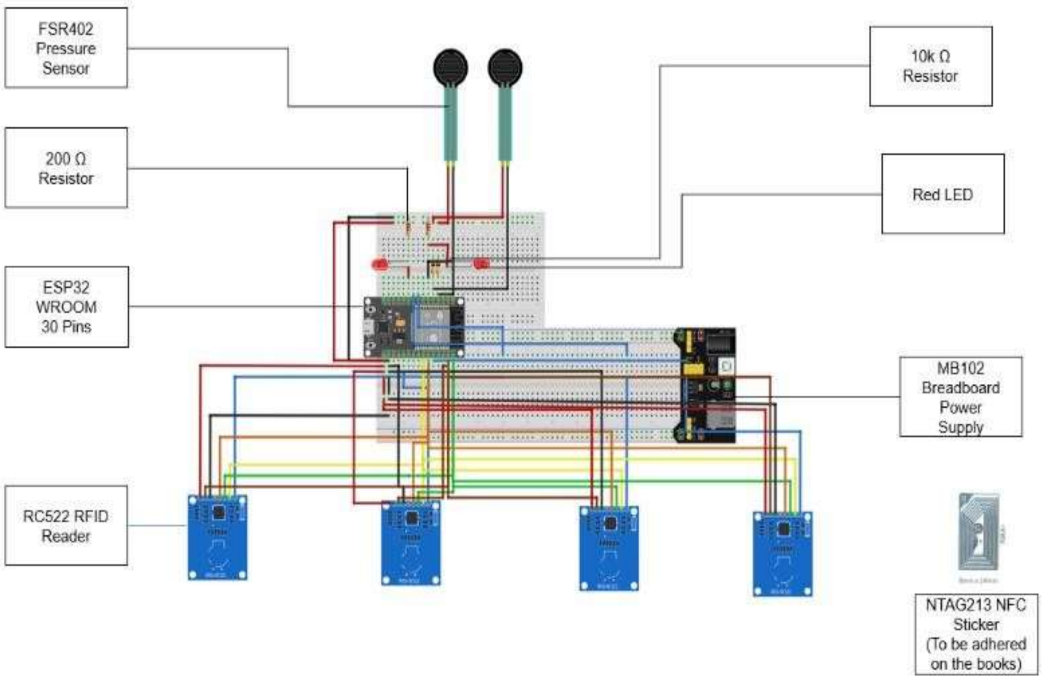
The prototype was developed using commercially available and low-cost components to demonstrate the feasibility of implementing an affordable smart library solution. The ESP32 microcontroller was selected because it combines sufficient processing capability with integrated Wi-Fi connectivity, making it suitable for IoT applications requiring continuous communication with cloud platforms [11].

Four RFID RC522 modules were installed beneath individual bookshelf sections to identify books according to predefined categories. RFID technology was selected because it enables contactless identification, improves inventory accuracy, and reduces manual inspection compared with conventional barcode systems [1], [7]. Two FSR402 pressure sensors were installed beneath library chairs to detect seat occupancy through pressure changes, allowing real-time monitoring of study space availability [8]. Figure 2 shows the schematic diagram for hardware development.

Figure 2. Schematic diagram for hardware development.



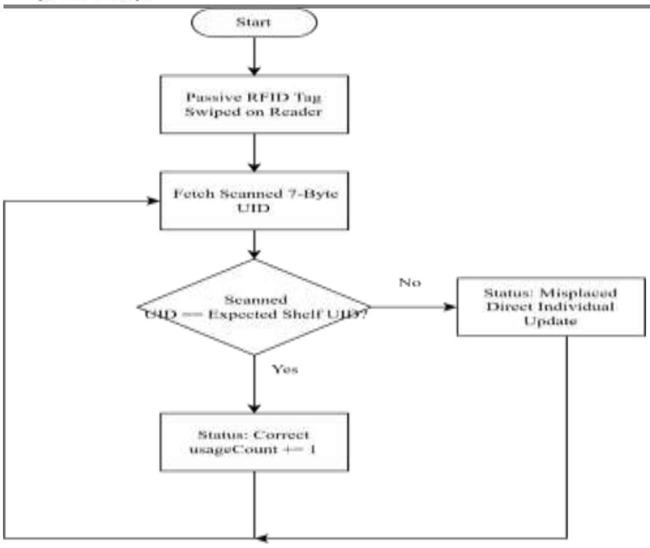
The complete prototype was developed with a material cost of approximately RM121.54, demonstrating that the proposed framework can be implemented using affordable hardware without compromising monitoring capability. This characteristic increases the potential for adoption by higher education institutions with limited financial resources.

The selection of hardware components and system functionalities was further supported by the user requirements survey, which identified real-time seat occupancy monitoring, misplaced book detection, and web-based accessibility as the most preferred features among respondents.

System Operation

The proposed system continuously monitors both library resources and study spaces through firmware executed on the ESP32 microcontroller. During operation, each RFID reader periodically scans its assigned bookshelf and compares the detected RFID tag with the predefined shelf assignment to determine whether a book is correctly positioned or misplaced. This process is shown in Figure 3.

Figure 3. Decision process for RFID-based book validation and misplacement detection.



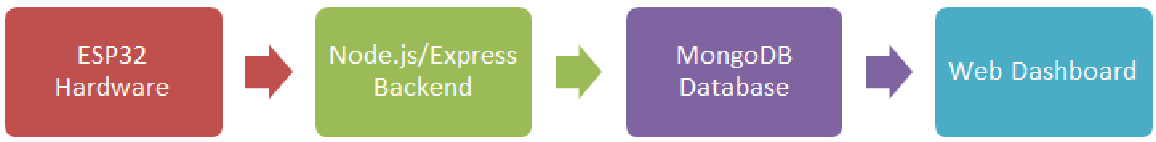
To improve understanding of library resource utilization, the firmware also records the duration that a book remains absent from its designated shelf. Books removed for less than three seconds are interpreted as temporary handling, whereas books remaining absent for more than eight seconds are classified as in-house reading activities. Unlike conventional library management systems that record only borrowing transactions, this mechanism provides additional information regarding books used within the library without formal circulation records.

Seat occupancy is monitored independently using FSR402 pressure sensors connected to the analog inputs of the ESP32. Once the measured sensor value exceeds the predefined threshold, the seat status changes automatically from “Available” to “Occupied”, and the updated information is transmitted immediately to the cloud platform. This enables users and library administrators to obtain real-time information on study space availability while supporting more efficient facility utilization [8], [9].

Data Management and Monitoring

All validated sensor data are transmitted through Wi-Fi to a cloud-based backend developed using Node.js and Express.js. The backend processes incoming requests, updates the MongoDB database, and provides Application Programming Interfaces (APIs) that enable communication with the web dashboard. This workflow is shown in Figure 4. Furthermore, cloud-based architectures have been widely adopted in IoT applications because they provide scalable storage, centralized management, and real-time accessibility across multiple devices [9], [13].

Figure 4. General workflow of the proposed Smart Library Management System.



The web dashboard presents operational information through interactive tables, summary indicators, and graphical visualizations showing book availability, misplaced books, seat occupancy, and reading activity trends. Functional testing was conducted to verify RFID detection, seat occupancy monitoring, cloud synchronization, and dashboard responsiveness. In addition to the technical evaluation, user acceptance findings obtained from the questionnaire survey were analysed to determine whether the proposed system functionalities corresponded to users' operational requirements and expectations. This combined evaluation provides both technical and user-centred perspectives on the feasibility of the proposed Smart Library Management System.

RESULTS AND DISCUSSION

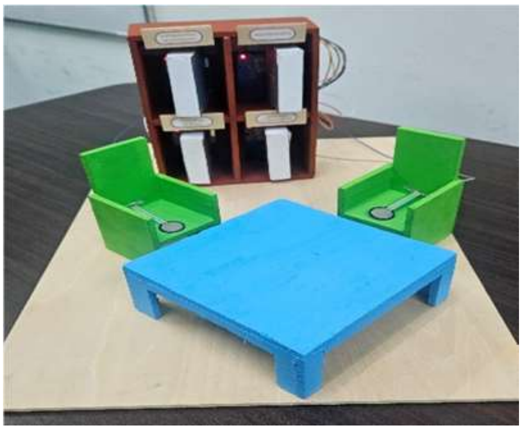
Prototype Development and System Integration

The proposed Smart Library Management System was successfully developed as a functional IoT prototype integrating RFID technology, FSR402 pressure sensors, cloud computing, and a web-based dashboard as shown in Figure 5. The successful integration of these components demonstrates the feasibility of implementing a unified platform capable of simultaneously monitoring library resources and study space utilisation in real time. Throughout functional testing, the sensing devices, embedded controller, cloud platform, and dashboard communicated reliably, enabling continuous acquisition and visualisation of operational data.

The prototype consists of RFID-enabled bookshelves, pressure-sensitive seating modules, an ESP32 microcontroller, and a cloud-based monitoring platform connected through a wireless network. Despite being developed using commercially available and low-cost hardware, the system maintained stable communication throughout testing and successfully synchronized sensor information with the cloud database. This demonstrates that affordable IoT technologies can provide practical solutions for improving library management without requiring expensive commercial systems.

The successful system integration confirms the practicality of adopting IoT technologies in academic libraries, particularly for institutions seeking cost-effective approaches to support Smart Campus initiatives and digital transformation programmes.

Figure 5. The prototype of the Smart Library Management System.



RFID-Based Book Monitoring Performance

The RFID-based monitoring subsystem successfully identified books according to their predefined shelf locations and automatically distinguished between correctly placed and misplaced books. Whenever a book was returned to the wrong shelf, the system immediately updated its status as “Misplaced”, enabling librarians to identify shelving errors without performing manual inspections. Conversely, correctly positioned books were automatically validated, ensuring consistency between the physical library collection and the digital inventory. The example of this monitoring process can be seen in Figure 6.

Real-time synchronization between RFID readers and the cloud database ensured that every change in book status was immediately reflected on the dashboard. The system also recorded book usage information based on shelf removal duration, allowing administrators to identify frequently accessed resources and better understand user reading patterns.

These findings demonstrate the effectiveness of combining RFID technology with cloud-based monitoring for inventory management. Similar improvements in inventory accuracy have been reported by Arfan [1], Suhaimi et al. [7], and Poornima et al. [5], who highlighted the advantages of RFID over conventional barcode systems. However, unlike previous studies that primarily focused on inventory management, the proposed framework extends RFID functionality by incorporating automated misplaced-book detection and in-library reading analytics, providing more comprehensive operational information for library administrators.

Figure 6. Real-time dashboard showing book validation and misplaced book detection.

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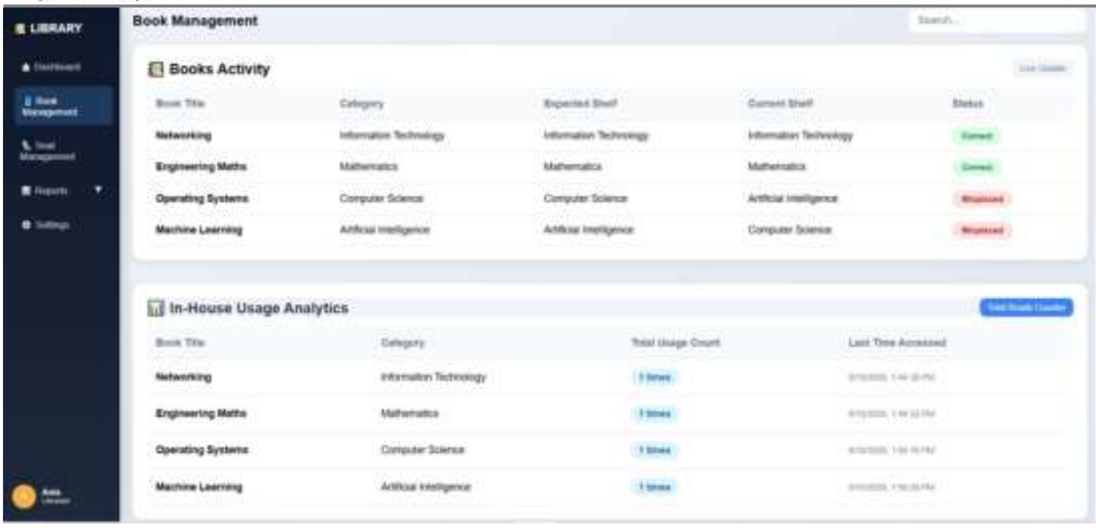


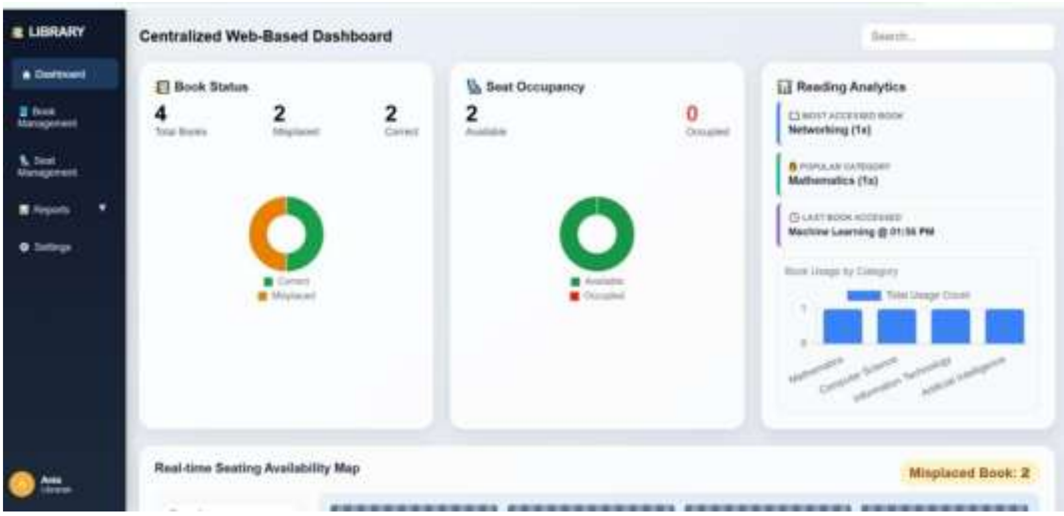
Dashboard Monitoring and Reading Activity Analytics

The developed web dashboard successfully centralized information collected from all sensing devices, providing administrators with real-time visualisation of book availability, seat occupancy, and library usage statistics as shown in Figure 7. During functional evaluation, dashboard information was updated automatically following every successful data transmission from the ESP32, demonstrating reliable synchronization between the hardware devices and cloud platform.

In addition to inventory monitoring, the dashboard generated analytical information regarding frequently accessed books, recent reading activities, and subject utilisation patterns. Such information provides valuable insights into user behaviour and enables evidence-based decisions regarding collection development, shelf arrangement, and library resource planning.

Unlike conventional library management systems that only record borrowing transactions, the proposed framework captures books temporarily removed from shelves for in-library reference. This additional functionality provides a more comprehensive representation of library resource utilisation and addresses one of the major limitations identified in previous smart library studies [2], [6]. Consequently, the proposed dashboard supports not only operational monitoring but also strategic planning for future library services.

Figure 7. Web-based dashboard displaying real-time library monitoring and usage analytics.



Real-Time Seat Occupancy Monitoring

The seat occupancy monitoring subsystem successfully detected seat usage using FSR402 pressure sensors and automatically updated seat status on the cloud dashboard as illustrated in Figure 8. Once pressure exceeding the

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predefined threshold was detected, the corresponding seat status changed immediately from “Available” to “Occupied”, providing users and library administrators with current information regarding study space availability.

The graphical dashboard displayed occupancy information through an intuitive colour-coded interface, allowing vacant and occupied seats to be identified quickly. This capability has practical implications for improving space utilisation, reducing unnecessary searching for available seating, and enhancing students' overall library experience.

Previous studies have demonstrated that sensor-based occupancy monitoring improves facility management in academic libraries [8]. However, these systems generally operate independently from inventory management platforms. In contrast, the proposed framework integrates seat occupancy monitoring with RFID-based book tracking and reading activity analytics, enabling administrators to manage both physical resources and learning spaces through a single monitoring platform.

Figure 8. Real-time seat occupancy monitoring interface.

User Acceptance and Usability Evaluation

To complement the technical evaluation, a user requirements and market survey was conducted to assess the acceptance, perceived usefulness, and practical demand for the proposed IoT-based Smart Library Management System. The survey involved 70 respondents, comprising predominantly university students (85.7%), followed by public users (12.9%) and a small proportion of library staff. Most respondents (75.7%) were between 18 and 24 years old, representing the primary user group of academic libraries.

The survey findings indicate that library users continue to experience difficulties in locating library resources. Approximately 70.0% of respondents reported that they had experienced situations where a book listed as available in the OPAC could not be located on the physical shelf, either frequently (22.9%) or occasionally (47.1%). Furthermore, 61.5% of respondents indicated that they spend more than five minutes searching for misplaced books, while 22.9% stated that they eventually give up searching altogether. These findings demonstrate the practical need for an automated book tracking system capable of identifying misplaced books in real time.

User perception towards library resource management was also highly positive. More than 94% of respondents agreed that monitoring books frequently used within the library would assist librarians in improving collection management. Additionally, respondents expressed considerable frustration regarding "phantom inventory," where books appear available in the catalogue but are missing from their expected shelf locations, with the majority assigning frustration scores of 4 or 5 on a five-point scale. These results further justify the implementation of RFID-based tracking and real-time inventory monitoring.

Regarding study space management, 82.9% of respondents reported having experienced situations where they could not find an available study seat despite visiting the library. Moreover, 88.6% indicated that they currently walk around the library manually to locate an empty seat, demonstrating the absence of an efficient occupancy monitoring mechanism. These findings support the integration of FSR sensors and a real-time occupancy dashboard within the proposed system.

The proposed IoT features also received strong support from respondents. A real-time web-based seat availability dashboard was identified as the most preferred feature by 81.4% of respondents, followed by real-time alerts for misplaced books (62.9%) and automated tracking of in-library reading statistics (52.9%). When asked which functionality they considered most important, 52.9% selected live seat availability monitoring, highlighting the importance of efficient space management in modern academic libraries.

Overall, the proposed system demonstrated a high level of user acceptance. 87.1% of respondents preferred having a physical bookshelf indicator to assist in locating misplaced books, while 75.7% believed that the proposed IoT-based Smart Library Management System would be more user-friendly than conventional manual library management methods. Furthermore, the open-ended feedback suggested additional functionalities such as room reservation reminders, desktop notifications for librarians, enhanced web-based book searching, and automatic book sorting. These recommendations provide useful directions for future system enhancement and indicate strong market interest in adopting smart library technologies within Malaysian higher education institutions.

DISCUSSION

The results demonstrate that the proposed Smart Library Management System successfully integrates RFID technology, IoT devices, cloud computing, and web-based analytics into a unified platform capable of supporting multiple aspects of library management. Functional evaluation confirmed reliable communication between sensing devices, the cloud platform, and the web dashboard, enabling continuous real-time monitoring of book placement, in-library reading activities, and study space utilisation. Unlike conventional library management systems that primarily record circulation transactions, the proposed framework provides a comprehensive operational view of library resources and facilities.

As shown in Table 2, existing smart library systems have successfully adopted technologies such as RFID, cloud-based dashboards, and IoT platforms to improve various aspects of library management. However, most previous studies focus on specific functionalities and do not provide a comprehensive solution that integrates multiple library services within a single framework. The proposed Smart Library Management System extends these existing capabilities by combining RFID-based book tracking, automated misplaced-book detection, real-time seat occupancy monitoring, in-library reading analytics, and cloud-based dashboard monitoring into a unified IoT platform. In particular, continuous shelf validation enables misplaced books to be detected automatically without requiring manual inspections, directly addressing the phantom book problem that frequently affects resource accessibility in academic libraries. Furthermore, the integration of real-time occupancy monitoring and reading activity analytics provides additional operational insights that are generally absent from existing systems. Collectively, these integrated features support more efficient resource management, improve operational decision-making, and enhance the overall user experience in academic libraries.

Table 2. Comparison with Previous Smart Library Implementations

Feature	Proposed System	Apeksha et al. [2]	Sungkur et al. [5]	Suhaimi et al. [6]
RFID-based book tracking	✓	✗	✓	✓
Barcode-based book management	✗	✓	✗	✗
Misplaced-book detection	✓	✗	✗	✓

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Real-time seat occupancy monitoring	✓	✗	✗	✗
In-library reading analytics	✓	✗	✗	✗
Cloud/Web dashboard	✓	✓	✓	✓
Unified monitoring platform	✓	✗	✓	✗
Low-cost implementation	✓	✓	Not emphasized	✓

Another important contribution of this study is the introduction of in-library reading activity analytics, which records books temporarily removed from shelves even when no formal borrowing transaction occurs. This functionality provides additional information on resource utilisation that is typically unavailable in conventional library management systems, enabling administrators to better understand user behaviour and optimise collection management.

From a practical perspective, the prototype demonstrates that a comprehensive smart library system can be implemented using affordable and commercially available hardware with a total development cost of approximately RM121.54. This cost-effective approach increases the potential for adoption by higher education institutions with limited financial resources while supporting Malaysia's Smart Campus agenda. Moreover, the use of readily available hardware components facilitates future maintenance and system expansion without requiring specialised infrastructure or proprietary technologies.

In addition to the prototype validation, the user acceptance survey further supports the practical relevance of the proposed framework. The majority of respondents reported experiencing difficulties in locating misplaced books and available study spaces, while more than three-quarters perceived the proposed IoT-based system as more user-friendly than existing manual practices. These findings indicate that the developed system addresses actual operational challenges encountered by library users rather than merely demonstrating technical functionality. Consequently, integrating user-centred requirements with IoT technologies enhances both the practicality and potential adoption of the proposed Smart Library Management System within Malaysian higher education institutions.

Although the developed prototype successfully demonstrated the technical feasibility and functional effectiveness of the proposed framework, several limitations should be acknowledged. The evaluation was conducted using a prototype-scale implementation within a controlled laboratory environment; therefore, factors such as long-term reliability, network scalability, environmental interference, maintenance requirements, and user behaviour under real operating conditions were not investigated. Future work should include pilot deployment in operational academic libraries to evaluate system performance over extended periods, assess user satisfaction following continuous use, and examine scalability across larger library environments. Furthermore, integrating mobile applications, predictive analytics, and artificial intelligence could enhance personalised library services, resource forecasting, and strategic decision-making.

CONCLUSION

This study presented the design and development of an Internet of Things (IoT)-based Smart Library Management System to improve resource management and service delivery in academic libraries. By integrating RFID technology, FSR402 pressure sensors, an ESP32 microcontroller, cloud computing, and a web-based dashboard, the proposed framework enables real-time monitoring of book locations, study seat occupancy, and in-library resource utilisation within a unified platform. The successful prototype implementation demonstrates that IoT technologies can effectively automate routine library operations, minimise reliance on manual monitoring, and improve the accuracy and accessibility of library information.

The results indicate that the proposed system effectively addresses several operational challenges commonly encountered in conventional library management, including misplaced books, inefficient seat utilisation, and the limited visibility of in-library reading activities. In addition to validating the technical feasibility of the prototype, the user acceptance and usability survey revealed strong support for the proposed smart library features, suggesting that the developed system aligns well with the practical needs and expectations of library users. These findings highlight the value of combining user-centred design with IoT technologies to deliver solutions that are not only technically functional but also relevant to real-world library operations.

This study also contributes to the advancement of smart library research by providing an integrated framework that combines resource tracking, occupancy monitoring, and usage analytics within a single IoT ecosystem. Unlike many existing approaches that focus on individual library functions, the proposed system offers a more comprehensive solution capable of supporting data-driven decision-making, improving operational efficiency, and enhancing the overall library experience. Furthermore, the use of affordable and commercially available hardware demonstrates that smart library technologies can be implemented cost-effectively, making the framework suitable for higher education institutions seeking to support Smart Campus initiatives and accelerate digital transformation.

Although the proposed framework achieved its intended objectives, the current evaluation was limited to a prototype-scale implementation in a controlled environment. Future research should focus on deploying the system in operational academic libraries to evaluate its long-term reliability, scalability, maintenance requirements, and user experience under real-world conditions. Further enhancements, including integration with existing library management systems, mobile applications, predictive analytics, and artificial intelligence, could extend the system's capabilities and support more personalised and intelligent library services.

Overall, the proposed Smart Library Management System provides a practical and scalable foundation for the development of next-generation academic libraries. By integrating real-time sensing, cloud-based monitoring, and user-oriented functionalities, the framework has the potential to enhance operational efficiency, improve user experience, and support the ongoing digital transformation of higher education libraries in line with Malaysia's Smart Campus vision.

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