Effectiveness of RFID Smart Library Management System

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ABSTRACT

Libraries are crucial for diverse resources, particularly for students and educators. The Library Management System (LMS) in Perpustakaan Raja Tun Uda (PRTU) still used barcode technology, which was inadequate and could increase the workload of the librarians. This study presented the development and evaluation of the Smart Portable Library Management System (SPLMS) using RFID technology. The study addressed the gap in the literature by focusing on the impact of angle adjustment on the performance of UHF RFID readers in reading RFID tags placed on book spines. The study was conducted by implementing the SPLMS and performing system testing at different angles. The scope of the study encompassed the design and implementation of the SPLMS, system testing with varying angles, and evaluation of the reader's success rate in reading RFID tags. The validation of ZK-RFID101 of the results have shown that the reader has a 100% success rate for distances between 1 and 3 meters, but the success rate drops to 80% at 5 and 6 meters due to radio frequency interference. The main findings indicated that increasing the angle from 0 to 90-degrees improved the reader's performance, although certain tags still presented challenges. The results from the five conducted trials strongly indicated that a 90-degree angle was the optimum performance. The study concluded that the angle and placement of RFID readers was crucial for optimal performance in library management systems. The SPLMS provided librarians with a user-friendly dashboard for efficient book collection management, boosting productivity and enhancing user experience.

Keywords: *Radio Frequency Identification (RFID); Library Management System; Internet of Things; Node-RED; RFID Tags; MySQL*

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Introduction

Efficient library resource management has long been a challenge faced by librarians and institutions globally. Various technologies have been introduced over the years to enhance library operations. Among these, Radio-Frequency Identification (RFID) technology stands out as a promising solution to revolutionize library management. This technology facilitates the seamless tracking, identification, and management of library materials. The present study delves into the development and assessment of a Smart Portable Library Management System (SPLMS) that harnesses RFID technology to optimize library operations. By adopting this innovative approach, the study aims to streamline library management, improve librarian efficiency, and enhance the overall user experience.

Figure 1 shows Perbadanan Perpustakaan Awam which known as Perpustakaan Raja Tun Uda (PRTU). This PRTU located at Seksyen 13 Shah Alam. The PRTU is the headquarters and functions to administer, maintain and coordinate libraries throughout the State of Selangor. Students, lecturers, and Selangor citizens frequently visit the PRTU. There are 6 levels with a total space of 203,600 square feet in this PRTU. This space can be occupied by 2,500 person and 400,000 books can be kept [1]. Additionally, the PRTU attracts up to 8,000 visitors each day on the weekends, public holidays, and school holidays.

Figure 1: Perpustakaan Raja Tun Uda

Due to the enormous quantity of books kept at the PRTU, the librarian frequently encounters into issues such as missing books, misplaced books, and book searching especially at peak hour on the weekends. Moreover, there are few of bookshelf need to be monitored since they contain rare books that can only be read but cannot be borrowed. Therefore, librarian have difficulty to keep track whether the book is on the shelf or not. Moreover, the existing

library management system use in PRTU is barcode. It seems to be not very convenient since the to librarian need to scan one single book at a time. Hence, this study intends to assist the PRTU staff in tracking all book movement. Advanced technology has created Smart Shelf based on RFID technology. With the aid of automated systems, this smart shelf application enables high accuracy product inventory [2]. But the cost of this Smart Shelf is expensive.

The primary objective of the study is to develop and assess the effectiveness of the SPLMS at PRTU. This project proposed to develop a SPLMS with dashboard management using dedicated software that is Node-Red which is low cost and can be used in the PRTU. By implementing the SPLMS and conducting comprehensive testing, the research aims to evaluate the system's performance in a real library setting. Specifically, the study explores how different angles and placements of UHF RFID readers impact the system's ability to read RFID tags on book spines. This research provides practical insights into the integration of RFID technology in libraries, emphasizing the importance of RFID reader placement for optimal performance and the potential challenges with specific tags.

Literature studies

Technology of library management system has grown over the years. According to the traditional of library management system, all tasks require manual support [3]. Librarians must write down every detail about each book on paper. The information on the paper needs regular checking by the librarian. Because so many papers were used to store the information, a lot of space was needed. Technology gives a lot of changes to the traditional of library system. Many libraries around the world use a variety of technology to run their process of circulation such as renewing, borrowing, checking in, and checking out of the books. According to the traditional of library management system used have been replaced by advance technology.

Barcode technology can improve library operations by enhancing transaction efficiency, reducing workloads for library employees, and enhancing services for patrons. Using a barcode, data may be quickly and precisely accessed [4]. Development of technology has introduced QR code in library management system but this technology still in primary stage. With the growing use of smartphones and their ability to read sensible data, QR codes can be widely employed in both businesses and institutions [5]. Compared to barcodes, RFID is a more recent technology. Better accuracy in managing the book collection due to RFID has led to fewer books being purchased [6]. Furthermore, time efficiency occurs because RFID tags can be read more quickly than barcodes, enabling the rapid reading of stacks of books simultaneously [7].

Table 1: Comparison between barcode, QR code and RFID

Items	Barcode	QR Code	RFID
Technology	Laser scanner	Optical scanner	Radio frequency
Range	Few inches to a foot	Few inches to a foot	30 feet or more (passive) 60 to 300 feet (active)
Cost	Low	Low	Low (passive) High (active)
Accuracy	Accurate	Accurate	Accurate
Line of sight	Required	Required	Not required
Information Collected	Fast	Fast	Extremely fast
Capability to scan	One item	One item	Multiple items
Automation	Human operator	Human operator	Only fixed reader

Table 1 above shows the comparison of various technologies used in libraries. Based on the comparison to the different kind of technology such as Barcode, QR code and RFID. The RFID technology gives a better option than others. RFID stands for Radio Frequency Identification. There are two main RFID which are active and passive. Compared to active tags, passive tags are typically less expensive, smaller, and battery-free, which has led to lower read ranges for passive tag [8]. Passive RFID will be used in this study because it only covers a small area. Moreover, it only needs a fixed reader to operate the system and the biggest advantage of using RFID technology in the library is librarian can scan multiple books at a time.

In the world of programming, efficiency and simplicity are highly sought-after qualities. One such tool that has gained popularity is Node-RED. Node-RED is an open-source programming tool that is commonly used for Internet of Things (IoT). Node-RED is a popular IoT platform that is widely used for building IoT applications using visual programming [9]. It has become a popular tool for dashboard and back-end development due to its ability to connect a broad range of hardware devices and software to web services [10]. The programming tool provides a platform for data analytics and data visualization. It can also be integrated with other software such as SQL database management tools like InfluxDB to provide a database management system [11]-[12], [13]. Node-RED is used for displaying data, monitoring, alarming, and triggering actions based on certain rules. It provides a live dashboard for monitoring and alarming purposes, and displays notification messages for different parameters such as electrical quantities or environmental conditions [14]-[15]. Node-RED can also be accessed remotely by various devices that can use web browsers to view the webpage interface

such as computers and smartphones [12]. As such, Node-RED can be utilized in a variety of applications, including library management systems, as a flexible, efficient, and easily integrated dashboard solution.

Designing a basic model in Fusion360 involves utilizing the software's features to create and optimize various designs for different applications. Fusion360 is a computer-aided design (CAD) software that offers a range of tools for modeling, simulation, and optimization. It is widely used in various fields such as robotics [1], [4], [6], additive manufacturing [1]-[2], [7], heat transfer optimization [3], vehicle design [5], and medical modeling [7], [9].

A thorough review of Library Management System research in Malaysia shows that, there is few studies focusing on developing complete system which integration of hardware and software. The paper [16] emphasized the challenges in library management efficiency and advocated the use of RFID technology while highlighting the importance of training and protection against potential attacks. However, their study primarily focused on qualitative data. The paper [17] aimed to prevent book theft through an RFID approach and proposed a filing system using four antennas. Nonetheless, the implementation faced limitations such as high costs associated with antenna placement and the absence of a database for comprehensive book tracking.

The paper [18] sought to transform the library management system in SK Jelutung using a QR approach, introducing a web-based borrowing book software design for schools. Their system lacked the capability to track book data and could only scan one book at a time. The paper [19] aimed to maintain book data tracking by employing RFID and proposed a shelf management system for libraries. However, the system was not portable and used Microsoft Visual Basic. The paper [20] focused on designing a hardware system for book location detection using RFID, with a borrowing and returning system through tag scanning at each shelf. The system used Arduino Uno and lacked a Graphical User Interface (GUI). The paper [21] concentrated on creating a user-friendly GUI but opted for the barcode approach, proposing a manual library management system to be computerized, but their solution was solely software-based.

Methodology

Figure 2 shows the flowchart illustrated the step-by-step process involved in a mechatronics project. It began with conducting a literature review to gather knowledge and identify existing solutions. This helped in designing and procuring the necessary parts for the mechatronic system. The next step involved integrating the hardware and software components to create a functional system. Afterward, the system underwent validation to ensure it met the desired specifications. Once validated, the system was installed, and its performance was continuously monitored and improved as needed. Finally, a

conclusion was drawn based on the project's outcomes, highlighting successes and potential areas for future enhancements. This comprehensive approach ensured a systematic and successful development and implementation of the mechatronics system.

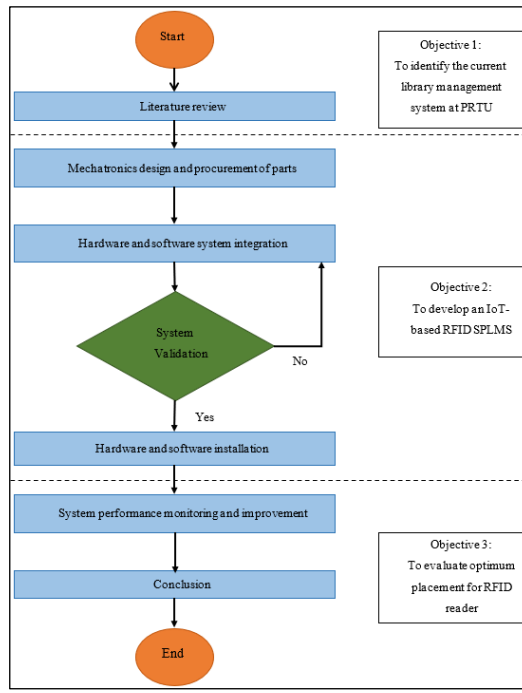

Figure 2: Methodology flow chart

Data flow

The Smart Portable Library Management System (SPLMS) prototype consisted of various components in the process layer, such as the ESP8266 and ZK-RFID101 devices, RFID tags, and push buttons as shown in Figure 3. These components were programmed using the Arduino IDE and monitored through the serial monitor. The prototype development utilized Fusion360 software. In the IoT layer, specific protocols like MQTT were used for communication and data formatting between IoT devices. The platform server comprised Node-RED and MySQL software. Data was pushed to Node-RED for dashboard visualization and also stored in MySQL as a database. The application layer was web-based, allowing librarians to access the dashboard through a laptop.

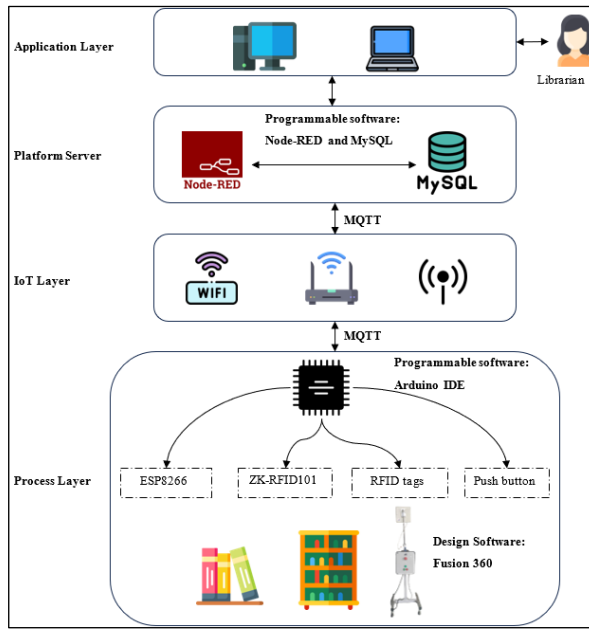

Figure 3: Overall data flow of SPLMS system

Components

The ESP 8266 is the main component that was used for coding. The components and coding were chosen precisely. Table 2 shows the list of components for the hardware used.

Table 2: List of components

Component	Function
ESP8266 NodeMCU	To read inputs and convert them into output based on user-friendly hardware and software.
UHF RFID integrated reader (ZK-RFID101)	To read and capture information stored on a tag attached to an object.
RFID tags	(RFID) tag is a device that uses radio waves to communicate wirelessly with RFID reader.
Push button switch	A mechanical device where the user manually presses a button to regulate an electrical circuit
Power supply 220V	The standard household voltage 220V
Adapter 12V 2A	The power supply for ZK-RFID101
Switching power supply 12V 5V	To convert a 12V input to a 5V output

Circuit

The ZK-RFID 101 was connected in accordance with the circuit diagram shown in Figure 4. The ZK-RFID 101 was connected to the ESP8266 NodeMCU microcontroller. The ZK-RFID 101 was powered by a 12V adapter. For data transmission, pin DATA0 was connected to pin D6 on the microcontroller, while pin DATA1 was connected to pin D5. 5V was supplied to the ESP8266 NodeMCU by a switching power supply. The switching power supply received power from the 12V 2A adapter, while the adapter received power from an external 220 V power source.

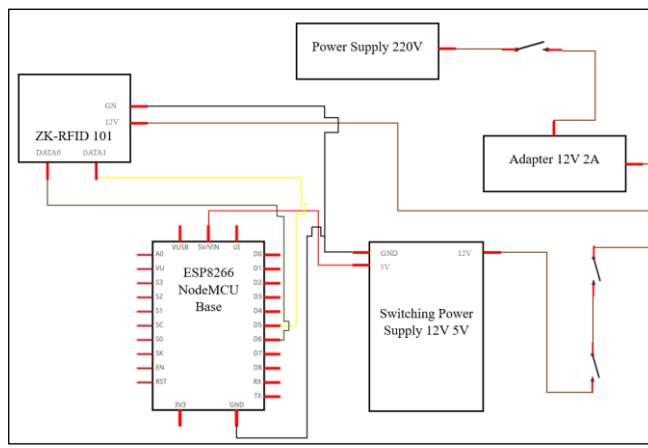

Figure 4: Circuit diagram of ZK-RFID101

Hardware design and setup

In Figure 5, the prototype of the Smart Portable Library Management System (SPLMS) was depicted. It consisted of a push button that allowed the librarian to turn the product on or off as needed. Additionally, there was an emergency button that served the purpose of quickly stopping the SPLMS in case of any unforeseen circumstances. Moving on to Figure 6, it showcased the SPLMS setup for monitoring the performance of a ZK-RFID101 at various angles. Specifically, the figure illustrated the system when the angle was set to 0 degrees.

Block diagram and flowchart of the system

The Smart Portable Library Management System (SPLMS) was a proposed system with a block diagram consisting of components like adding book details, deleting book details, and book searching, all stored in a database which was MySQL as shown in Figure 7. The system included a dashboard that demonstrated its functionality and provided an interface for the librarian to efficiently access and search for books.

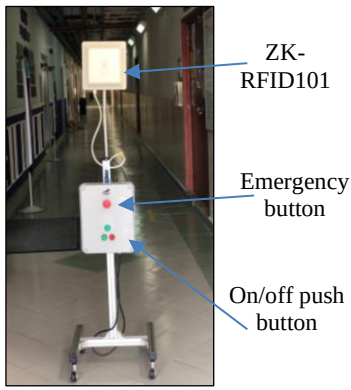

Figure 5: Prototype of SPLMS

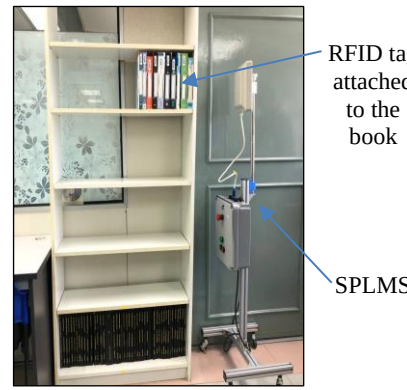

Figure 6: SPLMS setup

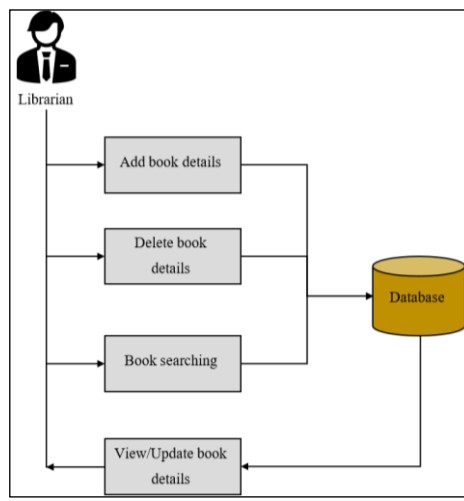

Figure 7: Block diagram of the SPLMS

The process began with the setting up of the system and the retrieval of a book with an RFID tag as shown in Figure 8. The RFID reader scanned the tag and transmitted the information it had obtained to the database. If the data was found in the database, the system displayed the return data. The process ended when the book's status was displayed through the dashboard.

Development of software

The Arduino IDE was used to program Arduino microcontrollers and interface with hardware. Data from Arduino could be sent to Node-RED for

visualization on a dashboard. MySQL was used to store the data as a database. Fusion 360 was a 3D modeling software for creating objects and prototypes. Table 3 shows the list of softwares used.

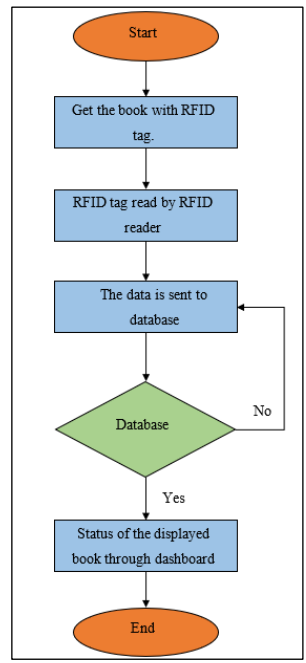

Figure 8: Flowchart of the effectiveness RFID system

Table 3: List of softwares

Software	Function
Arduino IDE	For uploading and communicating with programs, it creates a connection with the Arduino hardware.
Node-RED	An open-source programming tool for creatively and quickly linking hardware, APIs, and web services.
MySQL	An open-source database software that complies to the SQL standard.
Fusion 360	A 3D modelling program with the ability to model, simulate, and document.

Position of tags in books

Position tags play a crucial role in optimizing the effectiveness of UHD RFID technology in books. Error in multiple tag book stack detection results when

tags overlap [22]. In the case of UHF RFID, the position of the tag on the book spine can affect the read rate. According to research, tags placed right close to the spine are always read, but those placed towards the book's opening, which are farther away from the spine and inventory reader, are not always read [23]. The strategic positioning of the UHD RFID tag on the spine ensures enhanced readability, minimizes interference, and maximizes data transmission efficiency as shown in Figure 9.

Figure 9: Position of book tagging

Placement of UHF RFID reader (ZK-RFID101)

The UHF RFID reader (ZK-RFID101) was positioned at three different angles such as 0 degrees, 45 degrees, and 90 degrees as shown in Figure 10. The purpose was to find the angle that provides the best performance in reading RFID tags accurately and reliably. By comparing the results, it is possible to determine the optimal angle for achieving optimal performance. This information is valuable for industries that rely on RFID technology for tasks like inventory management and asset tracking.

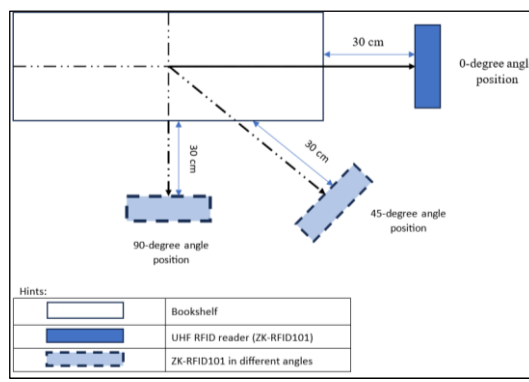

Figure 10: Top view of ZK-RFID101 placement

Results and Discussion

Dashboard

Figure 11 showed the homepage of the system provided the librarian with multiple options for managing the library's book collection. By completing a form, the librarian could add book details, delete books from the system, and view/update existing books.

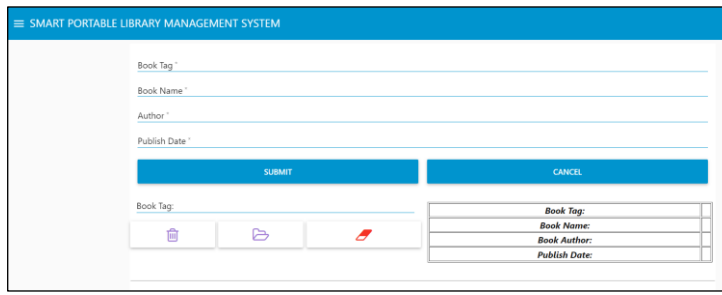

Figure 11: Dashboard of SPLMS

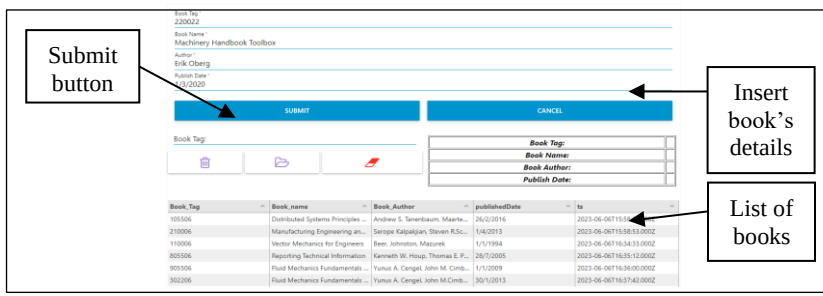

Figure 12: Add book menu

In Figure 12, the librarian was presented with a form to complete the book's information. After completing the form, the librarian could select the "Submit" button. The book's information was securely stored in the database upon submission. Additionally, the dashboard displayed a list of books' details for simple access and visibility, allowing the librarian to effectively manage the collection.

In Figure 13, the librarian has the ability to enter book tags that they wish to remove. After the librarian has inserted the book tag, librarian will be able to select the "Delete" button. The information on the tag belonging to the book will be removed from the database. The dashboard may have shown the librarian that the selected book's tag had been removed.

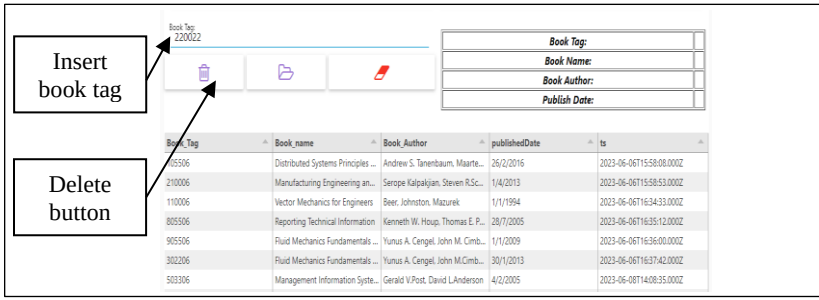

Figure 13: Delete book menu

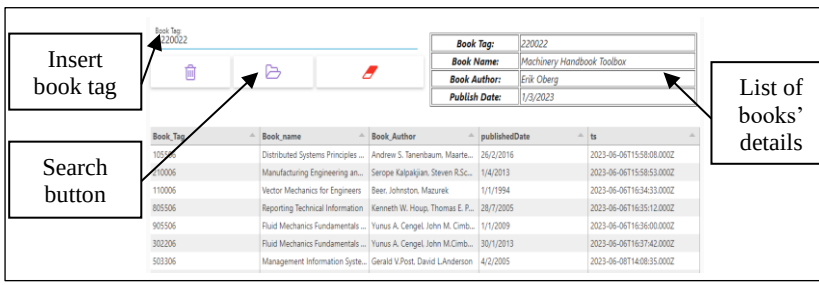

Figure 14: Book searching menu

Figure 14 showed how the librarian could conduct a search for book details by first inserting the book tag and then clicking the search button. It showed up on the dashboard for the librarian so that they were able to view it.

The homepage was built using Node Red and SQL. It enhanced library management and helped librarians work quickly. It updated all book details. This system's disadvantage disabled librarians from updating book data on the dashboard. Thus, the library progressed quickly, attracting many patrons. The librarian had to monitor and maintain the database to detect missing books.

System testing

Validation of smart portable library management system

The maximum reader range for the ZK-RFID101 was 6 metres, according to the manual [24]. The effective range of the RFID reader was shown in Table 4. The appropriate symbol indicated that the reader sent the data. The ZK-RFID101 reader's most useful range was from 3 metres to 1 metre. When the range reached 5 and 6 metres, it was almost 80%. This happened as a result of radio frequency interference, which impaired and weakened the signal received by the RFID reader [25]. In RFID networks, reader-to-reader interference could also reduce the read rates of passive RFID tags [26].

Table 4: The RFID readers's effective range

Trials	Range of the RFID reader in meters (m)					
	1	2	3	4	5	6
1	√	√	√	√	√	×
2	√	√	√	√	√	√
3	√	√	√	×	×	√
4	√	√	√	√	√	√
5	√	√	√	√	√	√
Percentage	100%	100%	100%	80%	80%	80%

Performance testing based on different angles

The system testing the effect of the angle on the reader's ability to successfully read RFID tags placed on the spine of a stack of 10 books, with a distance of 30 cm between the reader and the books.evaluated the performance of a UHF RFID reader at three different angles which were 0 degrees, 45 degrees, and 90 degrees. The aim was to determine

In the case of the 0-degree angle as shown in Table 5, where the reader was positioned in front of the book's front cover, the results showed that the reader achieved a 100% success rate for most book tags. However, tags 302206, 503306, 202206, 603306, and 402206 consistently had a 0% success rate. This suggests that at a 0-degree angle, the reader had difficulties reliably reading these specific tags.

Table 5: Reader when 0-degree angle

Trials	Book Tag									
	105506	210006	110006	805506	905506	302206	503306	202206	603306	402206
1	√	√	√	√	√	×	×	×	×	×
2	√	√	√	√	√	×	×	×	×	×
3	√	√	√	√	×	×	×	×	×	×
4	√	√	√	√	×	×	×	×	×	×
5	√	√	√	√	√	×	×	×	×	×
Percentage	100%	100%	100%	100%	60%	0%	0%	0%	0%	0%

At the 45-degree angle as shown in Table 6, where the reader was tilted slightly, there was an improvement in the success rate compared to the 0-degree angle. Most book tags achieved a 100% success rate, except for tag 302206 which still showed a 60% success rate. Additionally, tags 202206 and 402206 continued to have a 40% success rate. Meanwhile, the tag 603306 had the lowest success rate with 0%. This indicated that even with the angle adjustment, the reader faced challenges in consistently reading these particular tags.

The best performance was observed at the 90-degree angle as shown in Table 7, with the reader placed in front of the book's spine. The approach used in this testing is similar by other research [27]. At this angle, most book tags

achieved a 100% success rate. However, tag 202206 presented difficulties, resulting in a lower success rate. Tag 302206 showed a 60% success rate, indicating that the reader struggled to consistently read these tags even at the optimal 90-degree angle.

Table 6: Reader when 45-degree angle

Trials	Book Tag									
	105506	210006	110006	805506	905506	302206	503306	202206	603306	402206
1	√	√	√	√	√	×	×	×	×	√
2	√	√	√	√	√	√	×	√	×	×
3	√	√	√	√	√	√	×	×	×	×
4	√	√	√	√	√	×	√	√	×	×
5	√	√	√	√	√	√	×	×	×	√
Percentage	100%	100%	100%	100%	100%	60%	20%	40%	0%	40%

Table 7: Reader when 90-degree angle

Trials	Book Tag									
	105506	210006	110006	805506	905506	302206	503306	202206	603306	402206
1	√	√	√	√	√	√	√	×	√	√
2	√	√	√	√	√	√	√	√	√	√
3	√	√	√	√	√	√	√	×	√	√
4	√	√	√	√	√	×	√	×	√	√
5	√	√	√	√	√	×	√	√	√	√
Percentage	100%	100%	100%	100%	100%	60%	100%	40%	100%	100%

The 90-degree angle is considered an optimum angle for the placement of an RFID reader due to several factors. Firstly, at this angle, the reader is positioned directly in front of the book's spine, which provides the most direct and unobstructed path for the RFID signals to reach the tag [23]. This alignment maximizes the signal strength and minimizes signal loss or reflections, resulting in higher read rates and improved overall performance.

Moreover, at a 90-degree angle, the reader's antenna is oriented parallel to the orientation of most RFID tags, which are typically attached to or embedded within the spine or cover of the book. This alignment optimizes the coupling between the reader's antenna and the tags, enhancing the electromagnetic interaction and, consequently, improving the chances of successful tag reading [28].

Despite the advantages of the 90-degree angle, some tags may still experience reading difficulties. One possible reason is that the frequency band of the RFID system is 902 – 928 MHz. At this frequency, certain materials or environmental factors may interfere with the propagation of RFID signals [29]. For instance, metal surfaces or liquids can absorb or reflect RFID signals, leading to weaker or distorted signals reaching the tags [30]. The testing takes place in the Sports Engineering and Artificial Intelligence Centre (SEA-IC),

which consists of a metal device or machine. This encounter disrupted the RFID signal.

Furthermore, the design and construction of certain RFID tags might not be optimal for the chosen frequency band. Each RFID tag is designed with specific characteristics, and some tags may be more tuned to operate effectively at different frequencies [31]. Consequently, when operating at 902 - 928 MHz, some tags may not exhibit the same level of sensitivity or response as they would at a different frequency [32], resulting in lower success rates at the 90-degree angle.

The proposed SPLMS based on RFID technology demonstrates significant improvements in the effectiveness and efficiency of library operations when compared to the existing barcode technology system. RFID technology offers several advantages over barcoding, including faster and contactless book identification, simultaneous scanning of multiple books, and better accuracy [33]. The system's user-friendly dashboard enhances the librarian's ability to manage book details, deletions, and searches efficiently. Additionally, the performance t esting of the RFID reader at different angles revealed the optimal placement of the reader at a 90-degree angle, which further enhances its success rate in reading RFID tags on book spines.

Conclusion

The purpose of this study is to develop a fully integrated Smart Portable Library Management System (SPLMS) using RFID technology and assess its effectiveness at Perpustakaan Raja Tun Uda (PRTU). The study successfully implements the SPLMS, which provides a user-friendly dashboard for librarians to manage book details, deletion, and searching. System testing evaluates the performance of the UHF RFID reader at different angles and reveals that increasing the angle from 0 to 90 degrees improves the reader's success rate in reading RFID tags on book spines. However, certain tags exhibit lower success rates, suggesting the need for further optimization. The findings emphasize the significance of considering the angle and placement of RFID readers in achieving optimal performance. Further research is recommended to address the challenges with specific tags and explore alternative methods for tag placement, signal interference mitigation, and improvements in antenna design. The implementation of the SPLMS and the insights gained from this study contribute to the advancement of library management systems and provide valuable guidance for future research in the field.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest.

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