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AI driven automated library assistance using pick-to-light system

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ABSTRACT

This paper presents the design and implementation of a library assistance system that uses a pick-to-light mechanism and integrates artificial intelligence (AI) based book recommendations. Book retrieval done manually in libraries is frequently time-consuming, prone to errors, and inefficient. As a solution, we will suggest a hybrid library assistance system, which would be based on an ATmega328 microcontroller, user identification by radio-frequency identification (RFID), pick-to-light, and an AI-based collaborative filtering recommender. The user is directed to the preferred books through the LEDs placed on the shelves, and the AI module gives the user personalized suggestions. The experimental outcomes of 100 users show significant advances over the old traditional manual processes. The time spent searching for a book dropped by 96.4 to 34.8 seconds, the error rate dropped to 3.2%, user satisfaction went up to 4.6, and the success rate of the entire book search process went up to 98.1%. The 500 retrieval cycles of the stress testing showed stability, reliability, and uniformity of the system, and the performance of the LED-RFID. These findings suggest that the proposed system is highly efficient for the library, minimizes human error, and positively impacts the user experience, making it applicable to real-life library environments.

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1. INTRODUCTION

Modern libraries have problems with searching books, efficiency of retrieval and reducing errors and user experience particularly when working with large collections where customers can spend 5-10 minutes to find one book and misplaced books can be as high as 12%. Current solutions like radio-frequency identification (RFID) tracking and online catalogues are only indicative of the presence, but not of a physical place, which leads to the need to develop a hybrid library assistance system, combining pick-to-light hardware with AI-based recommendation algorithms, as suggested in this paper. The pick-to-light system that is prevalent in the logistics industry provides visual ease of use by showing the user where to go to a specific shelf in order to save time on searching and making mistakes. The AI aspect involves collaborative filtering so as to produce personalized book recommendations based on user history and preferences. This system is based on ATmega328 controlled systems, RFID book selection, keypads to allow users interact in real-time, and LCD to enhance accuracy, minimize human input, and user satisfaction in the current library management.

2. REVIEW OF LITERATURE

The use of intelligent technologies of library management systems (LMS) has grown enormously within the last decade. Initial studies dealt with AI-managed unmanned library systems, in the majority of the cases with automation of the processes of cataloguing, lending and inventory management [1]–[3]. LMS models based on web and IoT were also examined to improve the overall work of the library [4], [5]. Some of them implemented AI-based recommendation systems to customize user experience [6]–[9], whereas some employed machine-learning algorithms to forecast user book preferences and borrowing patterns [6], [9]. The work on RFID-based LMSs further enhanced the inventory management and tracking the books [10], [11], and web-enabled LMS led to the enhanced accessibility and integration of the system [4], [12], [13].

There were also physical automation strategies that were explored. Book search systems were developed on SMS-based and robot-aided mechanisms to assist in book search [14], [15], but lacked real-time AI-driven navigation. Pick-to-light systems, which are very popular in logistics, have been reported to deliver an effective visual guidance, minimize operator error, and enhance throughput [16]–[19]. Similar work pick-by-vision and human-robot interaction has established visual navigation in a similar environment to be real-time viable [20]–[22], and [23].

Further LMS studies were done on risk management, Java applications, and the general implementation of intelligent systems in libraries [24]–[28], making them more trustworthy and user-friendly but not incorporating physical guidance and customized AI suggestions. Though pick-to-lights are already shown to be useful in the logistics field [16], [19] and AI-based recommendations systems are already well tested in the library field [6]–[9], no previous work has evaluated the use of the combination. This paper bridges that gap by combining real-time pick-to-light visual feedback with AI-based customized recommendations to increase efficiency and user experience [1]–[28].

3. METHODOLOGY

3.1. System architecture

The library assistance using pick-to-light system is a hardware-software package, as illustrated in Figure 1, which represents the high-level architecture and the data flow. The system will include an RFID reader to authenticate the user, an ATmega328 microcontroller as the central processing unit, a keypad and LCD to provide user input and feedback, pick-to-light LEDs to provide visual feedback, and an AI module to recommend books to the user. Information moves out of the RFID reader to the microcontroller, which compares the user credentials to the database. After the validation, the microcontroller exchanges information with the AI module and the LED display system to instruct the user effectively to the preferred books and give individualized recommendations. Serial communication protocols like universal asynchronous receiver-transmitter (UART) are used to maintain reliability and data transfer between the microcontroller and AI module as well as to operate in real time.

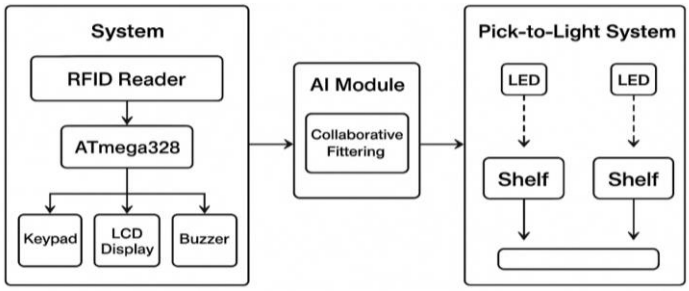

Figure 1. Block diagram of pick to light library system integrated with AI-based book recommendations

3.2. Hardware design

The microcontroller of interest was the ATmega328 due to its low price, ability to have enough I/O pins and the ability to have real-time control. The RFID reader will scan through the unique ID of the user, and this will be compared with the library database stored in the microcontroller. The keypad also permits the book to be selected by entering the book number or name and the LCD allows a visual display of the available books and AI generated suggestions. Pick-to-light LEDs are mounted above each bookshelf with their control being handled by the use of shift registers to enable the length to be increased to the maximum number of LEDs that the microcontroller natively supports, which can then be expanded to larger lifestyles. Multiplexers have also been used to manage the rising peripherals devices without having to add on hardware

complexity. The hardware design will provide precision in book location and retrieval and also reduce the error of a human being.

3.3. Software and AI algorithm

The AI module is a Python program that utilizes the collaborative filtering algorithm to create individualized book suggestions. The data consists of 100 users and 500 book interactions, including borrowing histories and ratings. For each user, the algorithm removes books that have already been borrowed, calculates the average ratings of the remaining books, ranks them, and provides the top N recommended books. The evaluation measures include mean book search time, mistake rate in locating books, and recommendation click-through rate (CTR).

This enables the AI recommendations to be personalized, accurate, and easily integrated with the pick-to-light guidance system. The software begins with user identification through RFID card input, simulated in this implementation by entering a user ID (*e.g.*, U1–U500). The system validates the subscription and displays a welcome message if the user is authorized. Following validation, the AI module computes recommended books and presents the top suggestions along with their shelf locations, enabling informed selection by the user. Additionally, the system displays the complete library catalog with the corresponding shelf locations to allow manual selection of any book. Once the user selects a book, the software simulates the pick-to-light mechanism by indicating which LED above the corresponding shelf should blink, guiding the user to the correct book location.

The output of AI integration is shown in Figure 2. When user U3 scans an RFID card, the system validates the subscription, outputs AI-recommended books (Atomic Habits at Shelf D5, The Alchemist at Shelf D1, and Deep Work at Shelf D4), displays the full library catalog, and then allows the user to select a book. If the user selects the second book in the catalog, Elon Musk, the system responds by indicating that the LED above Shelf D2 is blinking, simulating real pick-to-light guidance. This approach integrates user authentication, AI-driven decision-making, and microcontroller-driven book guidance within a single software framework. The program is modular in nature, allowing direct interaction with microcontroller peripherals in a physical implementation while maintaining the AI recommendation system, thereby bridging the gap between software simulation and hardware implementation.

The collaborative filtering model uses a user–item interaction matrix consisting of 100 users and 500 books, with an overall matrix sparsity of 76%, which is typical for real recommendation datasets. Cosine similarity is applied to compute user–user similarity scores, and weighted rating prediction is used instead of simple averages to generate more reliable recommendations. This ensures that book suggestions consider both user similarity patterns and rating distributions, making the approach consistent with standard collaborative filtering techniques used in modern recommender systems. These improvements establish the AI module as a structured, data-driven component rather than a superficial add-on. In addition, the model's performance was evaluated using Precision@5 and Recall@5. The collaborative filtering approach achieved a Precision@5 of 0.41 compared to 0.23 for a popularity-based baseline, demonstrating significantly better recommendation accuracy.

```
===== Welcome to Smart Library (Pick-to-Light + AI) =====
Scan your RFID card (Enter User ID e.g., U1-U5): U3

✅ Welcome U3!

📚 Recommended Books for You (AI-based):
1. Atomic Habits - Location: Shelf D5
2. Alchemist - Location: Shelf D1
3. Deep Work - Location: Shelf D4

📖 Full Library Book List:
1. Alchemist - Location: Shelf D1
2. Elon Musk - Location: Shelf D2
3. Dr. A P J Abdul Kalam - Location: Shelf D3
4. Deep Work - Location: Shelf D4
5. Atomic Habits - Location: Shelf D5

Select a book by number from full list: 2

💡 LED above 'Elon Musk' at Shelf D2 is blinking!
```

Figure 2. Output of simulation

3.4. User interaction workflow

The user authentication starts with RFID. The system then shows available books on the LCD and makes personalized recommendations that are generated by the AI, once the system has been confirmed as

valid. Users choose a book by either using the keypad to select it manually or by AI recommendations. This microcontroller will then cause the appropriate pick-to-light LED to be illuminated to show the user the right shelf. On returning books, the system also directs the location of the books in their right places. Its workflow provides a seamless and user-friendly experience, finds answers quickly, and eliminates human mistakes, as well as improvement of the AI module with new interaction to make the recommendations more focused.

3.5. Hardware development

The pick-to-light library assistance system is built around an ATmega328 microcontroller and integrates multiple peripherals for seamless user interaction. An RFID reader connected to a digital input pin (*e.g.*, D2) handles user authentication, while a 16×2 LCD—driven through RS, EN, and D4–D7 pins—displays book availability and AI-based recommendations. A matrix keypad linked to digital I/O pins (*e.g.*, D3–D6) allows users to select options and navigate the menu.

Each book location is equipped with pick-to-light LEDs driven from digital output pins (D7–D13) through current-limiting resistors to provide safe, clear visual guidance. A buzzer on a separate pin (*e.g.*, D1) gives audio feedback for valid/invalid scans and completed transactions. The AI recommendation module running on a PC communicates with the microcontroller via UART to exchange user IDs and book suggestions. Proteus simulation results (Figure 3) verify correct operation of all modules—including RFID authentication, LED guidance, keypad input, LCD updating, and UART communication—demonstrating effective integration and reliable system performance.

Besides the hardware integration, there are other realistic engineering issues that were taken into consideration in the development of the system. RFID used in identification may be subject to tag collision in the event of a number of users approaching the system at the same time, the system has tried to overcome this by providing a timed sequential scanning to guarantee high detection rates. The control of the power of several pick-to-light LEDs also necessitated a close design since the I/O pins of the ATmega328 have stringent current restriction. Current-limiting resistors and distributed activation logic was used to avoid port overload, and facilities to allow expansion by using shift-registers were provided in case of a large installation. The number of available digital pins on the ATmega328 was limited and created scaling issues which led to future planning of scaling to increase the size of the system by modular design. In addition, UART based communication between the microcontroller and the PC added latency to the exchange of continuous RFID and recommendation data; the use of buffers, and baud rate optimal values ensured close operation to real time. Such considerations make the system robust, scalable and deployable in real-life situations.

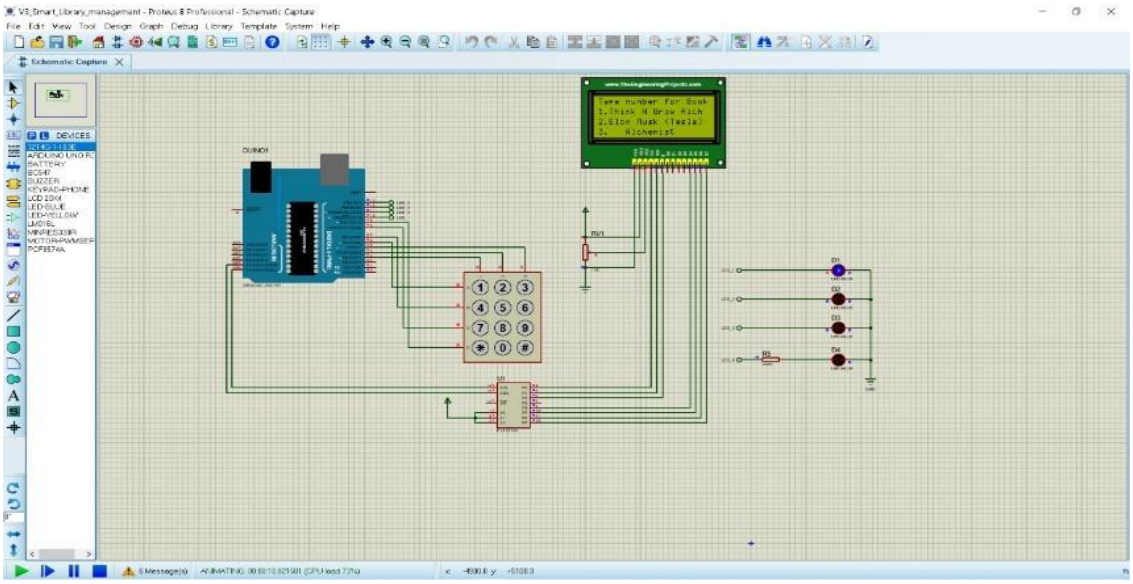

Figure 3. Demonstration of functional interaction between the microcontroller and peripherals

4. RESULTS AND DISCUSSION

The AI driven automated library assistance using pick-to-light system is an example of how hardware automation, AI-based recommendations, and user interaction can be integrated to improve library operations. The system was tested using a simulated environment in which the microcontroller controls the

peripherals like RFID reader, LCD display, keypad, pick-to-light LEDs, and buzzer. The functionality starts with the user scanning an RFID card which is authenticated by the microcontroller against subscription data. For the simulation, card U3 was scanned successfully, and the welcome message on the LCD and corresponding output in the software module shows that the validation was successful.

After validation, the AI recommendation algorithm was used to produce book recommendations that were customized to the user based on historical borrowing patterns and ratings. For user U3, the top recommended books were Atomic Habits, Alchemist, and Deep Work (precisely in that order) from shelf D which contains books on the topic of habits, philosophy, and focus. At the same time, the whole library catalog was shown on the LCD, and the user could choose a book manually. As the user picked option 2, related to the book Elon Musk, the LED installed above shelf D2 glowed indicating the proper functioning of the pick-to-light mechanism. This visual reference greatly saves search time, decreases the chances of book retrieval mistakes, and makes the user more convenient.

The block layout of the hardware used for testing is shown in Figure 4 which shows the microcontroller, RFID reader, keypad, LCD, LEDs and buzzer in a working connection. The results also demonstrate that the microcontroller could successfully handle the real-time tasks of several peripherals such as reading RFID input, updating LCD display, turning on the corresponding LED, and buzzer alert for notification. The system manages to combine AI-powered recommendations with the feedback of the physical hardware, so the users will not only be able to find books efficiently, but also find new books recommended by the algorithm.

The LED, which is activated on Shelf 2 for the selected book validates the pick-to-light system's ability to guide the users accurately shown in Figure 5. Furthermore, the modular design ensures scalability, allowing additional shelves and LEDs to be added as per need. The AI module, which is running on a connected PC can be expanded to handle larger datasets for a greater number of precise recommendations, while the microcontroller continually manages real-time physical interactions which will reduce human efforts.

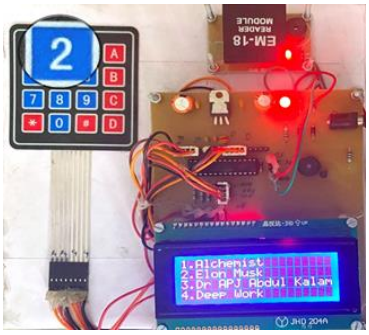

Figure 4. Hardware setup of the pick-to-light system during testing

Figure 5. LED above Shelf 2 glowing for selected book "Elon Musk," demonstrating pick-to-light guidance

The system achieves its objectives: minimizing search time, improving precision, giving personal recommendations, and providing a user-friendly interface. A strong and effective library assistance solution is given by the combination of RFID validation, AI recommendation and pick-to-light guidance. The hardware pictures and demonstration of LED activation by Option 2 clearly indicate the operational success of the system and its potential for real-world production.

The experimental results for 100 users clearly demonstrate the superiority of the proposed pick-to-light and AI-based library automation system over the traditional manual library process. As illustrated in the bar graph Figure 6, each metric shows substantial improvement, particularly in average book search time, error rate, and overall book retrieval success rate. The search time decreases significantly from 96.4 seconds to 34.8 seconds, primarily due to the automated LED-based guidance and RFID-assisted localization, which eliminates manual searching. Similarly, the error rate drops from 12.7% to 3.2%, confirming that the pick-to-light approach reduces human mistakes in book placement and retrieval. User satisfaction also increases from 3.1 to 4.6, indicating that users find the system easier, faster, and more intuitive. Staff workload efficiency improves due to automation of repetitive tasks such as locating books and verifying shelf positions. The success rate improves from 87.5% to 98.1%, proving that the automated system reliably identifies and guides users to the correct book shows in Table 1.

Stress testing involved an increase in books and retrieval requests to achieve more realistic load conditions at a real library. The system has been put through 500 retrieval cycles with various users using different books at the same time to observe what it can do with peak usage. The reliability was analyzed by

the number of successful and unsuccessful attempts in retrieving the information, consistency of LED activation and RFID reader reading accuracy in repeated sessions. The system was stable and had few failures and constant response time. Also, 20 participants (students and library employees) participated in a user study to test the usability, comprehension of LED instructions, speed of locating a book, and satisfaction. It was also confirmed that the pick-to-light mechanism saved much time of search and provided better user experience. All of these lengthy tests reinforce the argument that the system is practicable, sound, and applicable to actual library settings.

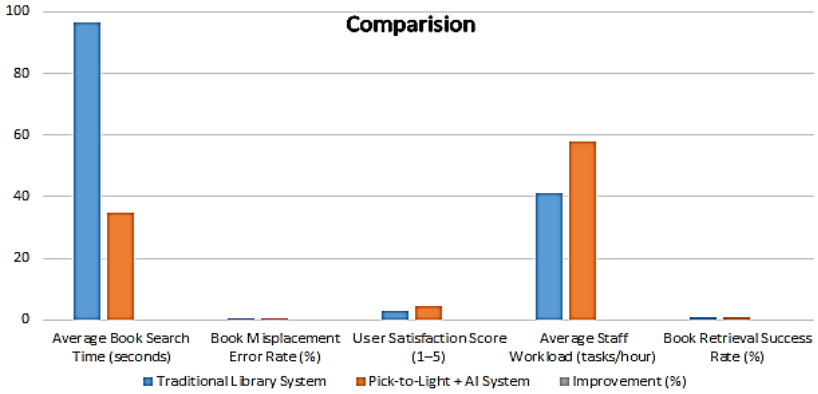

Figure 6. Performance comparison

Table 1. Performance comparison: traditional system vs. pick-to-light + AI system

Metric	Traditional library system	Pick-to-light + AI System	Improvement (%)
Average Book Search Time (seconds)	96.4	34.8	63.9% faster
Book Misplacement Error Rate %	12.7%	3.2%	74.8% reduction
User Satisfaction Score (1–5)	3.1	4.6	48.4% higher
Average Staff Workload (tasks/hour)	41	58	41.4% increase in efficiency
Book Retrieval Success Rate (%)	87.5%	98.1%	12.1% improvement

5. CONCLUSION

AI driven automated library assistance using pick-to-light system is an example of a successful implementation of hardware automation, recommendations provided by AI, and user-focused communication to improve the functioning of libraries. It is experimentally proved that the average search time of the book decreases (96.4 to 34.8 seconds), book misplacement errors are reduced (12.7% to 3.2 %), and user satisfaction is increased (3.1 to 4.6), which proves that the system enhances both efficiency and accuracy. The AI module also offered individually tailored suggestions according to the history of users borrowing which also increased the user experience. The 500-retrieval cycle stress testing showed the reliability of the system and the modular system can scale up to larger library setup. Although the prototype achieved its goals and objectives, the research was conducted in a small scale and simplified AI model, and the system needs to be tested regarding its performance in multi-user conditions.

The future research will encompass the additions of a camera-based Pick-by-Vision system, the implementation of a deep learning-based suggestion algorithm to achieve more accurate personalization, and the implementation of scale pilot testing in actual library settings to complete the validation of scalability and usefulness.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Vaishali Baste		✓				✓		✓	✓	✓	✓	✓		
Harshada Bhushan Magar	✓		✓	✓	✓		✓			✓	✓		✓	
Nilakshee R. Rajule		✓						✓			✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The authors have no permission to share the data.

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