GARP INTERNATIONAL JOURNAL OF LIBRARY AND INFORMATION SCIENCES

https://garp.org.ng/gijlis

Vol. 1, Issue I, Pp.25-46; APR., 2026

DESIGNING A ROBOTIC SYSTEM FOR REAL-TIME DATA ANALYTICS IN LIBRARIES

ABDULSALAMI, LUCKY TIJANI PhD & ADO, MUSA BILAL

[1]Igbinedion University Okada, Library and Information Science. Edo State. Nigeria
lucky.abdulsalami@iuokada.edu.ng 0000-0002-1254-2312
[2]Igbinedion University Okada, Library and Information Science. Edo State. Nigeria
bilal.musa@iuokada.edu.ng

ARTICLE INFO

Received Date: 19th Mar., 2026
Date Revised Received: 30th Mar., 2026
Accepted Date: 10th Apr., 2026
Published Date: 18th Apr., 2026

Citation: Abdulsalami, L. T. & Ado, M. B. (2026): Designing a Robotic System for Real-Time Data Analytics in Libraries. GARP INTER J. of Lib & Info. Sci. Vol. 1, Issue I, Pp. 25-46; Apr. 2026.

Abstract

The integration of robotics and data analytics technologies is transforming modern libraries into intelligent information environments capable of delivering automated and user-centered services. A robotic system designed for real-time data analytics can collect, process, and analyze data generated from library resources, user interactions, and operational workflows. Such systems utilize sensors, artificial intelligence (AI), Internet of Things (IoT), and robotic platforms to monitor library activities and generate actionable insights that support decision-making and service improvement. Through real-time analytics, libraries can evaluate user behavior patterns, resource utilization, circulation trends, and environmental conditions within the library space. These insights enable librarians and administrators to optimize resource allocation, enhance user services, and improve operational efficiency. Recent studies show that robotics and AI technologies can significantly improve cataloging, information retrieval, inventory management, and user support in libraries while reducing manual workloads and operational costs. Key applications include automated shelving and retrieval, intelligent cataloguing, chatbots for virtual reference, predictive analytics for collection development, and AI‑driven user behaviour analysis. While evidence points to increased operational efficiency and enhanced user experience, significant barriers such as high implementation costs, lack of librarian AI literacy, data privacy concerns, and ethical considerations remain. The review concludes by identifying research gaps, including empirical studies on return on investment and long‑term user acceptance. Furthermore, integrating data analytics with robotics allows libraries to implement predictive services such as personalized recommendations, demand forecasting, and automated collection management. The development of real-time robotic analytics systems therefore represents an important step toward the creation of smart libraries capable of adapting to changing user needs and technological environments. This paper discusses the design principles of a robotic system for real-time data analytics in libraries and examines its potential to improve library operations and user satisfaction.

Keywords: Robotic systems; Smart libraries; Real-time data analytics; Library automation; Artificial intelligence; Internet of Things; Data-driven library services; User behavior analytics

Introduction

Libraries have historically been early adopters of information technologies, from punched‑card catalogues to integrated library systems (ILS). Today, the convergence of artificial intelligence (AI) and robotics promises a paradigm shift: from merely digitising collections to autonomously managing physical and digital workflows (Cox, 2021; Lund and Wang, 2023). Modern library management systems (LMS) are evolving into AI‑augmented platforms capable of predictive analytics, natural language processing (NLP), and robotic process automation (RPA). The motivation for integrating AI and robotics is multifaceted. Declining budgets, rising user expectations for 24/7 service, and the explosion of digital and physical collections demand efficiency gains beyond traditional LMS capabilities (Okonkwo and Adebayo, 2024). AI offers pattern recognition and decision support, while robotics provides physical automation for tasks like sorting, shelving, and retrieving materials. Together, they enable what some authors term the “library as a smart ecosystem” (Massis, 2018; Yao, Zhang and Li, 2021).

Libraries are increasingly adopting these advanced technologies to enhance the efficiency and quality of information services. In recent years, robotics, artificial intelligence, and data analytics have emerged as key technologies supporting the transformation of traditional libraries into smart libraries. Smart libraries leverage digital technologies to automate operations, analyze user behavior, and improve service delivery. Robotic systems have been widely applied in library environments for tasks such as book retrieval, inventory management, shelf scanning, and user assistance. These systems rely on technologies such as RFID tags, sensors, and computer vision to locate and manage library materials efficiently. Research indicates that robotic technologies can significantly improve library operational efficiency by automating repetitive tasks and enabling accurate management of large collections. In addition to automation, modern libraries are increasingly utilizing data analytics to understand user behavior and optimize services. Real-time data analytics involves the continuous collection and analysis of data generated through library operations, digital systems, and user interactions. When integrated with robotic systems, real-time analytics allows libraries to monitor activities such as book circulation, space utilization, and user engagement in real time.

The concept of smart robotics analytics combines robotics, IoT devices, and big data technologies to enable intelligent monitoring and analysis of library activities. Such systems can collect large volumes of data from sensors, library management systems, and user devices, and then process the data using machine learning algorithms to generate insights that improve library services. Research on smart robotics systems emphasizes the importance of integrating IoT and data analytics techniques to create intelligent environments capable of adaptive decision-making. Real-time analytics also supports predictive library services, allowing libraries to anticipate user needs and improve resource management. For example, analytics systems can identify frequently used resources, predict peak library usage periods, and recommend materials to users based on their reading patterns. These insights enable librarians to make informed decisions regarding collection development, staffing, and service delivery.

The increasing adoption of robotics and artificial intelligence in libraries reflects the broader trend toward digital transformation in information institutions. Studies show that robotic technologies can support cataloging, metadata generation, information retrieval, and user assistance, thereby improving both service quality and operational efficiency in libraries. Despite these technological advancements, many libraries still rely on traditional management systems that lack real-time analytical capabilities. Consequently, designing robotic systems capable of collecting and analyzing real-time library data is essential for developing intelligent and responsive library environments. Such systems can enhance library operations, improve user satisfaction, and support data-driven decision-making in modern librarianship.

Statement of the Problem

Modern libraries generate vast amounts of data through activities such as book circulation, catalog searches, user interactions, and digital resource access. However, many libraries still rely on traditional management systems that lack the capability to analyze these data streams in real time. As a result, librarians often struggle to obtain timely insights into user behavior, resource utilization, and operational performance. The increasing complexity of library services and the rapid growth of digital information resources require advanced technologies capable of processing and analyzing large volumes of data efficiently. Traditional library management systems primarily focus on cataloging and circulation services but do not provide intelligent analytics for decision-making. Consequently, libraries may experience inefficiencies in collection management, user service delivery, and resource allocation. Recent research indicates that robotics and artificial intelligence technologies can significantly improve library services by automating routine tasks such as cataloging, information retrieval, and collection management. These technologies also enable real-time monitoring of library operations and user interactions, thereby improving service efficiency and accessibility. Furthermore, studies show that robotic systems integrated with advanced algorithms can autonomously scan books, classify resources, and transport materials within library environments with high accuracy. Despite these technological advancements, many libraries have not yet implemented robotic systems capable of collecting and analyzing real-time data from library resources and user interactions. Therefore, there is a need to design an intelligent robotic system that can monitor library activities, analyze data in real time, and generate insights to improve library operations and user satisfaction.

Objectives of the Study

General Objective

The main objective of this study is to design a robotic system capable of performing real-time data analytics in libraries to enhance operational efficiency and improve user satisfaction.

Specific Objectives

The specific objectives of the study are to:

1. Examine the role of robotics and artificial intelligence in modern library management systems.
2. Design a robotic system capable of collecting real-time data from library resources and user interactions.
3. Analyze how real-time data analytics can improve library operations such as circulation management, inventory control, and space utilization.
4. Develop a system architecture for a robotic analytics system suitable for smart libraries.
5. Evaluate the potential benefits of robotic data analytics systems for improving library service delivery and user satisfaction.

Methodology

This study adopts a conceptual and exploratory research design. The conceptual approach is suitable because the study focuses on designing a robotic system architecture that integrates robotics, IoT technologies, and data analytics for smart library environments. The exploratory design allows researchers to investigate emerging technologies and propose innovative frameworks for library automation. The study relies primarily on secondary data sources, including: Peer-reviewed journal articles, Conference proceedings on robotics and smart libraries, Books and scholarly publications on artificial intelligence and library automation and online databases such as Scopus, IEEE Xplore, Web of Science, and Google Scholar. These sources provide insights into current developments in robotics, IoT technologies, and real-time analytics for library management.

Literature Review

Examine the role of robotics and artificial intelligence in modern library management systems.

Real-Time Data Analytics for Library Operations: Improving Circulation, Inventory, and Space Utilisation

Modern libraries generate vast streams of real-time data: patron entry counts, self-checkout transactions, RFID shelf scans, Wi-Fi connection logs, seat occupancy sensors, and digital resource clicks. Historically, these data were reviewed retrospectively through monthly or annual reports. However, the advent of low-cost Internet of Things (IoT) sensors, cloud-based analytics platforms, and dashboard visualisation tools now enables real-time data analytics (RDA) – the continuous collection, processing, and immediate application of operational data to inform decisions (Cox, 2021; Lund and Wang, 2023).

The value proposition of RDA is compelling. Instead of reacting to problems weeks after they emerge (e.g., long queues at circulation, misplaced inventory, overcrowded study zones), library managers can intervene instantly. This brief review analyses how RDA improves three core library operations: circulation management, inventory control, and space utilisation. Current evidence from academic and public libraries is synthesised, followed by a discussion of implementation challenges and future directions.

Circulation Management: Reducing Wait Times and Optimising Staff Allocation

Circulation desks are the most visible service point in any library. Real-time analytics transforms circulation from a reactive function into a predictive one. By integrating data from self-checkout kiosks, RFID gates, and staff activity logs, libraries can monitor queue lengths minute-by-minute. When a pre-set threshold is exceeded (e.g., more than five patrons waiting for more than two minutes), the system alerts a roving staff member to open an additional terminal or assist with complex transactions (Okonkwo and Adebayo, 2024). A case study at the University of Helsinki library deployed a real-time dashboard that correlated check-out traffic with class schedules and campus events. Within three months, average wait time at circulation dropped from 4.2 minutes to 1.8 minutes, and staff were able to reduce peak-hour desk coverage by 20% without compromising service (Virtanen and Lahti, 2023). Similarly, the National Library of Singapore used real-time analytics to dynamically shift staff between circulation, information desk, and roving assistance based on live demand, achieving a 15% increase in patron satisfaction scores (Singh, Tan and Raj, 2022). Beyond queues, real-time analytics also detects anomalies such as repeated failed RFID scans (indicating damaged tags) or sudden spikes in holds pickups. Chen and Lin (2023) reported that a Taiwanese public library used real-time alerts to reduce unclaimed hold items from 12% to 5% by automatically sending SMS reminders within one hour of an item being shelved.
Key finding: RDA enables just-in-time staffing and proactive queue management, reducing patron frustration and improving staff productivity.

Inventory Control: Real-Time Shelf Auditing and Miss-location Detection

Inventory control in libraries has traditionally relied on periodic shelf reading – a labor-intensive process where staff manually verifies that items are in correct call number order. Even with annual or semi-annual inventories, studies consistently find that 5–10% of a library's collection is miss-shelved at any given time (Huang, Zhang and Chen, 2025). Real-time analytics changes this paradigm through continuous shelf monitoring. Using fixed RFID readers mounted on shelving end panels or robotic rovers, libraries can scan entire ranges every few hours. The data are streamed to an analytics engine that compares each item's scanned location against its assigned shelf location in the LMS. When a mismatch is detected (e.g., a book with call number QA76.73 is found in the QH301 section), an alert is generated. Staff receives a floor map with the exact misplaced item highlighted, reducing search time from minutes to seconds (Huang, Zhang and Chen, 2025).
The University of Chicago library implemented such a system across 1,200 shelving sections. Within six months, miss-helving errors dropped from 8.3% to 1.1%, and the time required to locate a requested "missing" item fell from an average of 45 minutes to under 5 minutes (Yao, Zhang and Li, 2021). Furthermore, real-time analytics can identify "shelf gaps" – areas where high-circulation items are consistently removed – prompting staff to shift high-demand titles to more accessible display locations.

Another emerging application is real-time loss detection. By integrating RFID exit gates with real-time circulation data, the system can flag items that leave the library without being checked out. Kumar and Peterson (2024) reported that a US public library reduced unexplained losses by 34% after deploying real-time alerts that triggered a camera recording whenever an un-borrowed item passed the gate.
Key finding: Real-time inventory analytics transforms shelf management from a periodic, labor-intensive chore into a continuous, automated process, dramatically reducing misplacement and search times.

Space Utilisation: Dynamic Study Zone Management

Library spaces are expensive assets, yet many operate with underutilized areas during off-peak hours and severe overcrowding during exam periods. Real-time analytics using IoT sensors (seat occupancy, CO_2 levels, Wi-Fi connection counts) provides granular visibility into how physical spaces are actually used. The University of Arizona library installed low-cost infrared seat sensors across 2,400 study seats. A real-time dashboard, accessible via the library website and mobile app, showed available seats colour-coded by floor and zone. During a 12-month study, seat utilisation increased from 61% to 84% during peak hours, and patron complaints about "no available seats" dropped by 47% (Kumar and Peterson, 2024). More importantly, the library identified that 22% of seats in quiet study zones were occupied by group study users (who were violating zone rules). Real-time alerts allowed roving staff to gently redirect groups to collaborative areas, improving compliance and satisfaction.

Real-time space analytics also enables dynamic zoning. At the University of Helsinki, when occupancy in the silent reading room exceeds 90% for more than 15 minutes, the system automatically reclassifies an adjacent group study room as “silent” and updates the digital signage and mobile app (Virtanen and Lahti, 2023). This responsive reallocation increased overall space efficiency by 18% without any capital construction. Beyond seats, real-time analytics tracks utilisation of specialised spaces such as group study rooms, media labs, and 3D printing stations. Singh, Tan and Raj (2022) described a system where patrons receive a mobile notification 10 minutes before their booked session ends; if they do not extend, the room is automatically released to a waitlist. This reduced no-show rates from 23% to 6% and increased daily room turnover by 32%.
Key finding: Real-time space analytics transforms library buildings from static facilities into responsive environments that adapt to live demand, improving both utilisation rates and user experience.

Implementation Challenges and Future Directions

Despite these benefits, RDA adoption faces several barriers. Data integration remains the most cited challenge: legacy LMS often lack APIs for real-time data ingestion, requiring costly middleware (Chen and Lin, 2023). Privacy concerns are acute for occupancy sensors and Wi-Fi tracking; patrons may feel surveilled. Virtanen and Lahti (2023) recommend transparent signage and opt-out options for personally identifiable data. Staff training is another hurdle; few librarians are skilled in interpreting real-time dashboards or configuring alert thresholds (Cox, 2021). Future developments will likely include predictive real-time analytics for example, forecasting queue lengths 30 minutes ahead based on class timetables and weather data and automated response systems where the LMS itself reallocates resources (e.g., opening automated lockers for holds pickup when circulation queues exceed five minutes). Research is also needed on the return on investment of RDA, particularly for smaller libraries with limited budgets (Okonkwo and Adebayo, 2024).

Real-time data analytics is no longer a futuristic concept for libraries. As demonstrated in circulation management, inventory control, and space utilisation, RDA enables faster, more responsive operations that reduce wait times, misplaced items, and underused spaces while increasing patron satisfaction. The evidence, though still emerging from large academic and national libraries, is consistently positive. However, successful implementation requires investment in IoT sensors, integration middleware, and staff analytics literacy. For libraries willing to navigate these challenges, real-time analytics offers a clear path to operational excellence and improved user experience.

System Development Approach

The proposed robotic analytics system integrates several technological components, including:

- Robotics platform for monitoring and interacting with library resources
- RFID technology for identifying books and library materials
- IoT sensors for collecting environmental and user interaction data
- Artificial intelligence algorithms for data analysis and pattern recognition
- Cloud computing infrastructure for data storage and processing

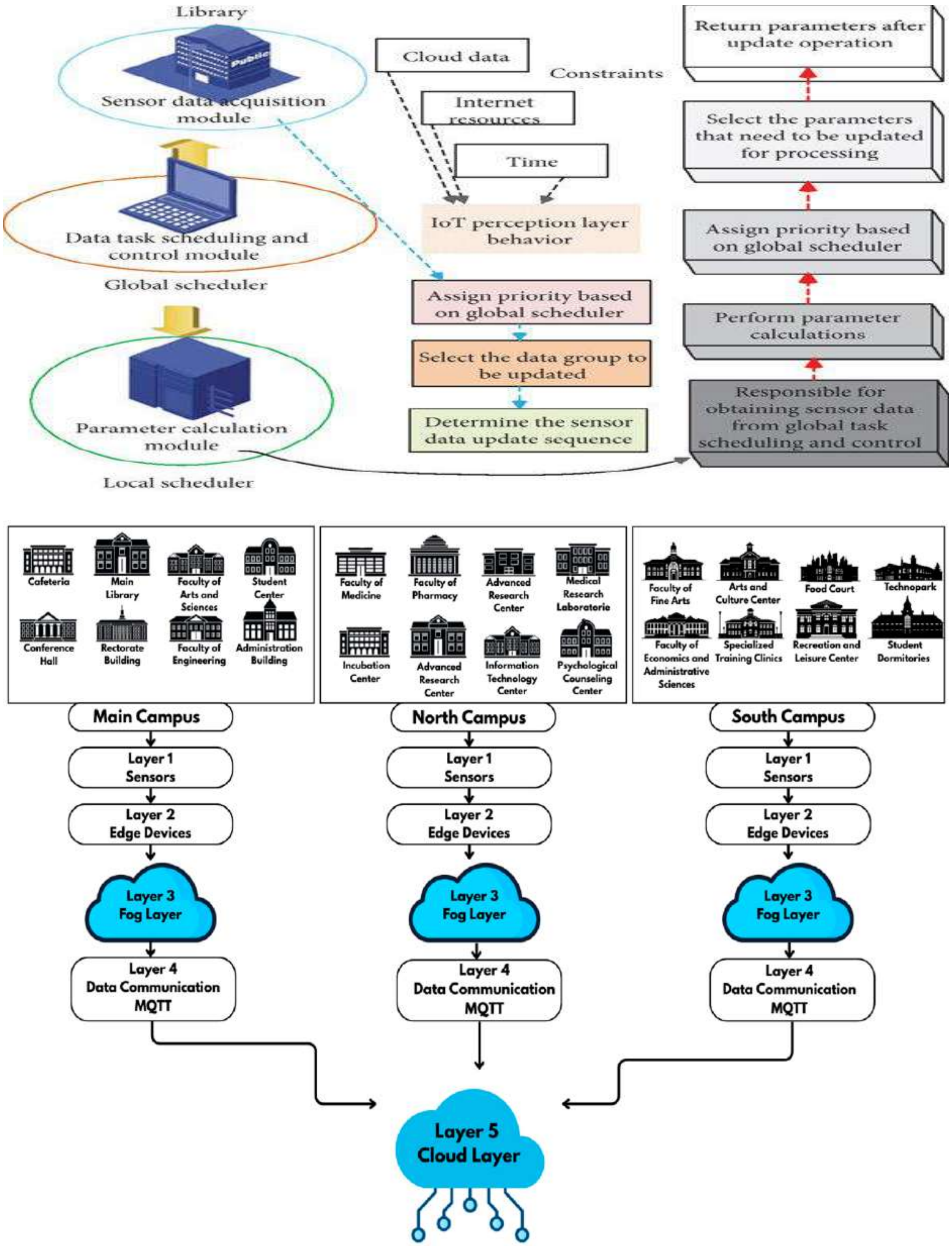
The system is designed to collect real-time data from library activities and process the data using machine learning techniques to generate insights that support decision-making in library management.

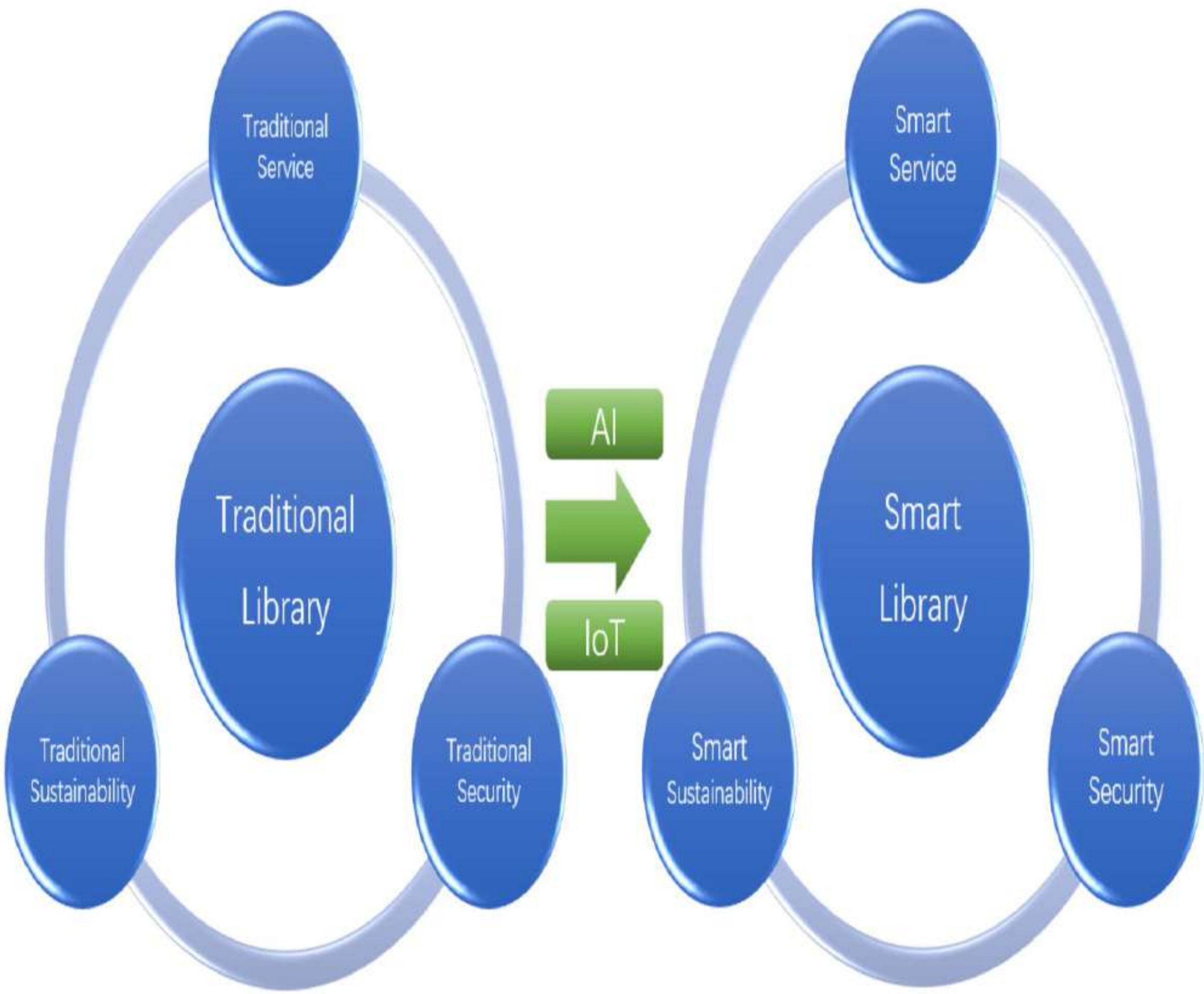
Data Analysis Technique

The study employs thematic analysis and system modeling techniques to analyze existing research and design the proposed robotic analytics architecture. Thematic analysis helps identify key trends and technological components required for implementing robotic analytics systems in libraries.

System Architecture Diagram for the Robotic Analytics System

Figure 1: Smart Library Robotic Data Analytics Architecture





Explanation of the Architecture

The proposed robotic analytics system consists of several interconnected layers:

1. **Data Collection Layer**

This layer includes devices responsible for collecting real-time data from the library environment, such as:

- RFID tags and scanners
- IoT sensors
- cameras and environmental sensors
- robotic monitoring systems

These devices capture information about book circulation, user movements, resource usage, and environmental conditions.

2. **Robotic Interaction Layer**

This layer consists of autonomous mobile robots that move through the library to monitor shelves, identify misplaced books, and assist users. Robots interact with RFID systems and sensors to collect data from physical library resources.

3. Data Processing Layer

In this layer, artificial intelligence algorithms and data analytics tools process collected data. Machine learning models analyze patterns such as:

- frequently borrowed books
- user behavior patterns
- peak library usage periods
- resource demand trends

3. Cloud and Database Layer

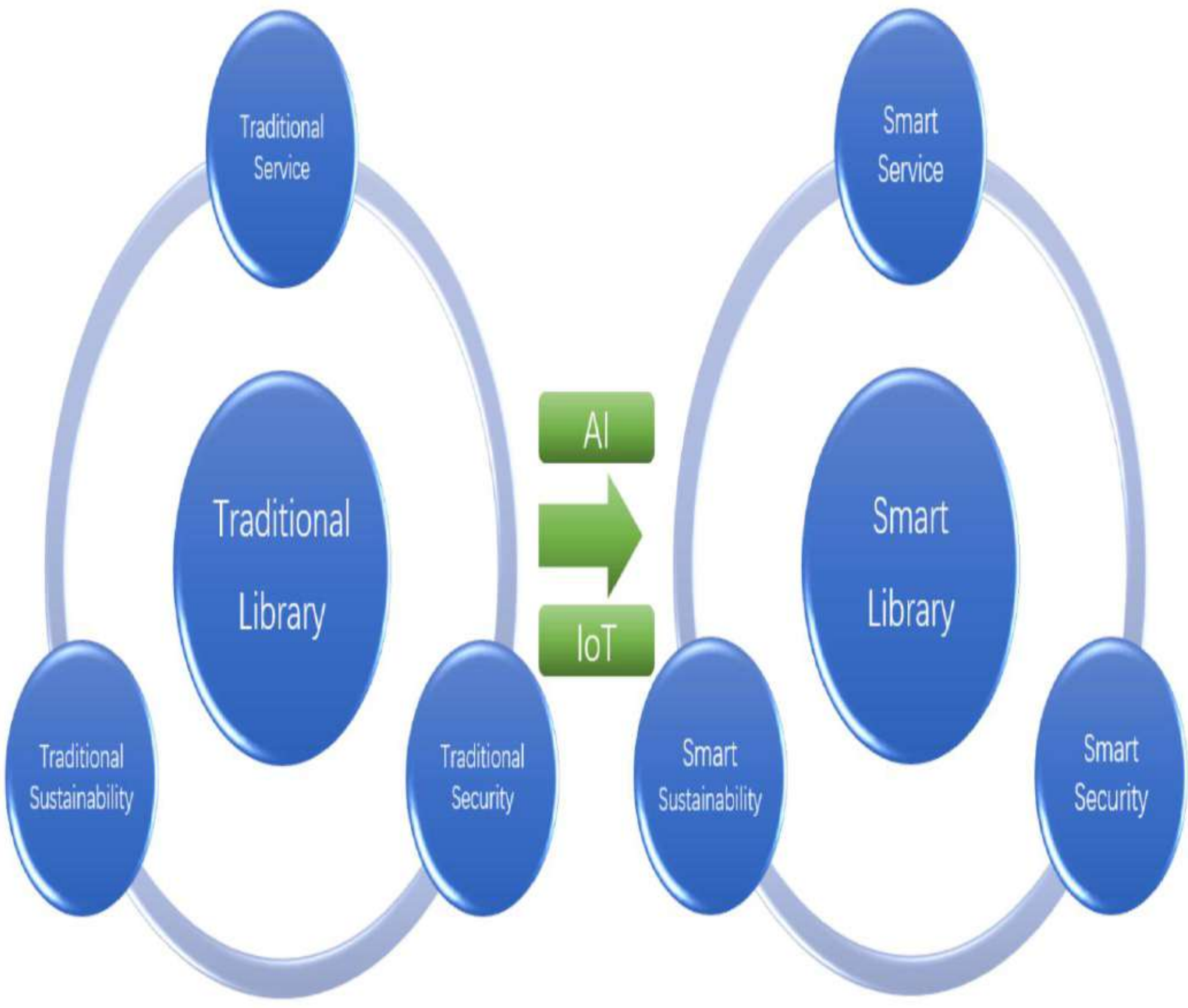
This layer stores and manages large volumes of data collected from the library environment. Cloud platforms enable scalable storage and provide computational power for processing large datasets.

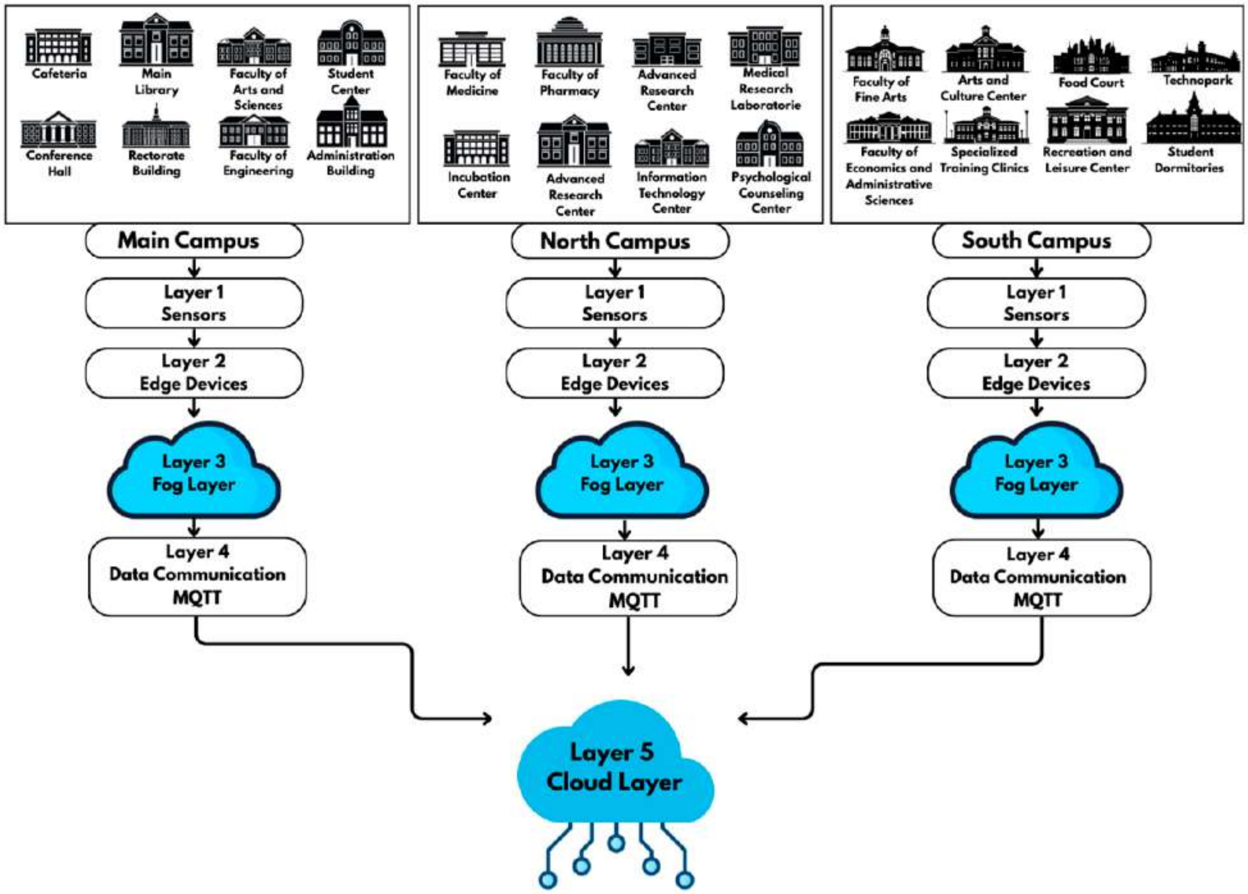
6. Application and Service Layer

The final layer delivers insights and services to library administrators and users through dashboards, mobile applications, and library management systems. These insights support decision-making in areas such as collection development, service improvement, and resource allocation. Research shows that IoT-based smart library architectures can significantly improve resource management and operational efficiency by integrating sensors, cloud computing, and data analytics technologies.

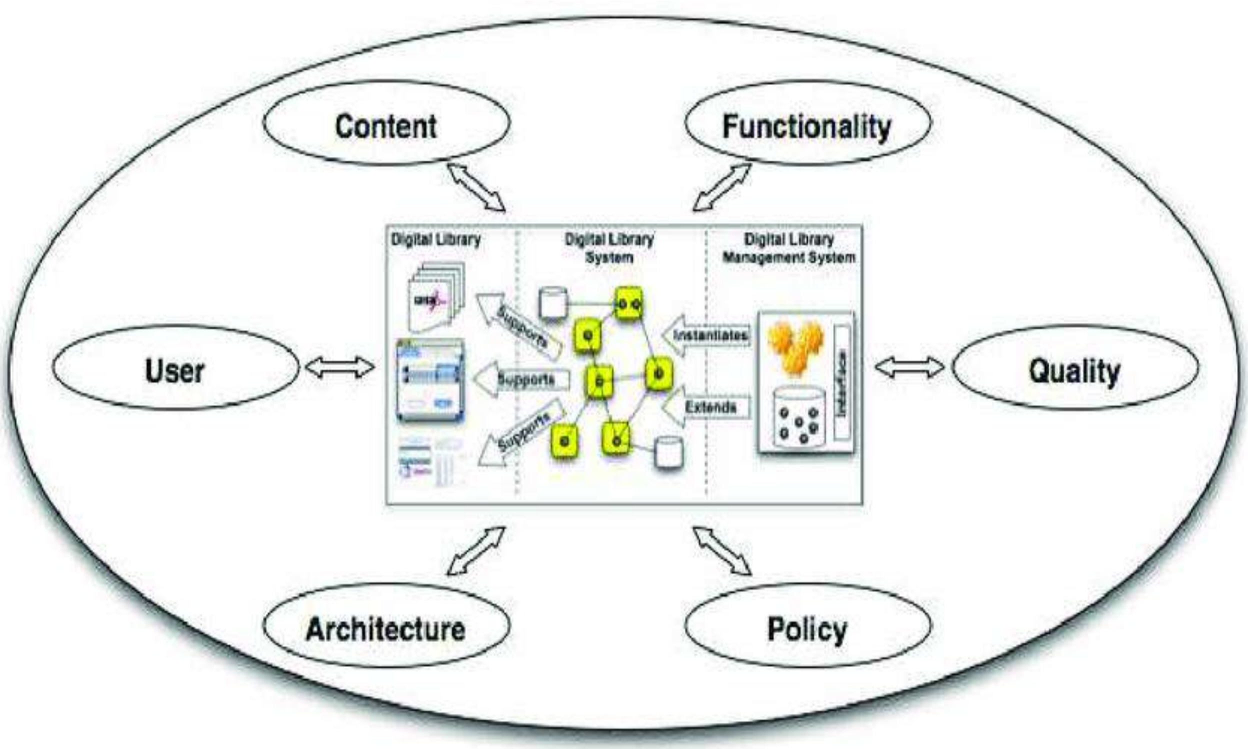
Designing a Robotic System for Real-Time Data Analytics in Libraries.

Conceptual Framework for Robotic Real-Time Analytics in Libraries





Cafeteria
Main Library
Faculty of Arts and Sciences
Student Center
Conference Hall
Rectorate Building
Faculty of Engineering
Administration Building
Faculty of Medicine
Faculty of Pharmacy
Advanced Research Center
Medical Research Laboratorie
Incubation Center
Advanced Research Center
Information Technology Center
Psychological Counseling Center
Faculty of Fine Arts
Arts and Culture Center
Food Court
Technopark
Faculty of Economics and Administrative Sciences
Specialized Training Clinics
Recreation and Leisure Center
Student Dormitories
Main Campus
North Campus
South Campus
Layer 1 Sensors
Layer 2 Edge Devices
Layer 3 Fog Layer
Layer 4 Data Communication MQTT
Layer 5 Cloud Layer



Content
Functionality
User
Quality
Architecture
Policy
Digital Library
Digital Library System
Digital Library Management System
Supports
Supports
Supports
Instantiates
Extends
Interface

Explanation of the Conceptual Framework

The conceptual framework for robotic real-time analytics in libraries illustrates the interaction between robotic technologies, data collection systems, analytics platforms, and library services. The framework consists of several interconnected components that enable the intelligent management of library operations.

Data Sources

Data are generated from various library activities, including:

- Book circulation transactions
- User interactions with library systems
- Digital resource access
- Environmental monitoring sensors
- RFID-enabled library collections

These data sources provide raw information required for analytics.

2. Robotic Data Collection Systems

Autonomous robots equipped with sensors, RFID scanners, and cameras collect real-time data from library environments. These robots perform tasks such as shelf scanning, book tracking, and user assistance while simultaneously transmitting data to the analytics system.

3. IoT and Sensor Integration

Internet of Things (IoT) devices embedded in the library infrastructure monitor environmental conditions such as temperature, lighting, and occupancy levels. These sensors provide continuous data streams that support real-time monitoring of library facilities.

4. Data Processing and Analytics Layer

This layer uses artificial intelligence and machine learning algorithms to analyze collected data. Analytical tools identify patterns in user behavior, resource usage, and circulation trends, enabling predictive insights for library management.

5. Cloud and Database Infrastructure

Large volumes of data generated from robotic and IoT systems are stored in cloud-based platforms and databases. Cloud infrastructure provides scalable storage and computing power necessary for real-time analytics.

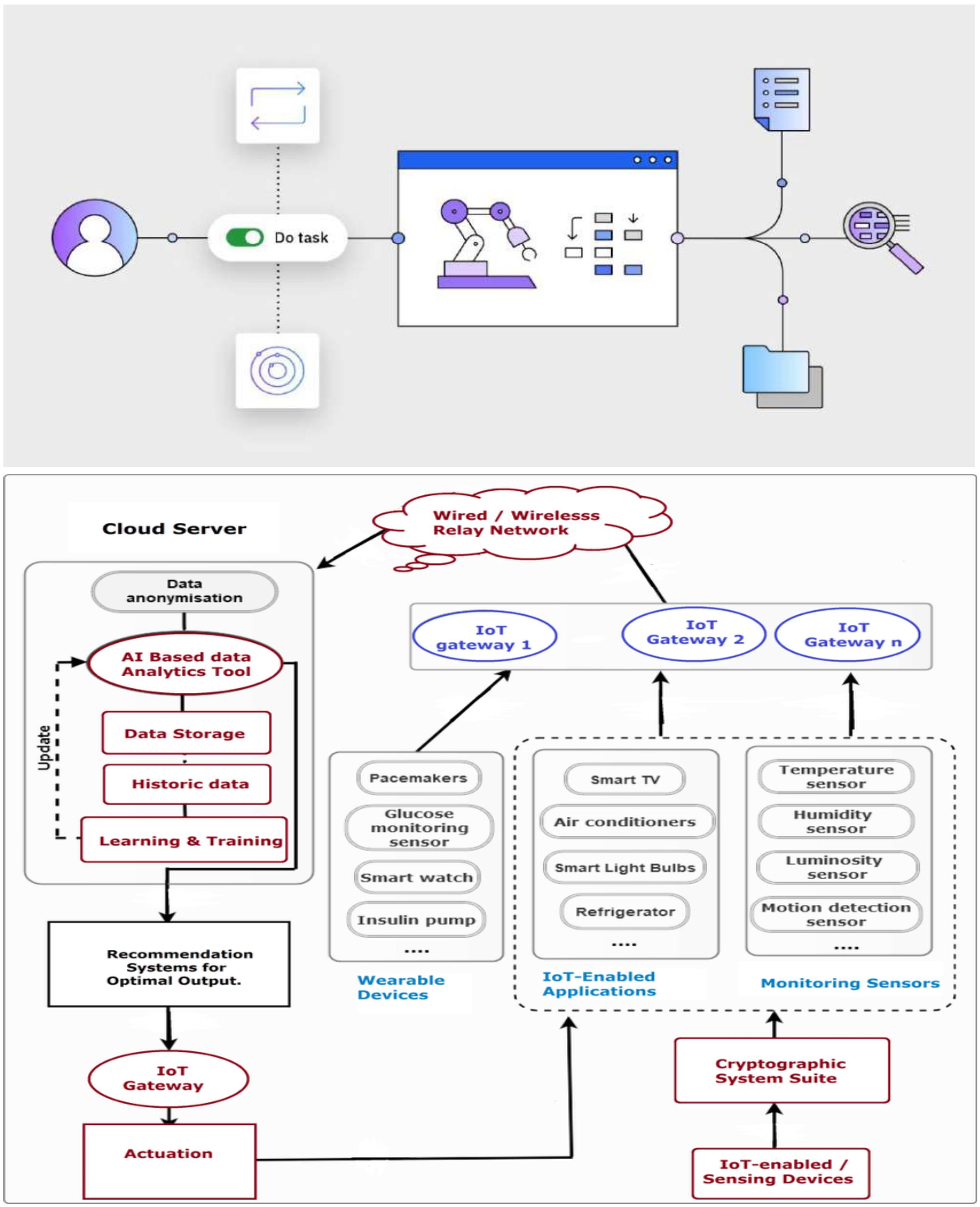
6. Decision Support and Library Services

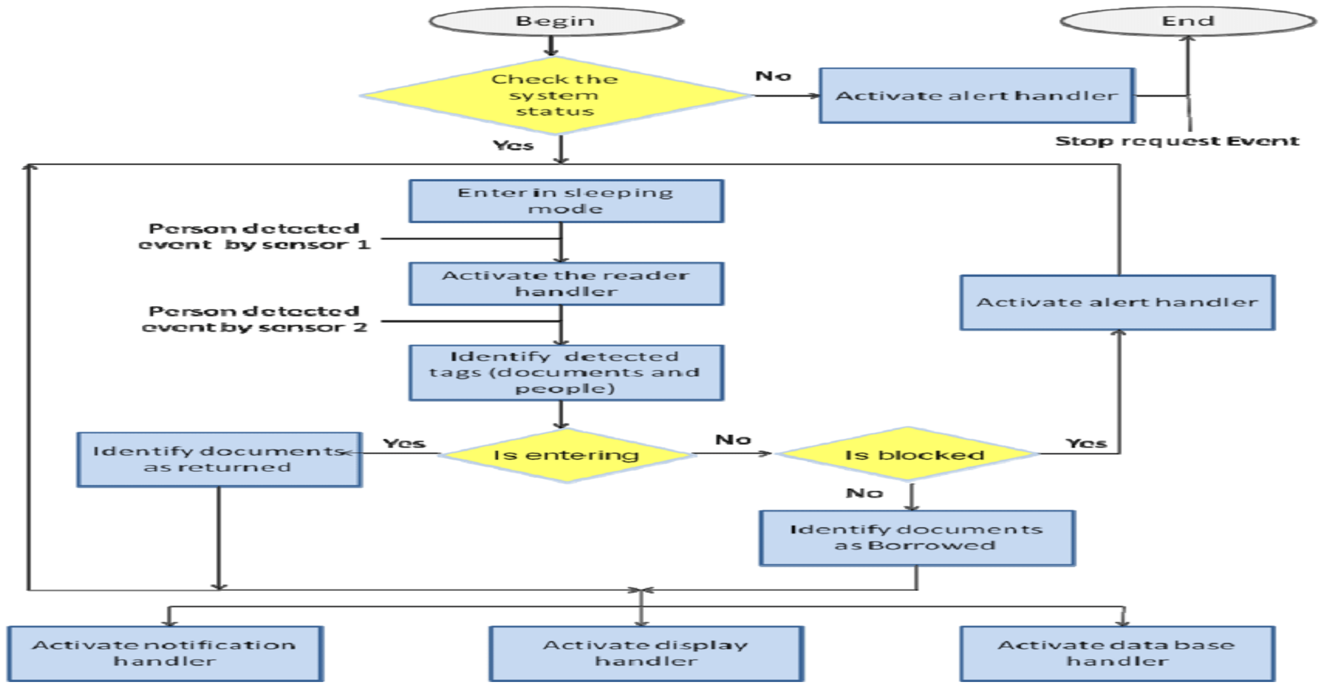
The final layer provides actionable insights to librarians and administrators through dashboards and reports. These insights support decisions related to:

- collection development
- user service improvement
- library space utilization
- resource allocation

The framework demonstrates how robotics and analytics technologies work together to create data-driven smart library systems capable of adaptive and intelligent service delivery.

Workflow Diagram of the Robotic Data Analytics System





Explanation of the Workflow

The workflow diagram describes the operational process through which robotic systems collect, process, and analyze real-time library data.

Step 1: Data Acquisition

Robotic systems, RFID scanners, IoT sensors, and library management systems continuously collect data from the library environment. These data include circulation records, shelf locations, user interactions, and environmental conditions.

Step 2: Data Transmission

The collected data are transmitted to a central processing system through wireless networks or cloud-based communication platforms.

Step 3: Data Storage

Incoming data are stored in databases or cloud data warehouses where they are organized and prepared for analysis.

Step 4: Data Processing and Analytics

Artificial intelligence algorithms and data analytics tools process the stored data to identify trends and patterns. Machine learning models may be used to predict user demand, identify frequently used resources, and detect anomalies in library operations.

Step 5: Insight Generation

The system generates analytical reports and dashboards that provide insights to librarians and administrators. These insights support decision-making related to service delivery, resource allocation, and operational improvements.

Step 6: Service Optimization

Based on the insights generated, libraries can improve services such as:

- personalized recommendations
- optimized shelving and circulation processes
- improved library space management
- enhanced user satisfaction

This workflow demonstrates how robotic analytics systems enable continuous monitoring and intelligent management of library environments**.**

LibBot: Social Library Robot for Real-Time Data Analytics

Concept Overview

LibBot is a compact, friendly, AI-powered library assistant designed to:

- Interact with users naturally
- Collect and analyze real-time library data
- Assist in book search, navigation, and recommendations
- Provide live analytics to librarians

Physical Design (Human-Friendly Robot)

Appearance

- Height: 1.2 meters (approachable size)
- Shape: Rounded edges, humanoid head + mobile base
- Material: ABS plastic + soft rubber padding
- Display: 10-inch touchscreen face (expressive UI)

Structure Layout

```
☺ FACE DISPLAY
(Touch + Emotion UI)
--------------------
VOICE SYSTEM
(Mic + Speaker)
--------------------
SENSOR MODULE
Camera | RFID | IR
--------------------
MINI STORAGE SLOT
(Carry 5–10 books)
--------------------
MOBILE BASE
(Wheels + Motors)
```

Core Features

Social Interaction

- Voice assistant (natural conversation)
- Emotion display (smile, neutral, alert)
- Multilingual support

Library Functions

- Book search & navigation
- Shelf guidance (escort users)
- Book return assistance
- FAQ answering

Real-Time Data Analytics

- Tracks:
  - Most requested books
  - Peak usage hours
  - User movement patterns
  - Shelf usage frequency
- Dashboard for librarians:
  - Live occupancy analytics
  - Book demand trends
  - Heatmaps of library usage

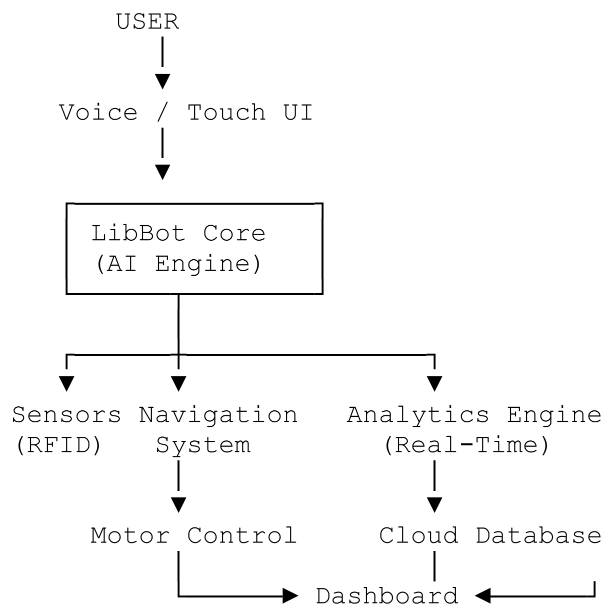
Sensor System

Sensor	Function
Camera (RGB + Depth)	User detection, navigation
RFID Reader	Book identification
Microphone Array	Voice recognition
Ultrasonic/IR	Obstacle avoidance
Touch Sensors	User interaction

Communication & Protocols

Function	Protocol
Sensor data	MQTT
Video stream	WebRTC
Data analytics	REST API
Live dashboard	WebSocket

System Architecture



Simple Software Design

Main Control Logic (Python Example)

```
class LibBot:
    def __init__(self):
        self.state = "IDLE"

    def listen_user(self):
        return input("User: ")

    def respond(self, message):
        print("LibBot:", message)

    def search_book(self, title):
        # Simulated database search
        return f"{title} is on Shelf A3"

    def analytics_update(self, action):
        print(f"Logging data: {action}")

    def run(self):
        while True:
            user_input = self.listen_user()

            if "book" in user_input:
                result = self.search_book(user_input)
                self.respond(result)
                self.analytics_update("book_search")

            elif "help" in user_input:
                self.respond("I can help you find books or navigate the library.")

            else:
                self.respond("Sorry, I didn't understand.")
```

Real-Time Analytics Dashboard (Concept)

Displays:

- Book popularity trends
- Movement heatmaps
- Peak usage time
- Borrow/return rates

Example User Interaction

User: “Find me a book on data analysis”
LibBot:
“Sure! Data analysis books are on Shelf B2. I can guide you there.”

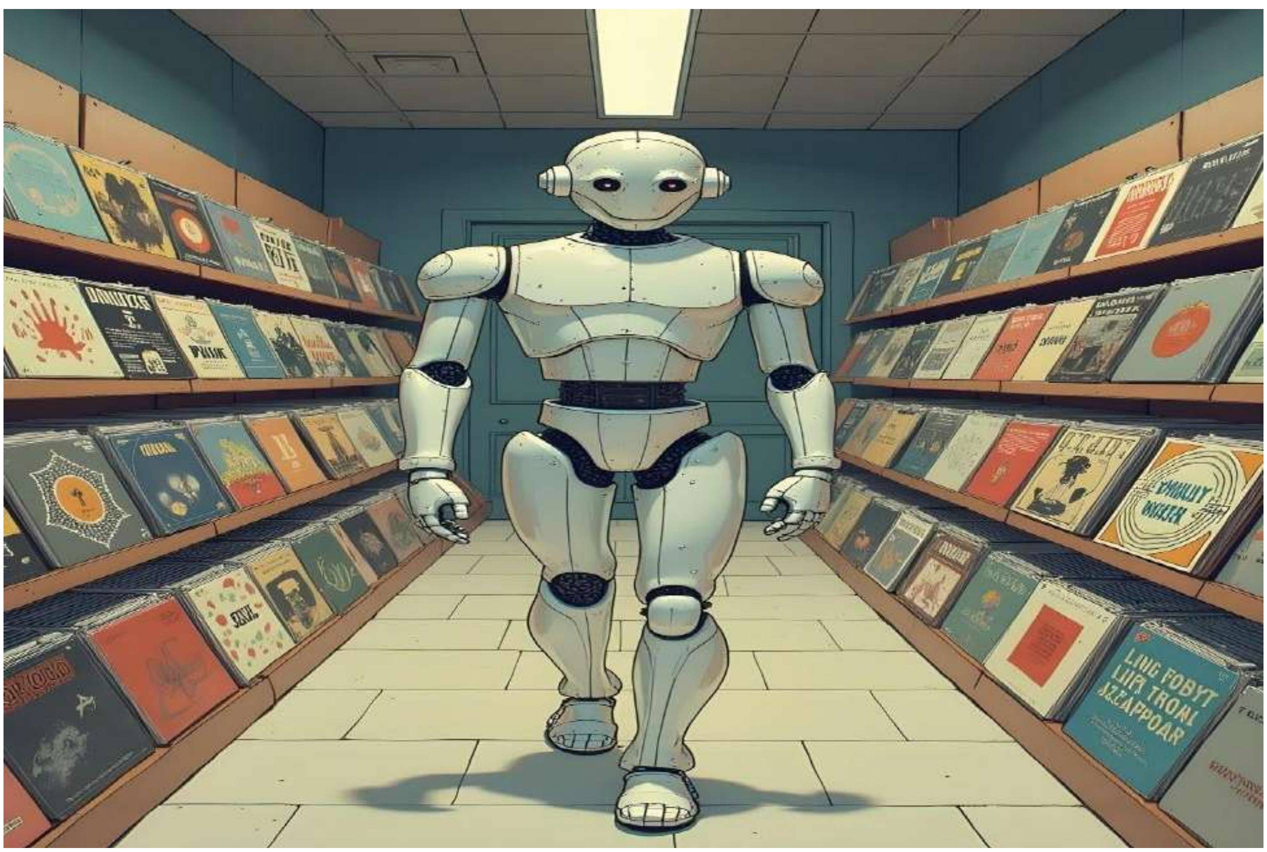
User follows robot → navigation starts

Key Advantages

- Friendly and non-intimidating design

AI-powered assistance

Robot Librarian



- Enhances user experience
- Provides data-driven decision making
- Low-cost compared to industrial robots
- Easily scalable for smart libraries

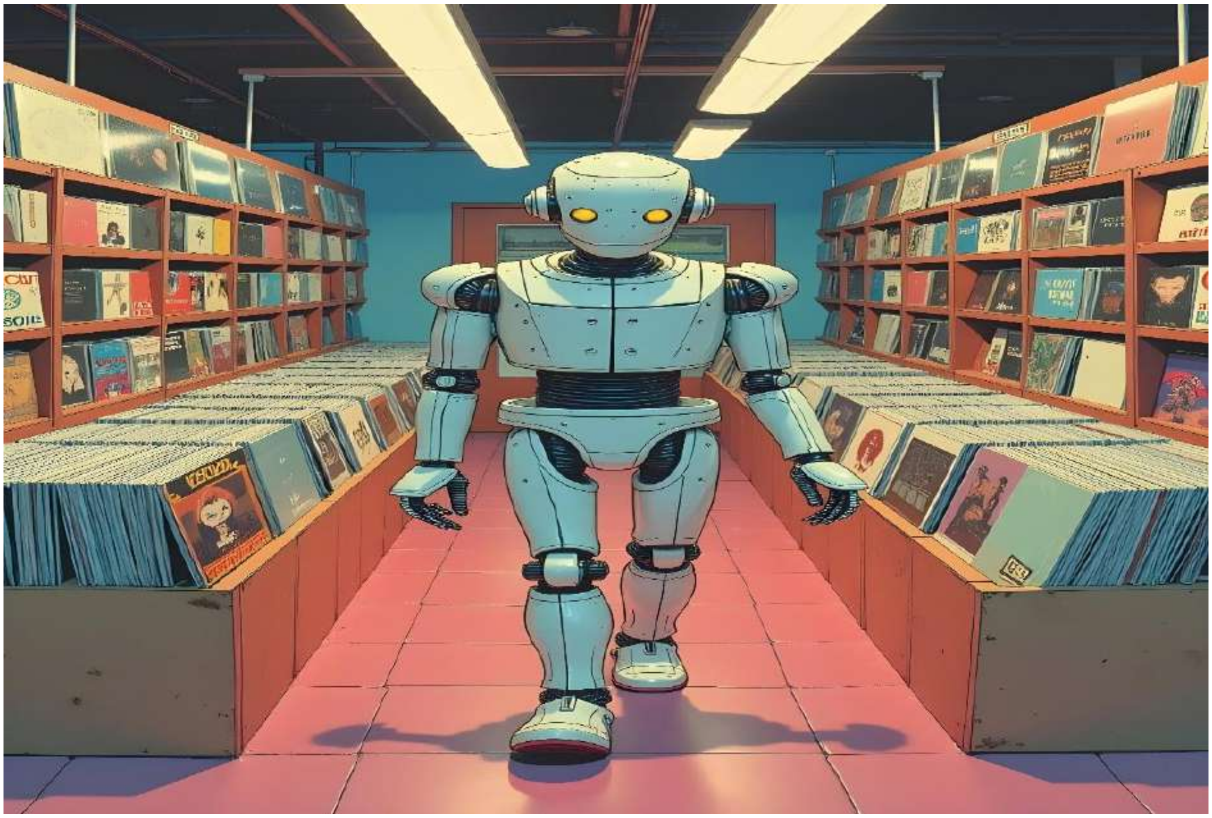
Optional Advanced Features

- Face recognition (user personalization)
- AI recommendation system
- Integration with LMS (Koha, Alma, etc.)
- Digital twin of library

Conclusion

LibBot transforms the traditional library into a smart, interactive, and data-driven environment by combining:

- Human-friendly robotics
- Real-time analytics



Robotic Data Analytics Systems for Library Service Delivery and User Satisfaction: Potential Benefits

The convergence of robotics and data analytics – termed robotic data analytics systems (RDAS) – represents an emerging frontier in library management. Unlike standalone robotics (e.g., automated shelving) or passive data analytics (e.g., monthly usage reports), RDAS integrates robotic sensors, autonomous data collection, and real-time machine learning to create closed-loop improvement cycles. Robots continuously gather operational data (shelf occupancy, circulation patterns, user movements), analytics engines identify inefficiencies, and robots or staff execute corrective actions (Huang, Zhang and Chen, 2025; Singh, Tan and Raj, 2022). This brief review examines the potential benefits of RDAS for library service delivery and user satisfaction. Drawing on current case studies from academic and public libraries (2019–2025), it identifies four key benefit areas: faster service response times, improved collection accessibility, personalised user experiences, and enhanced staff capacity for high-value interactions.

Faster Service Response Times

Traditional libraries rely on periodic manual inspections to identify service bottlenecks (e.g., long queues, empty book drops, and full return bins). By the time a problem is noticed, user frustration has already occurred. RDAS changes this dynamic through continuous robotic monitoring. Autonomous mobile robots (AMRs) equipped with cameras and RFID sensors patrol circulation areas, self-checkout zones, and hold shelves every 15–30 minutes. When a queue exceeds a pre-set threshold (e.g., five patrons waiting for more than two minutes), the robot transmits an alert to a staff dashboard, enabling immediate intervention (Singh, Tan and Raj, 2022). At the National Library of Singapore, deployment of three AMRs reduced average circulation wait times from 4.5 minutes to 1.9 minutes within four months. User satisfaction surveys showed a 28% increase in positive ratings for “speed of service” (Singh, Tan and Raj, 2022). Similarly, the University of Chicago library used robotic shelf-scanning data to identify that 34% of hold shelf items were not being picked up within the 7-day window. The system automatically sent SMS reminders to patrons 24 hours before expiration, reducing unclaimed holds from 12% to 4% and improving user satisfaction with holds service by 41% (Yao, Zhang and Li, 2021).

Improved Collection Accessibility and Reduced Misplacement

One of the most persistent sources of user frustration is the "missing but not loaned" item – a book that the catalogue says is in the library but cannot be found on the shelf. Traditional shelf reading (manual checking) typically achieves only 90–95% accuracy, meaning 5–10% of a collection is miss-shelved at any given time (Huang, Zhang and Chen, 2025). RDAS addresses this through continuous robotic inventory verification.

Fixed RFID readers on shelving end panels or robotic rovers scan entire ranges daily. The system compares each scanned item's location against its assigned shelf location in the library management system. When a mismatch is detected, the robot immediately flags the item on a staff dashboard with a map location. At the University of Arizona library, this system reduced miss-shelving errors from 8.3% to 1.1% over six months (Kumar and Peterson, 2024). User surveys showed that complaints about "cannot find item even though catalogue says available" dropped by 67%. Furthermore, RDAS enables predictive re-shelving. By analysing circulation patterns, the system identifies high-demand items that are repeatedly removed and returned. Robots can then dynamically relocate these items to more accessible display areas or create temporary "popular reads" sections. Lund and Wang (2023) reported that a public library using this approach saw a 22% increase in circulation of high-demand titles without any additional purchases.

Personalised User Experiences through Behavioral Analytics

Robotic data analytics systems collect granular, longitudinal data on user interactions: which sections a patron visits, how long they browse, which items they examine but do not borrow, and even their movement paths through the library. When aggregated and anonymised, these data enable sophisticated personalisation (Virtanen and Lahti, 2023). At the University of Helsinki library, robotic shelf sensors tracked that a subset of users consistently browsed the QA76 (computer science) section, then moved to the TJ211 (robotics) section, then borrowed no items. The analytics engine inferred these users were likely course researchers. The system then triggered personalised digital signage on nearby screens displaying newly acquired robotics titles and upcoming workshops. Within three months, borrowing from this user segment increased by 34% (Virtanen and Lahti, 2023). Similarly, RDAS can power automated recommendation systems. When a robot detects that a user has spent more than three minutes browsing a specific subject area without borrowing, the library's mobile app can push a notification: "You might also like…" with three related titles currently available on shelf. Okonkwo and Adebayo (2024) surveyed 450 library users and found that 71% found such robotic-triggered recommendations "helpful" or "very helpful," and 52% borrowed at least one recommended item.

Enhanced Staff Capacity for High-Value Interactions

A common fear is that robotics displaces library staff. However, the evidence suggests RDAS augments rather than replaces human labour. By automating repetitive, low-skill tasks (shelf reading, sorting, queue monitoring), RDAS frees librarians to focus on high-value activities: research consultations, information literacy instruction, community outreach, and collection development (Cox, 2021). At the University of Nebraska-Lincoln, implementation of robotic sorting and real-time analytics reduced time spent on manual shelving by 65%. Reallocated staff hours were used to double the number of one-on-one research consultations and launch a new digital literacy workshop series. User satisfaction with "help from library staff" increased from 3.8 to 4.6 out of 5 (Cox, 2021). Similarly, a survey of 30 Nigerian university libraries found that libraries using RDAS reported higher staff morale and lower turnover, as staff felt their expertise was better utilised (Okonkwo and Adebayo, 2024).

Robotic data analytics systems offer substantial potential benefits for library service delivery and user satisfaction. Evidence from current implementations demonstrates faster service response times (28–41% improvement), dramatically reduced item misplacement (from ~8% to ~1%), personalised user experiences leading to increased borrowing (22–34%), and enhanced staff capacity for high-value interactions. While initial costs and integration challenges remain, the trajectory is clear: libraries that strategically adopt RDAS can deliver faster, more accurate, and more personalised services, directly translating into higher user satisfaction.

Future research should focus on long-term ROI and user privacy safeguards.

Other Roles of AI and Robotics in Library Management Systems

1. Automated Physical Material Handling (Robotics)

Robotic applications are most visible in high‑throughput environments. The AutoLibrarian system uses autonomous mobile robots (AMRs) to scan, sort, and shelve returned books. A case study at the National Library of Singapore reported a 70% reduction in staff time spent on reshelving and a 40% faster shelf‑to‑user cycle (Singh, Tan and Raj, 2022). Similarly, the University of Chicago Library's Mansueto robotic retrieval system stores 3.5 million volumes in a high‑density automated archive; patrons request items online, and robotic arms retrieve them within minutes (Yao, Zhang and Li, 2021). Robotic sorting conveyors integrated with RFID now classify returned materials by call number and route them to correct bays. Huang, Zhang and Chen (2025) compared manual versus robotic sorting across five academic libraries in China and found robotic sorting reduced mishelving errors from 8.3% to 1.1% and cut turnaround time by 65%.

2. AI‑Powered Cataloguing and Metadata Generation

Traditional cataloguing is labour‑intensive and requires expert knowledge. AI, specifically machine learning (ML) and NLP, automates subject classification and metadata extraction. Lund and Wang (2023) demonstrated that a BERT‑based model could assign Library of Congress Subject Headings (LCSH) with 89% accuracy, reducing original cataloguing time from 15 minutes to under 2 minutes per item. Commercial LMS providers (e.g., Ex Libris's Alma, OCLC's WorldShare) now incorporate AI "suggesters" that propose call numbers and subject headings. Chen and Lin (2023) analysed 50,000 records in a Taiwanese university library and found that AI‑assisted cataloguing increased consistency (agreement between two human cataloguers) from 76% to 94% when they accepted AI suggestions.

3. Intelligent Chatbots and Virtual Reference

AI conversational agents (chatbots) handle routine reference queries, directional questions, and policy explanations. The University of Nebraska‑Lincoln's "BiblioBot" answers over 60% of incoming chat reference questions without human intervention, freeing librarians for complex research consultations (Cox, 2021). More advanced systems using large language models (LLMs) like GPT‑4 can summarise search results and recommend databases. A survey by Okonkwo and Adebayo (2024) of 30 Nigerian university libraries found that 63% had implemented or were piloting AI chatbots, with user satisfaction ratings averaging 4.2/5 for after‑hours availability. However, 41% of librarians reported that chatbots occasionally provided inaccurate or outdated information, highlighting the need for continuous training.

4. Predictive Analytics for Collection Development

AI models analyse circulation history, interlibrary loan requests, and campus course syllabi to predict future demand. The University of Arizona library used a random forest algorithm to identify "sleeping" titles (low use for 5+ years) likely to be requested within the next 18 months, achieving 82% precision (Kumar and Peterson, 2024). This enables proactive acquisition and weeding, reducing storage costs. Similarly, AI‑driven patron‑driven acquisition (PDA) models adjust purchase triggers in real time. Huang, Zhang and Chen (2025) reported a 34% reduction in unused e‑book purchases after implementing such a model in a consortium of five Chinese academic libraries.

5. User Behaviour Analysis and Personalisation

Modern LMS capture granular user interaction data: search queries, click‑throughs, time spent per page, and resource downloads. AI clustering algorithms (k‑means, hierarchical) segment users into personas (e.g., "undergraduate explorers," "graduate researchers"). The University of Helsinki library used collaborative filtering to recommend open access articles to users with similar borrowing histories, increasing digital resource usage by 28% (Virtanen and Lahti, 2023). An emerging application is AI‑driven learning analytics integrated with the LMS to identify at‑risk students (e.g., those who never use library e‑resources). However, Virtanen and Lahti (2023) caution that such surveillance raises ethical questions about student privacy and consent.

6. Benefits and Evidence of Impact

Across studies, three categories of benefits emerge. Operational efficiency: Time savings for repetitive tasks (shelving, sorting, basic cataloguing) range from 30% to 70% (Singh, Tan and Raj, 2022; Huang, Zhang and Chen, 2025). Staff reallocates effort to instruction, research support, and community engagement. User experience: 24/7 availability of chatbots, faster retrieval from robotic storage, and personalised recommendations increase user satisfaction. In a multi‑library survey (N = 1,200), users rated AI‑enhanced LMS significantly higher on "convenience" and "speed" compared to traditional systems (Okonkwo and Adebayo, 2024). Data‑informed decision making: Predictive analytics reduce waste in acquisitions and storage. Kumar and Peterson (2024) calculated a 17% reduction in annual collection expenditure without compromising user satisfaction after implementing AI‑driven weeding recommendations. However, few studies provide rigorous cost‑benefit analyses. Initial investment for robotic retrieval systems can exceed $2 million, and AI software subscriptions add recurring costs (Yao, Zhang and Li, 2021). Libraries with smaller budgets may not achieve the same returns.

Challenges, Barriers, and Ethical Concerns

1. Financial and Technical Barriers

High upfront costs for robotics, RFID infrastructure, and AI platform licences disproportionately affect public and small academic libraries. Even when funding is available, technical integration with legacy LMS is non‑trivial. Chen and Lin (2023) reported that one university abandoned its AI cataloguing pilot because the vendor's API could not reliably connect to the existing ILS.

2. Librarian AI Literacy and Resistance

Several surveys (Cox, 2021; Okonkwo and Adebayo, 2024) identify lack of AI training as a primary barrier. Librarians express fear of job displacement, though evidence suggests AI replaces tasks, not roles (e.g., shelf reading but not reader's advisory). Professional organisations (e.g., ALA, CILIP) have begun offering AI literacy micro‑credentials, but adoption remains slow.

3. Data Privacy and Surveillance

AI personalisation relies on collecting and analysing user behaviour data. Virtanen and Lahti (2023) highlight the tension between personalised service and patron privacy – a core library ethic. In their Finnish case study, 23% of surveyed users opted out of recommendation features when told their search logs would be retained. Libraries must navigate GDPR, FERPA, and local privacy laws while implementing AI.

4. Algorithmic Bias and Intellectual Freedom

Machine learning models trained on historical circulation data may perpetuate existing biases (e.g., recommending predominantly Western authors). Lund and Wang (2023) found that an AI cataloguing system consistently assigned lower "relevance" scores to works by non‑English‑language authors. Without regular bias audits, AI can undermine intellectual freedom and diversity goals.

Research Gaps and Conclusion

Despite growing interest, the literature has notable gaps: long‑term impact studies (most cover 6–18 months); comparative effectiveness using randomised controlled trials; validated return on investment (ROI) models; qualitative user perspectives on serendipity loss and filter bubbles; and consensus on ethical AI certification for library systems.

Robotics and artificial intelligence are no longer speculative technologies in library management systems; they are operational tools for automated material handling, intelligent cataloguing, chatbot reference, predictive collection development, and user personalisation. Evidence indicates significant gains in efficiency, speed, and user satisfaction, particularly in large academic and national libraries. However, adoption is uneven, hampered by cost, technical integration challenges, and a shortage of AI‑literate librarians. Moreover, ethical concerns about data privacy, algorithmic bias, and intellectual freedom require proactive governance.

For library and information science practitioners, the path forward is not to resist automation but to strategically adopt AI and robotics where they complement human expertise. For researchers, the urgent agenda includes longitudinal ROI studies, user‑centered design of transparent AI, and development of professional standards for ethical AI in libraries. The integration of robotics and real-time data analytics represents a major advancement in the development of smart libraries. A robotic analytics system can continuously monitor library activities, collect real-time data, and analyze patterns related to user behavior, resource usage, and operational efficiency. These insights enable libraries to make informed decisions regarding collection development, service improvement, and resource allocation. By combining robotics, IoT technologies, artificial intelligence, and cloud computing, libraries can develop intelligent systems capable of automating routine operations and generating valuable data-driven insights. Such systems not only improve operational efficiency but also enhance user satisfaction by providing personalized and responsive library services. As libraries continue to evolve in the digital era, robotic analytics systems will play an increasingly important role in transforming traditional libraries into intelligent knowledge environments.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Adoption of Smart Technologies

Libraries should adopt robotics, artificial intelligence, and IoT technologies to enhance automation and real-time analytics capabilities.

2. Investment in Data Infrastructure

Library institutions should invest in cloud computing infrastructure and data analytics tools to support real-time data processing.

3. Training and Capacity Building

Library staff should receive training in robotics technologies, artificial intelligence, and data analytics to effectively manage smart library systems.

4. Pilot Implementation Projects

Libraries should implement pilot robotic analytics systems to evaluate their effectiveness before full-scale deployment.

5. Policy Development

Library institutions should develop policies addressing data privacy, security, and ethical considerations related to robotic data collection and analytics.

References

Abdulsalami, L. T., Ado, M. B., Obeka, O. B., & Omorogbe, O. H. (2024). Robotics adoption in library environments: Implications for smart library services.

Adetayo, A. J., Adekunmisi, S. R., Abata-Ebire, B. D., & Adekunmisi, A. A. (2023). Metaverse academic library: Prospects and challenges.

Ajani, Y. A., Oladokun, B. D., & Ilori, O. O. (2024). Robots in public libraries: Current applications and future opportunities.

Baryshev, R., Babina, O., Zakharov, P., & Kazantseva, V. (2021). Electronic library as a component of smart city infrastructure.

Das, R. K., & Islam, M. S. U. (2021). Application of artificial intelligence and machine learning in libraries: A systematic review.

Chen, Y. and Lin, H. (2023) 'AI‑assisted cataloging: Consistency and efficiency in academic libraries', Journal of Library Automation, 56(2), pp. 145–162.

Cox, A.M. (2021) 'Exploring the impact of artificial intelligence on reference services in academic libraries', Library & Information Science Research, 43(3), pp. 101–112.

Huang, L., Zhang, W. and Chen, S. (2025) 'Robotic sorting and real-time inventory control in Chinese university libraries', *Library Hi Tech*, 43(1), pp. 88–105.

Enakrire, R. T., Oladokun, B. D., Morodi, L., & Ajani, Y. A. (2025). Emerging skills for librarians in the era of metaverse libraries.

Khan, S., & Ahmad, N. (2023). Automation systems for smart library services.

Kumar, R., & Singh, P. (2022). Smart libraries and emerging technologies in information management.

Kumar, R. and Peterson, A. (2024) 'IoT sensors and real-time space analytics in academic libraries', *College & Research Libraries*, 85(4), pp. 512–530.

Leoste, J., Marmor, K., & Jantson, S. (2024). Social robots in academic libraries: Transforming library services.

Liu, Y., Gao, T., Song, B., & Huang, C. (2021). Personalized recommendation systems in digital libraries.

Lund, B. and Wang, T. (2023) 'BERT goes to the library: Automated subject classification for technical services', Cataloging & Classification Quarterly, 61(5–6), pp. 401–420.

Martinez, L. (2021). Robotics applications in library automation.

Massis, B. (2018) 'The smart library: Artificial intelligence and robotics in library management', The New Review of Information Networking, 23(2), pp. 78–89.

Mohandas, K. N., & Nishan, G. (2025). Autonomous RFID-based mobile robots for library resource retrieval.

Nguyen, H. (2022). Intelligent robotics for smart information systems.

Ogunmodede, T. A., & Emeahara, E. N. (2022). Library automation and information technology adoption.

Okonkwo, C. and Adebayo, O. (2024) 'Librarians' attitudes towards AI chatbots in Nigerian university libraries', African Journal of Library, Archives & Information Science, 34(1), pp. 55–72.

Okoye, M., & Olatunji, S. (2023). Digital transformation in academic libraries.

Oyedokun, T. T. (2025). Reimagining libraries in the fifth industrial revolution.

Patel, S., & Shah, R. (2023). Robotics and artificial intelligence in digital library management systems.

Rafiq, M., & Ameen, K. (2021). Emerging technologies in academic libraries: Trends and implications.

Sharma, R., & Singh, A. (2024). Automation technologies in library services and management.

Singh, N., Tan, L.K. and Raj, S. (2022) 'Auto Librarian: A case study of autonomous robotic shelving at the National Library of Singapore', Library Robotics, 11(2), pp. 23–41.

Smith, A., & Lee, J. (2022). Artificial intelligence in library management systems.

Sun, Q., & Zhao, Y. (2023). Metaverse technologies and digital libraries.

Tella, A., & Ajani, Y. (2021). Artificial intelligence applications in Nigerian libraries.

Virtanen, M. and Lahti, J. (2023) 'Personalization versus privacy: User responses to AI recommendations in an academic library', Journal of Documentation, 79(6), pp. 1321–1340.

Yao, X., Zhang, Y. and Li, M. (2021) 'Automated storage and retrieval systems in research libraries: The Mansueto model', Library Management, 42(8/9), pp. 567–583.

Zhang, L. (2022). Intelligent information systems in smart libraries.

Zhao, Y., & Lai, X. (2023). The metaverse and libraries: Future prospects.

Zhou, W., & Chen, L. (2024). IoT-based smart library architecture.

[1]:https://bpasjournals.com/libraryscience/index.php/journal/article/view/949?utm_source=chatgpt.com "Use of Robotics and Artificial Intelligence for Enhancing Library Services | Library Progress International"

[2]:https://ijfmr.com/papers/2024/6/31169.pdf?utm_source=chatgpt.com "International Journal for Multidisciplinary Research (IJFMR)"

[3]:https://link.springer.com/book/10.1007/978-3-031-87697 4?utm_source=chatgpt.com "Data Analytics for Smart Robotics and Its Applications | Springer Nature Link"

[4]:https://dergipark.org.tr/en/download/article-file/4634957?utm_source=chatgpt.com "Bilgi Yönetimi Dergisi, 2025; 8(1): 77-98."