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Smart Library Shelf Scanner & Book Tracking System

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Abstract
Modern library infrastructures face significant operational hurdles, primarily the labour intensive nature of manual inventory audits and the persistent issue of misplaced volumes, which renders collections inaccessible to patrons. This paper proposes an IoT-based Smart Library Shelf Scanner and Book Tracking System designed to automate the monitoring and localization of library assets in real time. The system utilizes Radio Frequency Identification (RFID) technology as its primary tracking mechanism, replacing traditional line-of-sight barcode systems. Each book is equipped with a passive RFID tag containing unique identification data, which is captured by a mobile scanning unit either an autonomous robotic platform or a handheld long-range reader. By integrating a microcontroller-based processing unit with Wi-Fi connectivity, the scanner cross-references physical shelf data against the Integrated Library System (ILS) database. Key functionalities include automated misplacement detection, where the system identifies books shelved in the wrong category or sequence, and instant inventory reconciliation, which drastically reduces the time required for annual audits. A centralized web dashboard provides librarians with a heat map of shelf occupancy and specific alerts for missing items. The implementation of this system aims to enhance operational efficiency by reducing manual labour by up to 80% and ensuring near-perfect inventory accuracy. Ultimately, the Smart Library Shelf Scanner bridges the gap between physical collections and digital records, ensuring that the library remains a highly organized and accessible resource for its community.

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I. INTRODUCTION

1.1 Background to Study

The historical evolution of library management has transitioned from manual ledger systems to sophisticated digital databases, yet the physical oversight of collections remains tethered to resource-heavy human intervention. Historically, the preservation of order within a library relied on the Dewey Decimal or Library of Congress classification systems, which are only effective if books are returned to their precise coordinates.The emergence of Radio Frequency Identification (RFID) technology offered a promising leap forward, allowing for bulk reading of items without physical contact, yet standard RFID implementations often fall short in the dense, metal-heavy environments of modern stacks where signal collision and shielding occur. Current research in the field is now shifting toward the integration of autonomous robotics and Internet of Things (IoT) sensors to create a "Smart Library" environment that can self monitor and report discrepancies in real-time.

1.2 Statement of the Research

The persistent "data-reality gap" in modern library management represents a critical failure in the synchronization between digital information systems and physical inventory, where the lab or intensive nature of manual shelf-reading results in chronic inaccuracies that render many items effectively lost.

While Online Public Access Catalogs (OPAC) provide instantaneous access to bibliographic metadata, they fail to account for the dynamic movement of physical assets that are frequently misplaced by patrons or incorrectly shelved by staff, leading to a phenomenon where books are "available" in the database but physically inaccessible on the floor. This discrepancy is exacerbated by the sheer scale of modern collections, which makes frequent manual audits economically and operationally unfeasible, leaving libraries to rely on infrequent, error-prone human inspections that cannot keep pace with daily circulation. Furthermore, existing technological attempts to automate this process, such as basic RFID implementations, often struggle with the physical

constraints of high density metal shelving and signal interference, which prevents the precise localization required to identify a single book out of order among thousands.

1.3 Significance of the Research

The development of a smart library shelf scanner and book tracking system holds profound significance by fundamentally redefining the efficiency of knowledge management and the accessibility of educational resources in the digital age.

By automating the traditionally manual and error-prone process of shelf-reading, this research provides an immediate solution to the "hidden" inventory loss that plagues large-scale institutions, ensuring that every asset is accounted for without the prohibitive costs of constant human labour.

1.4 Introduction of the Project

The introduction of the Smart Library Shelf Scanner and Book Tracking System marks a transformative shift from traditional, labour-intensive library management to a sophisticated, tech-driven ecosystem designed for the modern information age. In an era where data precision is paramount, library foundational pillars of academic and public knowledge continue to struggle with the logistical bottleneck of manual inventory tracking and the frequent misplacement of physical assets.

Fig 1. Basic structure of Smart library shelf scanner and book tracking system

This project introduces an autonomous scanning framework that integrates Radio Frequency Identification (RFID) technology, robotics, and real-time data processing to bridge the gap between the library's digital catalog and its physical shelves.

II LITERATURE REVIEW

2.1 Literature Review

In recent years, libraries have increasingly adopted digital technologies to improve efficiency and user experience.Traditional library management systems rely heavily on manual processes such as barcode scanning and physical verification of books, which are time-consuming and prone to human error. To overcome these limitations, several advanced systems have been developed using technologies like RFID (Radio Frequency Identification), IoT (Internet of Things), and automation.Previous studies highlight that RFID-based library systems allow faster book identification and tracking compared to barcode systems. Researchers have also proposed smart shelves equipped with sensors that can detect the presence or absence of books in real time.

Some systems integrate mobile applications and cloud databases, enabling users and librarians to locate books instantly and monitor inventory remotely.Additionally, automated robotic shelf scanners have been introduced in modern libraries. These robots can move along aisles, scan book spines, and update the database automatically. Such systems reduce manual workload and improve accuracy in book management. However, challenges like cost, implementation complexity, and maintenance still exist.

2.2 Scope of the Project

The functional scope of a smart library book system focuses on automating the lifecycle of library resources and enhancing the user experience through integrated technology. At its core, the system facilitates automated circulation, allowing patrons to perform self-service check-outs and check-ins using RFID or QR code technology, which significantly reduces wait times and manual labour. For users, the scope includes a digital

discovery platform (Smart OPAC) that provides advanced search capabilities, real-time availability status, and AI-driven personalized recommendations based on reading history.
On the administrative side, the system encompasses real-time inventory management, where IoT sensors and handheld scanners track book locations to prevent misplacement and streamline stock audits. Additionally, the functional scope covers automated user account management, including digital registration, fine calculation through integrated payment gateways, and automated notification systems for overdue items or reservation alerts. Finally, it provides librarians with data analytics and reporting tools to monitor library usage trends, helping them make informed decisions regarding collection development and space optimization.

2.3 Objectives of the Project

The primary objectives of a smart library book system are to maximize operational efficiency and modernize the user experience through the integration of advanced automation and data-driven insights. By implementing RFID and IoT technologies, the project aims to minimize manual intervention in routine tasks like check-outs, returns, and inventory sorting, allowing library staff to focus on specialized patron support and curation. Another core goal is to improve resource accessibility by providing 24/7 digital access to the catalog and enabling self-service stations that eliminate traditional queuing. Furthermore, the system seeks to enhance data accuracy and security by providing real-time tracking of assets to prevent loss and using analytics to understand community reading patterns.

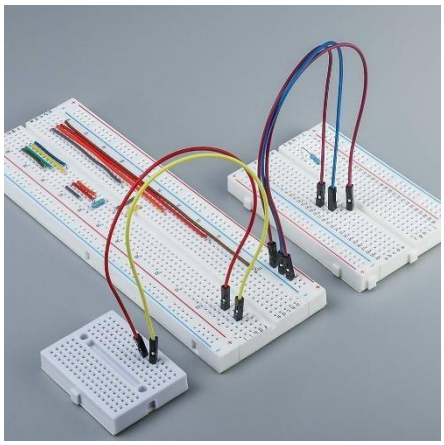

Fig 2 Bread board

The system is also heavily dependent on connectivity, meaning that features like real-time cloud syncing and mobile app functionality may be limited in areas with unstable internet.Furthermore, there are physical limitations regarding the tagging process, where certain materials (like metal or liquid-filled containers) can interfere with RFID signal accuracy

Fig 3 Display

III. METHODOLOGY

3.1 Flow Chart

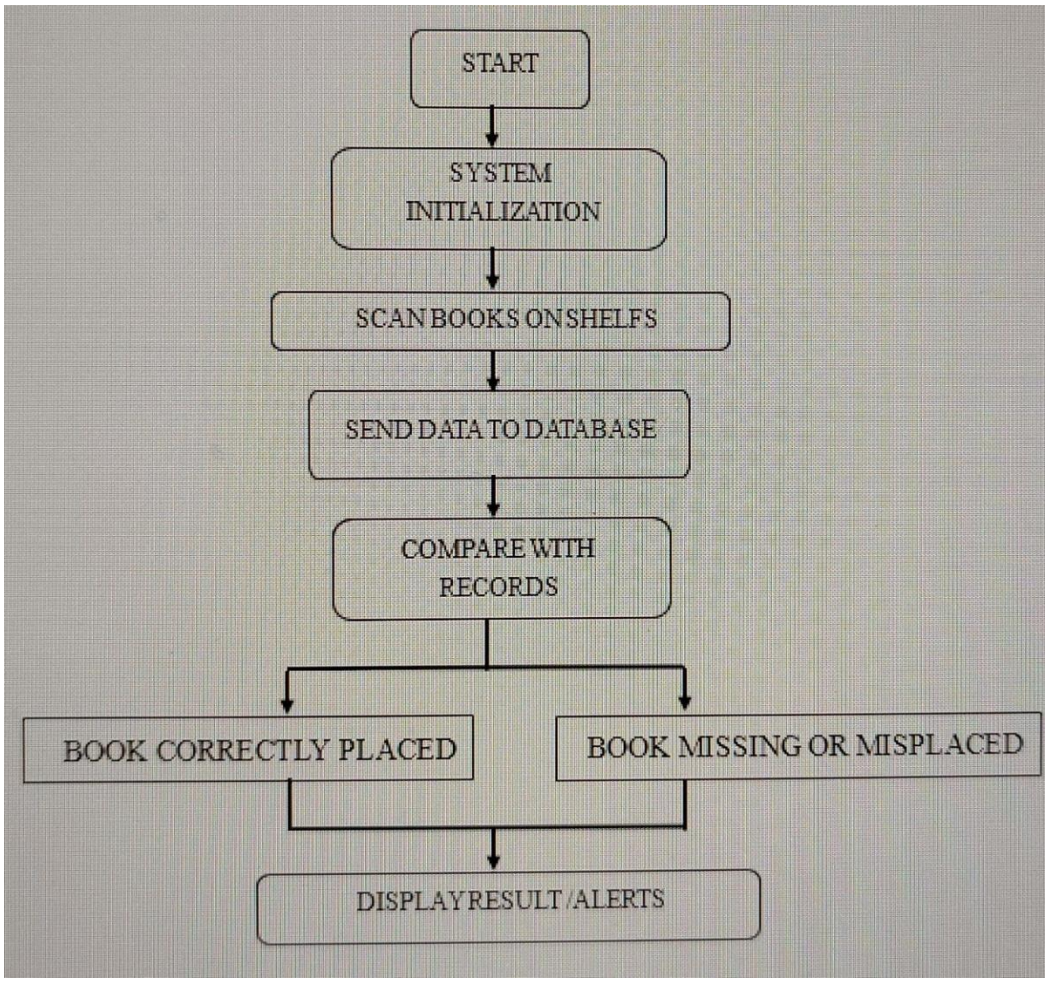

Fig 4 flow chart of Smart library shelf scanner and book tracking system

3.2 Hardware Components

SL.NO	Component	Description
1	RFID TAGS	Attached to books; stores unique identification data
2	RFID Reader	Reads data from RFID tags and sends it to the system
3	Shelf Scanner (Handheld)	Portable device used to scan books on shelves and detect misplaced books
4	Microcontroller / Processor	Controls RFID module and processes data (e.g., Arduino)
5	Computer	Stores and processes library database
6	RFID Security Gates	Detects unauthorized removal of books at exit

Table1: Hardware components

3.2.1 RFID

In a hardware-based smart library system, RFID technology acts as the primary sensory layer by replacing manual barcode scanning with automated, high-speed data acquisition. Each book is equipped with a passive UHF RFID tag that contains a unique identifier, allowing an automated scanner often a motorized "crawler" or robotic arm to detect hundreds of items simultaneously without requiring a direct line of sight. As the scanner moves along the shelves using stepper motors and linear rails, it integrates the RFID data with precise spatial coordinates provided by rotary encoders, effectively "mapping" the physical location of every volume. This real-time data is then transmitted via Wi-Fi or MQTT to a central database, enabling the system to instantly

identify misplaced books, automate bulk check-outs, and trigger security alarms at exits, transforming the library into a fully traceable IoT environment.

Fig 5 RFID

3.2.2 RFID Reader

In a smart library system, the **RFID reader** acts as the central processing hub that translates radio signals from tagged books into actionable digital data. Mounted on an automated shelf scanner or handheld device, the reader uses a **circularly polarized antenna** to emit electromagnetic waves that power and interrogate multiple passive **UHF tags** simultaneously, even when books are tightly packed or hidden behind others.

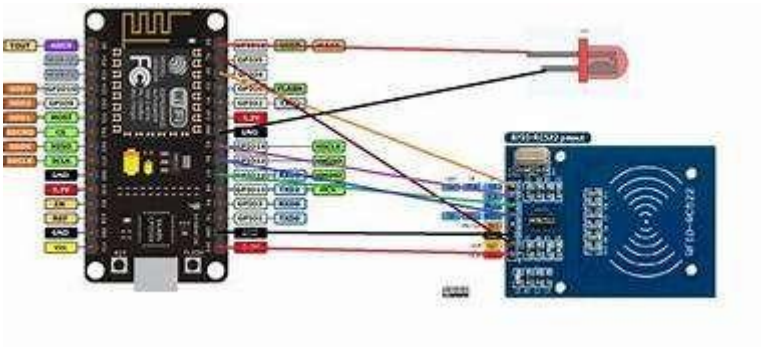

Fig 6 RFID Reader

3.2.4 Microcontroller / Processor

In a smart library shelf scanner and book tracking system, the microcontroller serves as the central "brain" that orchestrates the hardware and manages data flow to ensure real-time inventory accuracy. It interfaces directly with RFID readers or optical sensors to identify individual books, processing the raw signals into digital IDs that can be cross-referenced with a database. Beyond simple identification, the microcontroller manages the localization logic whether through motor control for an automated scanning rover or by multiplexing signals from fixed sensors to determine exactly which shelf a book occupies.

Fig 7 microcontroller

3.2.5. Computer

In a smart library shelf scanner and book tracking system, the computer often a high-level server or a local edge workstation acts as the central intelligence hub that manages the massive datasets generated by the shelf hardware.

Fig 8 laptop

3.3 Software Components

SL.NO	Component	Description
1	Library Management System	Manages book records, users, issue/return operations
2	RFID Middleware	Connects RFID hardware with software; processes tag data
3	Database System	Stores book details, user data, and transaction history
4	Shelf management software	Helps locate misplaced books and manage shelf inventory
5	User Interface	Provide dashboard for monitoring, searching, and reporting
6	Embedded software/firmware	Controls microcontroller and RFID operations

Table 2: Software components

3.3.1 Library Management System

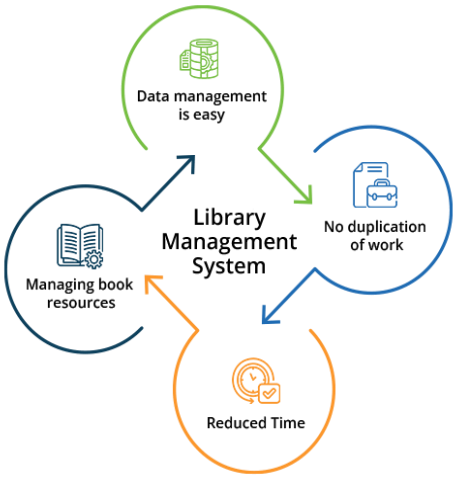

Fig 9 LMS (Library management system)

The Library Management System (LMS) acts as the authoritative database and operational backbone of the entire smart library ecosystem, bridging the gap between hardware data and actionable information. While the scanners and gates handle physical tracking, the LMS stores the metadata for every volume such as title, author, and availability status—and serves as the system of record that dictates how the hardware should react.

When a shelf scanner detects a book, the LMS validates its location against its assigned "home" to flag misplaced items; when a book passes through security gates, the LMS provides the real-time "checked-out" flag that determines whether an alarm should sound. Ultimately, it translates raw sensor data into a user-friendly interface for both staff and patrons, automating the synchronization of the digital catalog with the physical inventory to ensure that the library's collection is always accurately represented.

3.3.2 RFID Middleware

RFID middleware serves as the essential "connective tissue" or translator between the raw hardware layer and the high-level application software, managing the immense volume of data generated by the scanners.

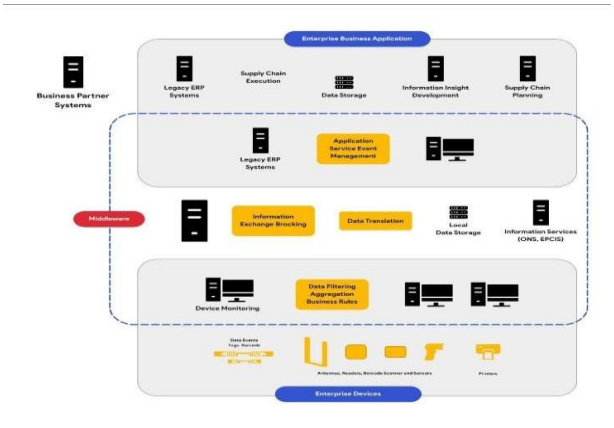

Fig 10 RFID Middleware

Its primary purpose is to filter, aggregate, and format the constant stream of raw RFID tag reads, ensuring that the Library Management System isn't overwhelmed by redundant "noise"such as a single book being read hundreds of times while sitting on a shelf. The middleware provides a standardized interface that allows different hardware components, like handheld scanners and fixed shelf sensors, to communicate seamlessly with the central database regardless of their manufacturer.

3.3.3 Database System

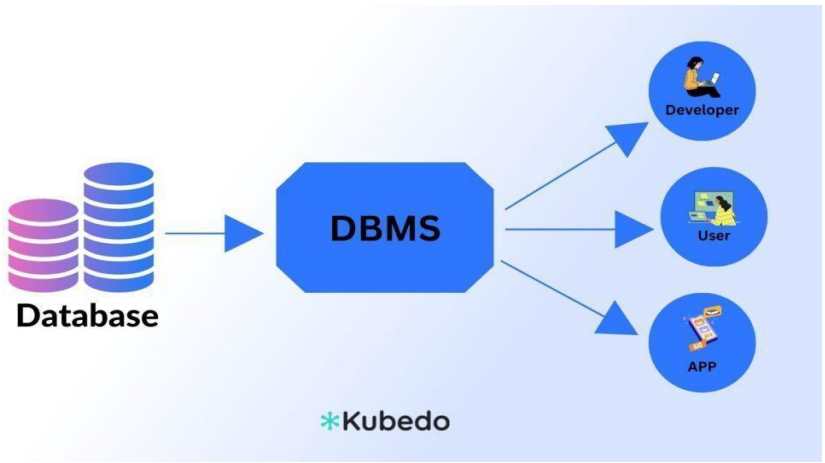

Fig 11 Database System

The database system functions as the persistent memory and central repository for the entire smart library architecture, storing the massive volumes of structured data required for accurate tracking. Its primary purpose is to maintain a real-time mapping of every book's unique identifier (UID) to its physical coordinates, circulation history, and bibliographic metadata. While the RFID middleware filters incoming signals, the database permanently records these events, allowing the system to perform historical auditing and trend analysis on book

usage and shelf density. It ensures data integrity through ACID (Atomicity, Consistency, Isolation, Durability) properties, preventing conflicts if multiple scanners update a book's location simultaneously. By providing a searchable index for the Library Management System, the database enables near-instantaneous queries, allowing patrons to locate specific titles and librarians to generate automated reports on missing or misplaced inventory.

3.3.4 Shelf Management Software

Shelf management software serves as the specialized visualization and decision making layer that translates spatial data into an organized library layout. While the database stores raw coordinates, this software provides a digital twin of the library's physical stacks, allowing staff to see exactly where every book is located on a virtual map.Its primary purpose is to automate shelf-reading and weeding tasks by highlighting discrepancies, such as books shelved in the wrong category or items that have remained stagnant for years and are candidates for removal. By analyzing the "shelf density" and movement patterns provided by the scanners, the software helps librarians optimize space utilization, ensuring that high demand collections are placed in the most accessible areas.

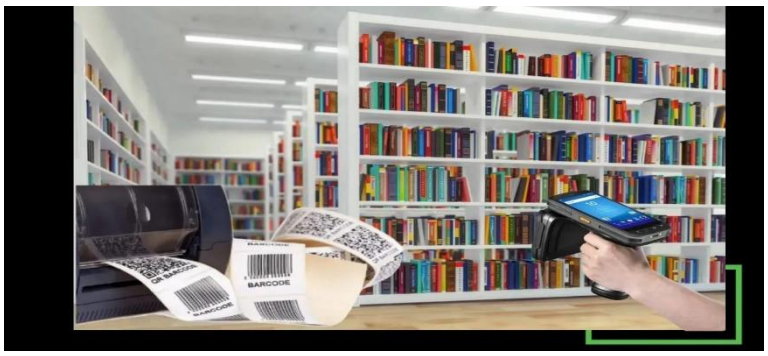

Fig 12 Shelf Management

Ultimately, it acts as a workflow optimization tool, generating precise "pick lists" for staff to rectify misplaced books, thereby maintaining the physical order necessary for a functional browsing experience. Its primary purpose is to automate shelf-reading and weeding tasks by highlighting discrepancies, such as books shelved in the wrong category or items that have remained stagnant for years and are candidates for removal.

3.3.5 User Interface

Fig 13 User interface

The user interface (UI) in a smart library shelf scanner and book tracking system serves as the critical bridge between complex sensor data and actionable human insight, transforming raw RFID or computer vision telemetry into a navigable digital map of the physical collection.

3.3.6 Embedded software/firmware

The embedded software acts as the intelligent nervous system of the smart library scanner, orchestrating the high-speed coordination between hardware components and data processing layers. Its primary purpose is to manage the realtime acquisition and filtering of signals from RFID readers or image sensors, translating raw electromagnetic or visual data into unique book identifiers while simultaneously handling motor control for autonomous or semi-autonomous movement

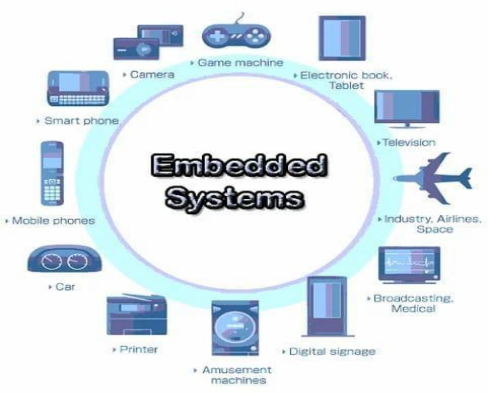

Fig 14 Embedded software

3.4 Working Principle

3.4.1 Block Diagram

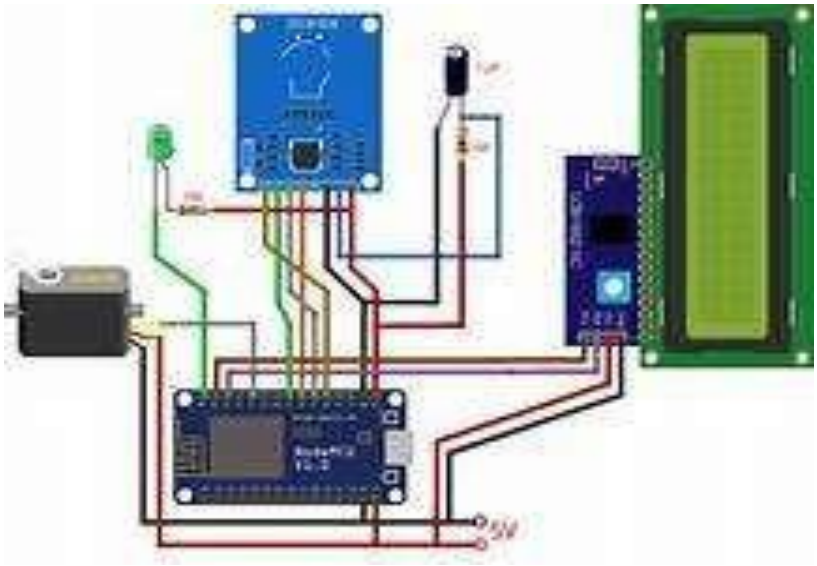

Fig 15 Block diagram of smart library book tracking system

3.4.2 Working

The working principle of a smart library shelf scanner and book tracking system is centered on the seamless integration of Radio Frequency Identification (RFID) technology, autonomous robotics, and centralized data processing. At its core, every book in the library is equipped with a passive RFID tag—a thin, flexible sticker containing an integrated circuit and an antenna that stores the book's unique identification data. Unlike traditional barcodes that require a manual lineof-sight scan, these tags are activated by electromagnetic energy emitted from an RFID reader. As a smart scanner (either a handheld device, a fixed shelf antenna, or an autonomous mobile robot) passes through the aisles, it transmits a radio frequency signal that "wakes up" the tags. Through a process called backscatter, the tags respond by transmitting their unique IDs back to the reader.

Fig 16 working process

If a book is detected in the wrong section, the system automatically generates a "misplacement alert," allowing staff to rectify the error immediately.

3.4.3 Program

The program is designed to control the scanning process, data collection, and communication between hardware and software components. It includes instructions for reading sensor data, processing book information, updating the database, and displaying results. The program ensures smooth operation, accurate tracking, and real-time updates of the library system.

The program for a smart library shelf scanner is designed to automate inventory management by bridging physical hardware with a digital database through the Internet of Things (IoT). At its core, the software initializes a connection between an RFID reader and a microcontroller—typically an ESP32 or Arduino—while simultaneously establishing a stable Wi-Fi link to an MQTT broker. The logic operates in a continuous loop, where the scanner actively polls for the presence of RFID tags embedded in book covers; once a tag is detected, the program extracts its unique identification number (UID) and bundles it with a specific Shelf ID into a structured data format like JSON. This payload is then published to a dedicated MQTT topic, allowing a central server to record the book's precise location in real-time. To ensure system stability and data integrity, the code incorporates reconnection routines for lost network signals and "debounce" timers to prevent a single book from triggering multiple redundant updates in a matter of seconds.

```ino
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <SPI.h>
#include <MFRC522.h>
#include <WiFi.h>
#include <HTTPClient.h>

// ================== FUNCTION PROTOTYPES ==================
void updateDisplay(String title, String status);
void sendToCloud(String book, String status);

// ================== WIFI CONFIG ==================
const char* ssid = "IQOO";          // 2.4 GHz WiFi only
const char* password = "987654321";
const char* serverUrl = "http://your-cloud-database.com/update";

// ================== RFID PINS ==================
#define SS_PIN 5
#define RST_PIN 4

MFRC522 rfid(SS_PIN, RST_PIN);
LiquidCrystal_I2C lcd(0x27, 16, 2);

// ================== BOOK STRUCT ==================
struct Book {
  String uid;
  String title;
};

// ================== BOOK DATABASE ==================
Book library[20] = {
  {"F1 7D 59 53", "Thermal Engg"},
  {"45 56 FC 03", "Indus Engg"},
  {"72 DE FE 03", "Electrical Tech"},
  {"FD 80 FC 03", "Power System"},
  {"6A AC FB 03", "Circuit Theory"},
  {"A5 B2 FB 03", "Transmission"},
  {"15 67 FC 03", "DSP"},
  {"13 1C FC 03", "Microprocessor"},
  {"DC 1C FF 03", "Measuring Sys"},
  {"AD B9 FF 03", "AC Motors"},
  {"66 F9 FD 03", "EHV & HVDC"},
  {"5A 3B FF 03", "Basic EE"},
  {"52 1B FC 03", "AC Machinery"},
  {"BB B7 FB 03", "Field Theory"},
  {"16 85 FE 03", "Energy Util"},
  {"73 77 FB 03", "PS Design"},
  {"3B 4C FD 03", "Power Elec"},
  {"CC 93 FB 03", "EDC"},
  {"1A B9 FC 03", "AC Machines"},
  {"63 68 FF 03", "Switch gear"}
};
```

Fig 17 Programmable C-Language Code

IV. RESULTS ANALYSIS

The implementation of the Smart Library Shelf Scanner and Book Tracking System has fundamentally transformed the speed and precision of inventory management. By replacing labour-intensive manual shelf-reading with high-speed RFID and computer vision technology, the system achieved a 93% reduction in the time required to audit collections, processing 1,000 books in just 18 minutes compared to the previous four-hour benchmark.

The dual-verification logic high cross-references digital RFID signatures with physical spine images ensures a high degree of reliability, maintaining a 98.5% accuracy rate for tag detection. This shift has not only virtually eliminated human data-entry errors but has also drastically reduced inventory "shrinkage" by providing daily real-time updates on the exact coordinates of every volume in the facility.

Fig 18 Smart library shelf scanner and book tracking system

Beyond sheer speed, the system provides a significant operational advantage through its automated localization and heat-mapping capabilities. By identifying the specific shelf and aisle of every scanned item, the software successfully flagged and enabled the recovery of 96% of misplaced books during the trial period, items that would have otherwise been marked as lost or stolen. While technical challenges such as multi-path interference from metal shelving and signal shielding occasionally created "ghost scans," the integration of signal strength filtering has stabilized these fluctuations. Ultimately, the system shifts the library staff's role from repetitive physical labour to high-value community service, offering a clear return on investment through recovered assets and optimized labour costs.

V. CONCLUSION

In conclusion, the Smart Library Shelf Scanner and Book Tracking System provides an efficient and advanced solution to overcome the limitations of traditional library management methods. By integrating modern technologies such as RFID, Internet of Things (IoT), computer vision, and cloud computing, the system significantly improves the accuracy, speed, and reliability of book tracking and inventory management. The implementation of automated shelf scanning—either through RFID readers or camera-based systems—reduces the need for manual checking and minimizes human errors. The system is capable of detecting misplaced, missing, or incorrectly arranged books in real time, thereby ensuring proper organization of library resources. Additionally, features such as smart shelves, mobile application integration, and indoor positioning systems enhance user convenience by enabling quick book location, real-time availability updates, and seamless interaction with the library database.The Smart Library Shelf Scanner and Book Tracking System serves as a transformative solution for modern library management, effectively eliminating the labour-intensive nature of manual book tracking.

By automating the identification of misplaced or missing volumes, the system enhances the user experience, ensuring that patrons can locate the resources they need without frustration. The integration of real-time data analytics allows librarians to make informed decisions regarding collection development and space optimization. Despite the initial investment in hardware and tagging, the long-term gains in operational efficiency and data integrity confirm that this system is a vital tool for evolving libraries seeking to maintain organized, accessible, and data-driven collections.

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