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# Bookstore scenario

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# System Goals

Our system should be able to:

- Unpack incoming boxes and retrieve books.
- Sort books by genres then by alphabetical order.

### 3 Bookstore scenario: Sort newly arrived books into shelves

Imagine you have to design a robot system, which is supposed to unpack newly delivered books and sort them. New products are delivered on palettes in outer packaging. Unpacked books are supposed to be sorted according to genre and then alphabetically in the respective shelves.

# Environment Setup

**Designated Zones:**
- Unloading zones for bulk shipments
- Library hall for navigation
- Shelving units optimized for automated placement

**Environment Setup:**
- Calibrated lighting for enhanced vision-based recognition
- LiDAR and occupancy grid mapping for seamless navigation

**Safety and Efficiency:**
- Clearly marked safety zones for co-existing with human workers
- Minimized interference for smooth operation

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# Assumptions

**Environmental Assumptions**

- **Flat Operating Space**: The bookstore is level.
- **Organized Layout**: The shelves are properly structured with clear genre sections.
- **Adequate Space**: Aisles are wide enough for the robot to maneuver without obstruction.
- **Consistent Lighting**: The bookstore has good lighting.

**Book Identification Assumptions**

- **Books Have Barcodes**: The robot will use barcode scanning for identification
- **Book Dimensions Are Standardized**: The robot does not need to handle extreme variations in book sizes (e.g., oversized or tiny books).

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# Assumptions

**Book Delivery & Unpacking Assumptions**

- **Books Arrive in Standard Packaging**: A uniform carton, to make the robot use predefined unpacking strategies.
- **Books Are Properly Labeled**: *dewey_decimal_class* or other metadata is accessible via a database lookup.
- **Each book is shrink-wrapped**: Prevents damage and facilitates pickup.

**Software Assumptions**

- **The Bookstore Maintains a Digital Database**: The robot can access a database to retrieve location information.
- **Automated Sorting Algorithm**: The system includes an algorithm that determines the correct shelf placement based on the book's metadata.

*Shrink-Wrapped Books*

*Books Delivery*

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# Required Knowledge

**Perceptual Knowledge**

- **Machine Learning:** Cartons(contact surface, edges, pallet position), Book (includes book covers, barcodes, book spine), Navigation (humans, obstacles, doors, surface lines, shelves), Signs (Alphabetical order, OCR).
- **Object localization and segmentation:** Tabletop segmentation and RANSAC.

**Knowledge-Based Reasoning**

- **Open Library API:** retrieve dewey classification codes.
- **AI-based classification:** Natural Language Processing to infer genre if not explicitly labeled.
- **Book Store Database:** book categories and their shelf locations, available shelf spots, and book registry.

# Required Knowledge

**Motion Planning Knowledge**

- **Grasping Strategy:** using robotic two arms with suction gripper.
- **Digital Map:** mapping incoming percepts to an explainable model.
- **Obstacle Avoidance** : using LiDAR.
- **State Estimation Techniques** : using Bayesian filters.
- **Sample-Based Planning** : using RRT.

**Human-Robot Interaction (HRI) Knowledge**

- **Communication & User Interface:** input sorting preferences or manually override decisions.
- **Collaboration with Humans:** prompt a human for assistance.
- **Behavioral Adaptation** : wait or reroute if a human is blocking access to a shelf.

# Hardware

**Actuators (Motion & Manipulation)**

Two Robotic Arms:
- Used for picking books, handling packages, and placing books on shelves.
- Suction gripper to avoid damaging books

Mobile Base (Wheels or Tracks):
- Ensures stable mobility across the bookstore.
- Should support omnidirectional movement for tight spaces and flexibility.

Motorized Vertical Rail System:
- Moves the camera up and down to match the required shelf height.

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# Hardware

**Sensors**

RGB-D Camera:
- Used for object recognition and depth estimation.
- Helps identify books, recognize barcodes, and estimate distances.

*Intel RealSense D455*

Barcode Scanner:
- Essential identification of books (ISBN).
- Confirm the aisle and the shelf. (e.g aisle D, shelf 8)

*Zebra OEM SE4710*

LiDAR:
- Ensures obstacle detection and avoidance during movement.

*RPLIDAR A2*

Proximity Sensors:
- Helps detect when the book is close enough for suction engagement.

*Sharp GP2Y0A21YK0F*

# Hardware

**Computational Unit (Processing & Control)**

**Embedded Computer for AI & Vision Processing:**
- Runs object recognition, path planning, and motion control.
- Must support GPU acceleration for deep learning models.

**Microcontrollers:**
- Used for motor control, gripper actuation, and sensor interfacing.
- Should support omnidirectional movement for tight spaces and flexibility.

**Wireless Communication Module:**
- Allows remote communication with APIs
- Monitoring and updates.

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# Software and AI Components

**Perception**

Digital Twin:
- Simulates the bookstore environment to enhance decision-making

Unpacking:
- Detect and classify boxes and pallets.
- Determine the exact position and orientation of the boxes.
- Detect the best grasping point for a box.
- Edge detection for box opening approach.

Book Handling:
- Recognize different book parts (front cover, back cover, spine)
- Barcode scanning to fetch book metadata (genre, publisher, ISBN) from a database.
- Optical Character Recognition (OCR) to extract book titles and author names, as fallback in case database fetching fails.

Motion & Path Planning Perception:
- Perceive obstacles and plan a clear path.

Shelf Recognition and Slot Detection:
- Recognize different shelves and their assigned categories.
- Determine empty slots for book placement.

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# Software and AI Components

**Planning and Reasoning**

Sorting Strategy:

- Decide where each book should go based on: genre, alphabetical order, available space.
- Keeping an inventory database that saves travel time to the shelves.
- Infer genre, using NLP, if not explicitly labeled.
- Possible human input for outliers (rare genres, anthologies, etc.).

Task Planning & Execution:

- Follow a logical order: detect box → approach → pick up → open → extract book → classify → store.
- Probabilistic state estimation (e.g, Bayes Filter) to minimize uncertainty in book positioning.
- Failure Handling:
  - Retry without change
  - Retry with parameter adjustment (position, orientation, suction force, etc.)
  - Retry with action change (approach method)
- Implement feedback loops to improve quality of decisions.

Ontology:

- Provides a structured representation of knowledge about the bookstore.
- Distinct classes (main hall, storage) and sub-classes(sections, aisles, shelves, slots)

# Software and AI Components

**Human-Robot Interaction**

Speech & Visual Interface:

- A simple touchscreen UI for book status updates and manual overrides.
- Voice Commands (ASR - Automatic Speech Recognition) for quick instructions (e.g., “Sort these books into Science Fiction”).
- Emergency stop mechanism.

Feedback & Notification System:

- Notify users about errors, completed tasks, or warnings.
- Color-coded LED system can indicate the robot’s.
- Employees can receive notifications remotely on their mobile devices.

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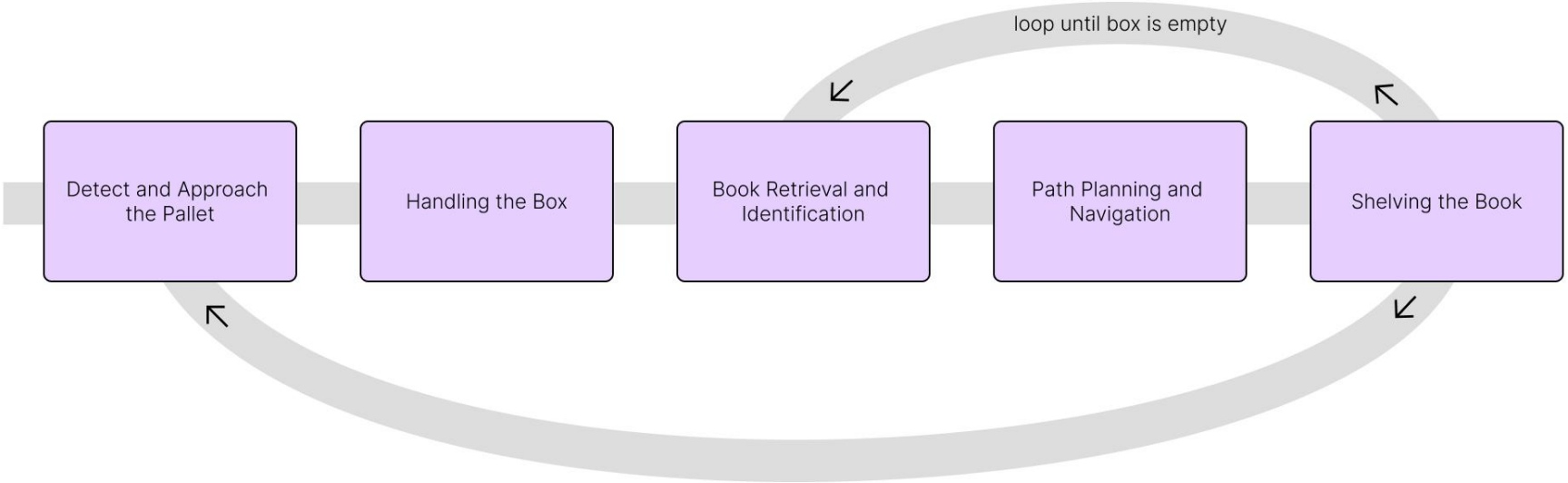
# Implementation Strategy



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# Justification of Choices

**Dual Robotic Arms with Suction Grippers:**
- Why two arms?
- Why suction grippers?

**Base Platform for Box Processing:**
- Why a base platform?

**Cutting Tool for Box Opening:**
- Why an automated box cutter?

**Barcode Scanning for Book Identification:**
- Why barcode scanning?

**Motion Planning and Obstacle Avoidance:**
- Why an emergency stop mechanism?
- Why a user interface for human intervention?

# Safety

**Collision Avoidance and Safe Navigation:**

- LiDAR and RGB-D Cameras.
- The robot continuously scans its surroundings to detect people, shelves, and obstacles.
- Slows down or stops if a person suddenly moves into its path.

**Emergency Stop and Fail-Safe Mechanisms:**

- Physical emergency stop buttons located on the robot's body for easy access by bookstore staff.
- Pressing the button immediately halts all robot functions.

**Error Recovery System:**

- If an obstacle blocks the path for too long, the robot recalculates its route or requests human intervention.
- If a book is misplaced or stuck, it alerts the operator via the user interface.

Thank you!