PDE 3802

ARTIFICIAL INTELLIGENCE (AI) IN ROBOTICS

ASSESSMENT PART A

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This report details an autonomous dual-robot system that organizes office items through coordinated perception, manipulation, and mobility. A gantry-mounted arm and a mobile robot work together to detect, collect, and sort objects safely and efficiently within an office environment.

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1. INTRODUCTION

1.1 Assessment Requirements

This assessment requires the design of an autonomous robotic system capable of identifying, locating, and organizing common office items such as mugs, notebooks, phones, keyboards, and books within a typical indoor environment. The report must outline a full system design that includes: a clear definition of the robot's mission and tasks; the key skills and interfaces required for its operation; detailed hardware and software architecture; dataset and model plans for perception; safety mechanisms and risk management strategies; and an indicative budget and bill of materials. The system is to be conceptualized with realistic technical feasibility in mind, though it does not need to operate under strict time constraints. Once the system architecture has been established, the concept is to be summarized in a short explanatory video that visually communicates the design rationale, functionality, and overall workflow.

In essence, this task involves synthesizing knowledge of robotic perception, navigation, and manipulation into a cohesive, plausible design capable of autonomously managing an office environment. The report should demonstrate not only technical understanding but also thoughtful consideration of integration complexity, safety, and practicality in a real-world context.

1.2 Basic Background

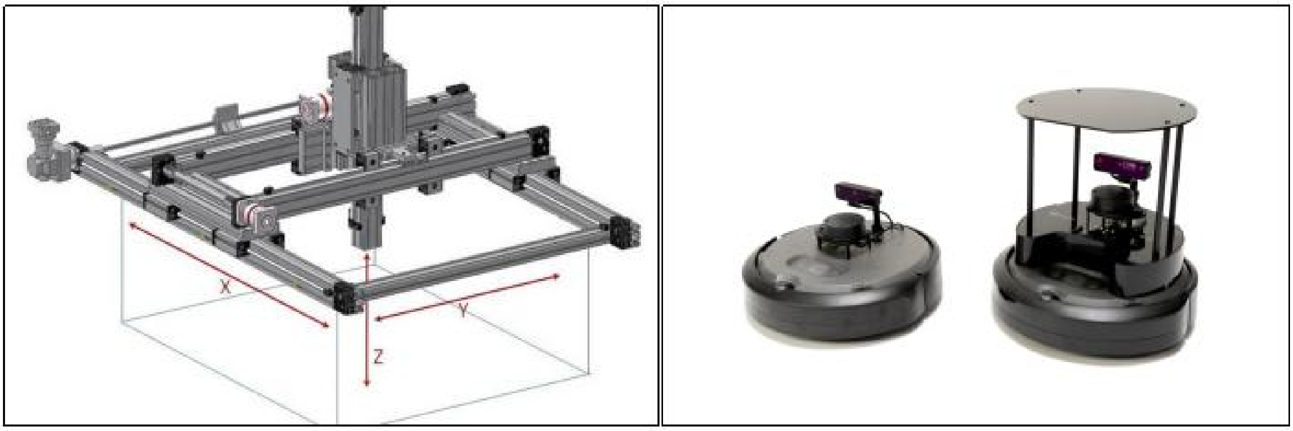

Image 1: Example Gantry (left) and Mobile (right) robots

The proposed solution is a **dual-robot system** designed to autonomously sort and organize office items into their designated storage zones. The system consists of two primary components: a **fixed-position gantry robot** equipped with a commercial gripper mechanism, and a **mobile base platform**—based on the TurtleBot architecture—responsible for object transport and storage organization. (See Image 1 above)

At the start of each operational cycle, a wide-angle camera surveys the office to identify misplaced objects. Once detected, the system determines their positions relative to a fixed gantry robot. The gantry, moving in the X, Y, and Z directions, retrieves each item and gently places it onto a mobile robot. The mobile robot then autonomously transports the object to its appropriate storage zone. Designed for a moderately sized office, this setup minimizes the complexity and hazards of large-scale gantry systems while maintaining efficiency. Separating the gantry's precise manipulation tasks from the mobile robot’s navigation duties enhances safety, accuracy, and coordination. Overall, this concept presents a balanced, intelligent approach to workspace organization—combining perception, manipulation, and mobility to maintain an orderly environment with minimal human input.

2. MISSION & TASKS

2.1 Mission Overview

The mission of the proposed dual-robot system is to **autonomously identify, collect, transport, and organize common office items into their designated storage zones**. Items such as mugs, notebooks, phones, keyboards, and other desk objects naturally accumulate in disarray during normal office use. This system is designed to operate during periods when the office is uninhabited—such as evenings, weekends, or holidays—allowing it to restore order without interfering with human activity.

The system leverages a **gantry-mounted gripper** for short-distance object handling and a **mobile robot platform** for safe transport of objects across the office. The combination of these two robots ensures both efficiency and safety: the gantry handles precise picking and placement onto the mobile platform, while the mobile robot carries items to storage zones. Over repeated operational cycles, the system ensures that the workspace remains organized.

2.2 High-Level Task List

Mission Initialization – The system begins by knowing which items need to be organized and where each should go. This step sets the plan for the rest of the process.

Workspace Observation – Using an overhead camera, the robot monitors the office to see which items are out of place or left in disarray.

Target Identification – The robot selects one item to pick up next, deciding what should be collected first based on its location or priority.

Gantry Approach – The gantry robot moves its arm carefully to the chosen item’s location to prepare for picking it up.

Object Pickup – The gantry’s gripper grabs the item gently and places it safely onto the mobile robot’s carrying platform.

Mobile Navigation to Storage – The mobile robot moves the item across the office to its correct storage area, avoiding obstacles along the way.

Handoff/Placement – The mobile robot places the object in its designated spot, making sure it is stable and properly positioned.

Organization Verification – The system checks that the item has been stored correctly and is ready for the next operation.

Recovery / Exception Handling – If something goes wrong, such as the object slipping or being in a difficult position, the robot tries again or logs the problem for review.

Cycle Completion – Once all visible items have been sorted, the system finishes the current cycle and waits for the next scheduled round, which may occur during off-hours like evenings, weekends, or holidays.

Below is a flowchart that depicts the cycle for the above steps. (*Fig 1*)

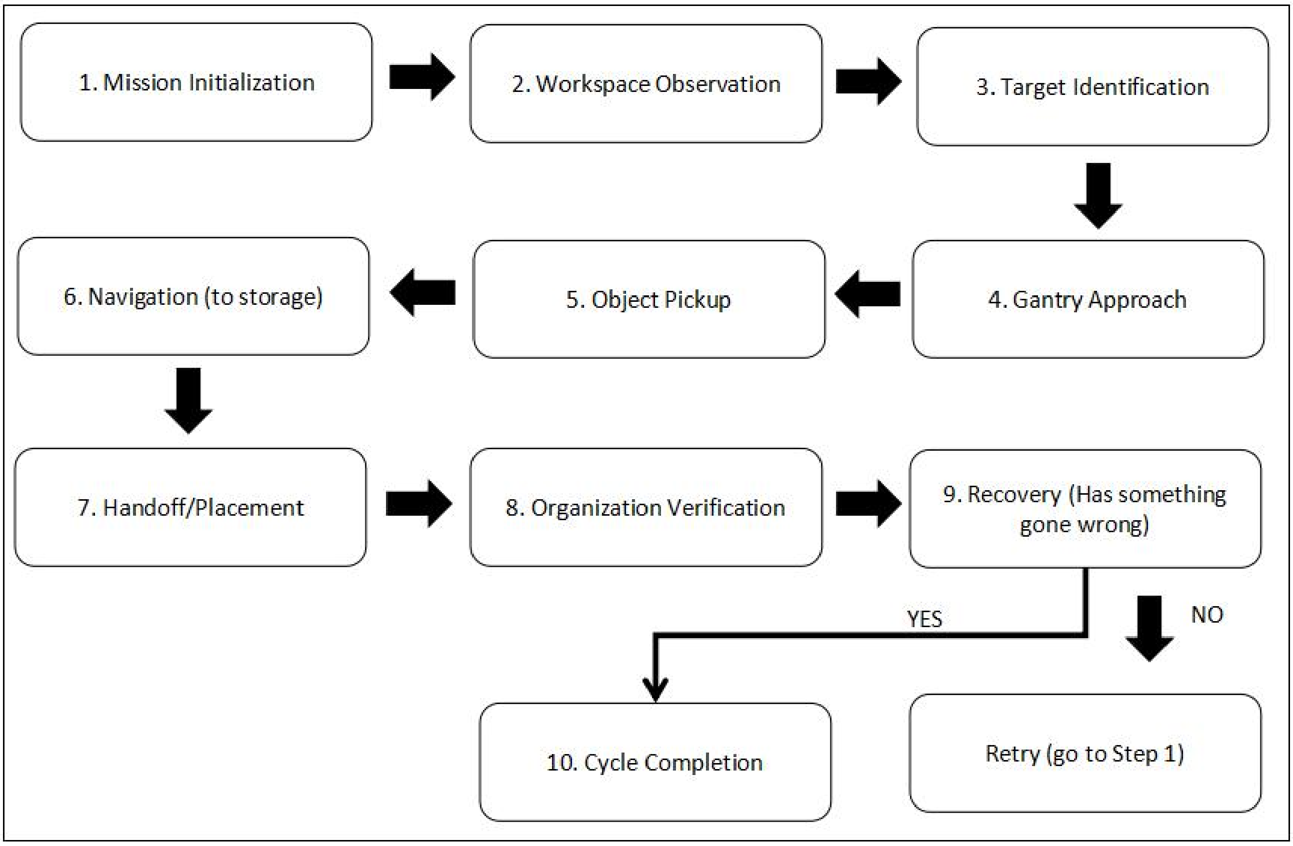

Figure 1: Task List Flowchart

3. REQUIRED SKILLS (WITH INTERFACES)

3.1 Summary Table

Table 1: Table showing list of required skills for sorting system

Skill	*Inputs*	*Outputs*	*Success Criteria*
Perception	RGB-D camera feed; AI detection model	Object identity and 3D position in workspace frame	Object fully visible, correctly classified, and with clear surrounding space
Localization	LiDAR, camera data, odometry	Robot and gantry position in office coordinate frame	Accurate enough for safe navigation and precise pickup
Planning	Object and robot positions; storage locations	Ordered task list and navigation paths	Correct execution order and collision-free motion
Manipulation	Object position and type; gripper feedback	Secure grasp and placement of object	Gentle grip, successful pickup verified by sensors
Human-Robot Interaction (HRI)	System logs and error states	Notifications or alerts to operator	Operator receives clear updates or warnings

3.2 Key System Skills

3.2.1 Perception

The perception system allows the robot to understand its environment and recognize objects that need organizing. It uses an RGB-D camera equipped with an object detection model to identify common office items such as mugs, folders, notebooks, and keyboards. The depth component provides spatial position data, allowing both robots to locate the object precisely within a shared office frame.

An object is only marked for collection when it is outside its designated storage area and free from obstructions. The system applies a *minimum clearance distance*—if any other object is too close, the item is temporarily skipped to prevent collisions or failed grasps.

Success Criteria: Objects are detected completely (no parts hidden), classified correctly, and meet the clearance requirement before pickup.

3.2.2 Localization

Both the gantry and the mobile robot must understand where they are in relation to the office layout and to each other. The system uses a combination of **LiDAR** and **visual SLAM** for position tracking, allowing accurate navigation and coordination within the same spatial frame. The gantry relies on precise localization to position its arm correctly above objects, while the mobile robot needs consistent accuracy for movement and docking.

Success Criteria: Each robot maintains a position estimate accurate enough for smooth motion and safe object handling.

3.2.3 Planning

Planning occurs in two levels. First, **task-level planning** determines which object should be collected next. A queue system stores up to three targets per cycle, ensuring the mobile robot does not exceed its carrying capacity. Next, **motion planning** defines safe routes for both the gantry and mobile robot, incorporating obstacle avoidance to navigate around furniture and office layouts.

Success Criteria: The planned sequence and routes are efficient, collision-free, and follow the proper order of operations.

3.2.4 Manipulation

The gantry system is fitted with a **two-fingered, adaptive gripper** designed to handle a variety of office items gently. It adjusts its grip based on object shape and applies just enough force to secure items without damage. The gripper includes **force feedback sensors** that confirm whether an object has been successfully grasped or released.

Success Criteria: The gripper secures and releases each item safely, confirmed through feedback readings.

3.2.5 Human-Robot Interaction (HRI)

Although the system operates autonomously, it maintains communication with a human operator. At the end of each cycle, or when an error occurs, the system generates a **notification or alert** summarizing its performance and any unresolved issues. These alerts can appear as on-screen logs or messages, providing transparency without the need for constant supervision.

Success Criteria: Operators receive clear, timely updates regarding system completion or faults.

4. SOFTWARE ARCHITECTURE

4.1 Structural Flow of Software

The software system is designed around a small group of modules that work together under **ROS 2 Jazzy** to manage the camera, gantry robot, and mobile robot. Each part has a clear role, and communication happens through named “topics” that describe the kind of data being shared. These topic names are examples, chosen to show their purpose, and can be created as needed in a real implementation.

The basic structural flow of this architecture is shown below (*Fig 2 overleaf*)

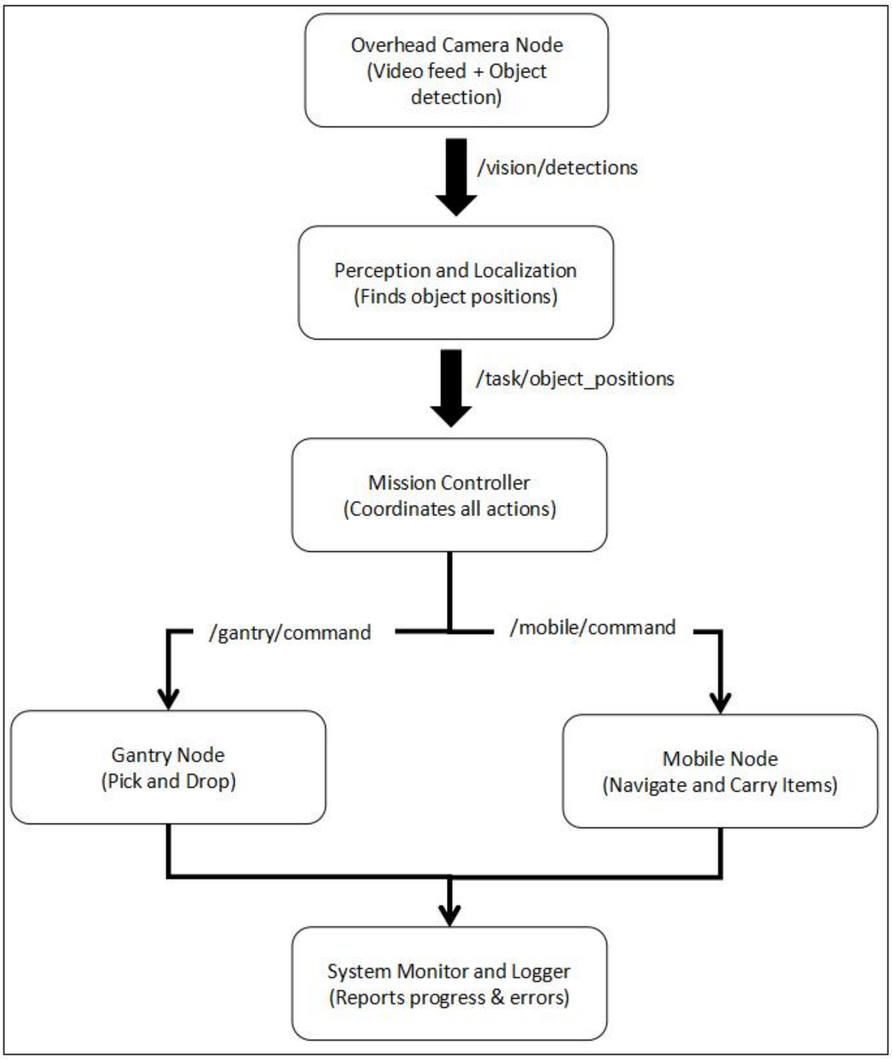

Figure 2: Structural Flow of Software with example topic names (ROS 2)

4.2 Data Flow Summary:

The **Overhead Camera** spots items and shares their locations.

The **Perception Module** places these items within the office map.

The **Mission Controller** decides which robot should act and sends commands.

The **Gantry** and **Mobile** robots perform their movements and update the **Monitor**, which records their progress.

This setup makes it easy to update or add new features later, such as improved detection or smarter scheduling.

5. DATASET & MODEL PLAN

The system is designed to recognize a wide range of common office items, including the ten specifically mentioned in the project brief—chair, bin, mug, bottle, book, keyboard, mouse, stapler, notebook, and phone—alongside several other frequently encountered objects such as folders, pens, and paper stacks. These categories collectively represent the most typical items found within a standard office environment, covering both large furniture elements and smaller desk accessories. Including this variety ensures that the system can handle the majority of everyday disorganization scenarios that occur in such workspaces.

To train the detection model, a custom dataset will be developed using video footage captured by the overhead RGB-D camera installed in the office. Frames will be sampled periodically from recorded sessions under different lighting and object placement conditions to ensure diversity. Each sampled frame will then be annotated manually, with bounding boxes drawn around visible objects using accessible tools such as **LabelImg** or **Roboflow**. This process ensures that the dataset reflects not only the actual workspace geometry and camera angle but also real-world clutter and occlusion patterns that the robot is expected to encounter during operation.

The object detection model will be developed and trained using a **YOLO-based framework**, chosen for its proven efficiency in balancing high detection accuracy with real-time processing capability. The model's performance will be measured through key metrics including **precision**, **recall**, and **F1-score**, which together provide a balanced view of detection reliability. Periodic evaluations using a **confusion matrix** will help identify which object classes are most prone to misclassification, guiding targeted retraining or dataset expansion efforts. In later iterations, as the system evolves to handle multiple simultaneous detections more effectively, additional metrics such as **mean Average Precision (mAP)** may be introduced to assess overall detection robustness across all object types.

This combined approach—custom dataset creation, iterative model refinement, and balanced metric evaluation—ensures that the system can accurately perceive, identify, and categorize a diverse set of office items in real-world conditions.

6. RISK & SAFETY

Safety is a key consideration for the dual-robot system, especially given that it operates autonomously in an uninhabited office. The system includes a **software-based emergency stop**, which can immediately halt all robot motion if unsafe conditions are detected or manually triggered remotely.

Both robots have **speed limits** to ensure careful movement: the gantry moves at slow, precise rates suitable for object handling, while the mobile robot travels at a moderate indoor speed to avoid collisions. A **minimum obstacle distance** is maintained for all movements, ensuring that the gantry or mobile platform does not collide with furniture or other objects; this clearance is small but sufficient to prevent accidental impacts.

In the event of **detection or localization failure**, the system will automatically pause and retry the operation, rather than proceeding blindly. Errors and operational events are **logged remotely**, allowing an operator to review activity and intervene if necessary.

Overall, these measures ensure that the robots perform pick-and-place and transportation tasks safely, minimize the risk of dropped items or damage, and maintain operational reliability during unsupervised cycles, such as nights, weekends, or holidays.

7. PROSPECTIVE BILL OF MATERIALS

The dual-robot system is designed using commercially available components to balance cost, performance, and integration simplicity. The following is a proposed bill of materials with indicative pricing (*Tab 1 overleaf*):

Table 2: Prospective Bill of Materials

Component	***Purpose***	***Approx. Cost (USD)***
Gantry Robot Frame + 2D XY motion system	Fixed robotic arm platform	$1,200
Two-fingered Adaptive Gripper	Object pickup and placement	$400
RGB-D Camera (overhead)	Object detection and localization	$300
Mobile Robot Base (TurtleBot 4 or similar)	Transport objects	$1,000
LiDAR / SLAM Sensor	Mobile localization & mapping	$500
Onboard Computer (NUC / Jetson)	Processing perception and planning	$600
Miscellaneous: cables, mounts, brackets, power supply	Integration and support	$200

Total Estimated Cost: ~$4,200

The budget emphasizes a **modular approach**, allowing individual components to be upgraded or replaced without redesigning the system. For instance, the camera or gripper could be swapped for higher-performance alternatives if needed. The estimate assumes a single office-scale deployment and does not include facility modifications, which are minimal due to the system’s compact footprint.

This budget ensures that the system remains practical for real-world deployment while providing sufficient computational and sensing capabilities for reliable autonomous operation.

8. REFERENCES

1.Siciliano, B., & Khatib, O. (2016). *Springer Handbook of Robotics*. Springer.

2.Craig, J. J. (2018). *Introduction to Robotics: Mechanics and Control*. Pearson.

3.Thrun, S., Burgard, W., & Fox, D. (2005). *Probabilistic Robotics*. MIT Press.

4.Redmon, J., & Farhadi, A. (2018). YOLOv3: An Incremental Improvement. *arXiv preprint arXiv:1804.02767*.

5.Quigley, M., et al. (2009). ROS: an open-source Robot Operating System. *ICRA Workshop on Open Source Software*.

6.Fox, D., et al. (1999). The dynamic window approach to collision avoidance. *IEEE Robotics & Automation Magazine*, 4(1), 23–33.

7.Krajník, T., et al. (2011). Navigation strategies for mobile robots using SLAM and visual perception. *Robotics and Autonomous Systems*, 59(10), 738–748.

8.Bohren, J., & Cousins, S. (2010). The SMACH high-level executive. *IEEE International Conference on Robotics and Automation Workshops*.