CS 556: Final Project Description

Warehouse AMR Autonomy: Mini-Kiva Autonomy Stack.

CS 556 Robotics, Spring 2025 Dr. Mary Pourebadi

Objective

Design a warehouse AMR autonomy system for a mobile robot resembling a Kiva-style robot (as used by Amazon). In the next four sessions, you will implement a control system to allow your robot to localize within a known warehouse layout (aisles/shelves), start from a staging/charging dock, service three pick tasks by navigating to tagged inventory bins, simulate an align/lift/engage gesture, and then return to the dock and signal completion. Note: The maximum time your robot gets to traverse the maze is 120 seconds.

What is Warehouse Robotics?
Warehouse robotics are machines that can perform various warehouse tasks, including storing, retrieving, and transporting inventory. They increase efficiency by taking the fastest feasible routes and improve safety by operating in hazardous or high-traffic environments.

Autonomous Mobile Robots (AMRs) are the most common types of warehouse robots. They independently navigate the warehouse, utilizing technologies such as machine learning, AI, and sensors to plan and adjust routes in real-time while managing unforeseen challenges (e.g., avoiding crowds/obstacles or evading falling objects).

1 Prerequisites

- Review the summary of your labs (CS556-Lecture13-Labs Review)
- Bring your laptop.

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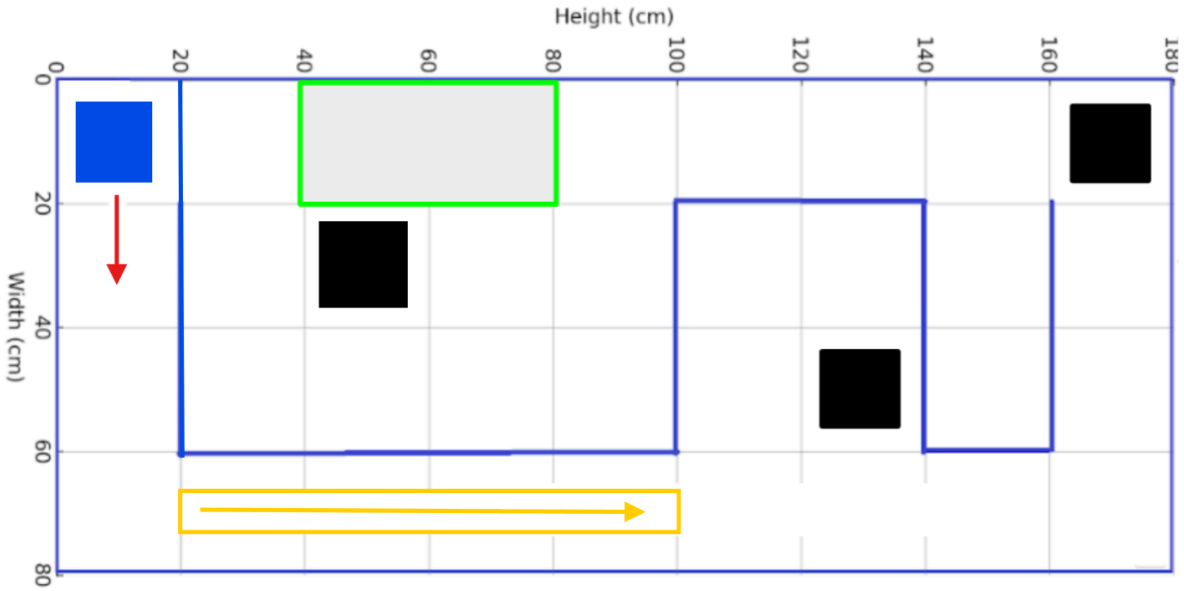
2 Project Description:

Each team will program a Pololu robot to autonomously navigate a **dynamic course simulating a warehouse environment**. The course consists of aisle-like corridors, line following segments, obstacles, and shelf (wall) sections.

Overview:



Warehouse AMR Demo Course — 180 × 80 cm Testbed

= Staging/Charging Dock
= Pallet / Obstacle
= Pick Location (Bin)
= Shelf / Wall Boundary
= Start / Dock Exit Path
= Fast Track Aisle / Path

- The maze map represents a **warehouse layout** with **aisles and shelving** (treated as fixed walls). Warehouse AMR Demo Course — 180 × 80 cm Testbed. Cell size (e.g., 20×20 cm), world origin (0,0) and robot origin (10x10 cm), axis directions, and walls lie **on** cell borders.

- **Obstacles** are placed in the **operations area (marked in green)** and resemble **pallets, totes, or carts**. The setup will remain the same during demo day.

- The robot starts at a **staging/charging dock** (**blue square**), and the start/dock exit path is marked with an **arrow.**

- The robot can travel as fast as it wants once it detects the **Fast Track Aisle/path** marked with **white tape.**

- The primary objective is to **locate and service three pick locations** placed in the layout, each marked by **a black square** for IR detection.

- **Layout assumption:** The map (size, cells) is known to students and may be pre-coded. Additionally, the placement of obstacles (green area items) is known and fixed. Bin/Pick Location markers will be unknown / not fixed and must be sensed at runtime. The fast-track aisle/path may change between runs and must be sensed at runtime.

- Color/legend consistency with the provided diagram: 🟦 Dock, 🟩 Pallet/Obstacle, ⬛ Pick Location (Bin), | Shelf/Wall Boundary,  fast track aisle.

Project Phases:

- **Phase 1: Navigation and Localization –** The robot navigates and localizes throughout the entire known layout.

- **Phase 2: Return to Staging/Charging Dock** – Once all three bins have been collected, the robot will return to the staging and charging dock.

- **Phase 3: Pick Detection & Service –** The robot identifies and services three pick locations.

- **Phase 4: Speed management and safety considerations –** speed may vary (static or dynamic). Operate conservatively to protect the robot and the course.

Execution Phases

Phase 1: Navigation and Localization

- The goal is for the robot to visit every traversable grid cell in the known aisle map.
- **Coverage**
    - Traverse the entire map and mark each traversable cell as visited.
    - Maintain a visit array (same dimensions as the map):
        - `V` = visited, `N` = not visited (initialize all traversable cells to `N`).
    - Stop when all traversable cells are `V`.
- **Navigation Method (choose one)**
    - **Wall following (left or right):** Move cell by cell; update the visit array each time you reach a cell center. Continue until all cells are `V`.
    - **Predefined path:** Execute a hardcoded route that passes through every traversable cell, marking `V` as you go.
    - Other equivalent methods are acceptable if they achieve full coverage.
- **Record traversed Path**
    - Moreover, during traversal, the robot needs to record its path using **waypoints and movement logs**. Hint: This can be done through various techniques, for example, having a new array for waypoints log and record the order of movements made from the beginning (departing the charging station) until collecting the third bin (for example: L L L L U R … L), and then traverse this in reverse.
- **Localization**
    - Maintain an accurate pose estimate while moving (e.g., using odometry with PID control or a particle filter).

- Use any combination of odometry, PID controllers, particle filters, and/or environmental cues to limit drift.

- **Completion Criteria**

  - All traversable cells are marked V (unless the third bin/location is picked).
  - The traversed path is recorded.
  - The robot remained accurately localized throughout the run (using the show method).

Phase 2: Return to Staging/Charging Dock

- Assuming that you completed three picks, **return to the staging/charging dock** by either:

  - (is allowed) (Efficient technique) **Reversing the recorded path**. Once all three bins have been collected, the robot will use the path to return to the dock, **or**

  - (extra credit) (Most efficient technique) Computing a **shortest path** on the known grid with updated obstacle costs, for example, preferred or efficiency, **or**

  - (Partial credit, but allowed) (Inefficient technique)The robot uses the first part of the algorithm from Phase 1, and traverses the entire map until it goes back to the charging dock (regardless of noting when three bins are collected).

- **Return tolerance:** distance/orientation window that counts as "docked" should be defined as **≤10 cm in x and in y directions, and a degree ≤30°**.

- Upon successful return to the docking station, **emit a beep** to signal completion.

- Logging: minimal required log (timestamps from start to end, robot's pose(x, y, theta), and events: bin#*i* pick-confirmed, docked).

Phase 3: Pick Detection & Service

- Use **line IR sensors** to detect **black squares** marking pick locations.

- **At a pick location:**

    - **Stop**; perform a brief **alignment motion/engaging a bin** (execute a **360° spin)**.
    - Update **the OLED** with **the completed pick count** (e.g., “Picks: 1, 2, or 3”).
    - Flash the **LED** on pick confirmation.
- Continue until **three pick tasks** are completed.

Phase 4: Speed Management and Safety Considerations

- Base speed may vary within **75–300** (static or dynamic). Operate conservatively to protect the robot and the course.
- The robot needs to detect markers for a **fast-track path** to speed up (providing service with higher time efficiency) and slow down in other locations, potentially around corners or areas where safety comes first (higher accuracy and safety).

Suggestions for Improved Performance

- **Search/Heuristics:** Use **A*** or **Greedy Best-First Search** on the **known grid**; bias heuristics to **minimize aisle changes** and prefer the **fast-track aisle** when clear.
- **Path Optimization:** Prefer **shortest-path** returns; treat **blocked aisles** and temporary obstacles as **dynamic costs**.
- **Speed Adjustment:** Slow near **shelf faces, intersections, tight corners, and dynamic obstacles**. *(Optional: add an **E-stop** input.)*
- **Pick Task Enhancements:** Add **an LED/buzzer** to the **pick confirmation**; implement **fine-alignment** (e.g., proportional control to center on a fiducial/marker).
- **Testing & Debugging:** Test with **varying pallet/tote placements** and **temporary aisle blocks** to validate dynamic re-routing. Simulate edge cases to ensure robustness.
- **Safety notes:** Make a beep sound when backing up (move backward).
- Other improvements as you find suited …