Coordinated Multi-Robot Frontier Exploration Summary

Overview

This assignment is an implementation of a coordinated multi-robot frontier exploration strategy. The approach is based on the method proposed in the paper:

"Coordinated Multi-Robot Exploration" by Wolfram Burgard, Mark Moors, Cyrill Stachniss, and Frank Schneider, published in IEEE Transactions on Robotics, 2005.

Key Concepts

- **Frontiers:** Grid cells adjacent to explored cells but themselves unexplored.
- **Color Scheme:**
  - Unexplored cells are shaded *light gray*.
  - Explored cells are shaded *teal*.
  - Frontier cells are shaded *yellow*.
- **Utility Function:** Each frontier cell has a utility based on its distance to another robot's target and a soft decay function:

$$p(d) = \max\left(1 - \frac{d}{d_{\max}}, 0\right)$$

- **Cost Function:** The cost to reach a frontier from a robot's position is approximated using the Manhattan distance:

$$\text{cost}(c) = |x_r - x_c| + |y_r - y_c|$$

  where (x_r, y_r) is the robot position and (x_c, y_c) is the candidate cell.
- **Score Function:** The overall score for a frontier is computed as:

$$\text{score}(c) = \text{utility}(c) - \alpha \cdot \text{cost}(c)$$

  where α is a tunable weight parameter balancing utility and travel cost.
- **Target Selection:** Each robot greedily selects the frontier cell with the highest score as its next target.
- **Coordination:** After a robot selects a target, all frontier cells within its sensor range are penalized for the next robot by applying the probability decay:

$$\text{utility}(c) \leftarrow \text{utility}(c) \cdot p(d) \quad \text{where } d \leq d_{\max}$$

  This prevents multiple robots from redundantly exploring the same region.
- **Utility Visualization:** The utility of the frontier cells is indirectly reflected in the cost-to-go maps. Higher utility areas are typically closer and more likely to be selected early, while penalized areas appear less accessible in the cost maps.
- **Cost Maps:** After simulation, shortest-path cost maps are computed from each robot's final position.

Simulation Result

Two robots are deployed from the center of the map and explore the grid cooperatively. Obstacles are predefined in the map. Robots update explored regions using a fixed sensor radius and iteratively detect and move toward frontier cells.

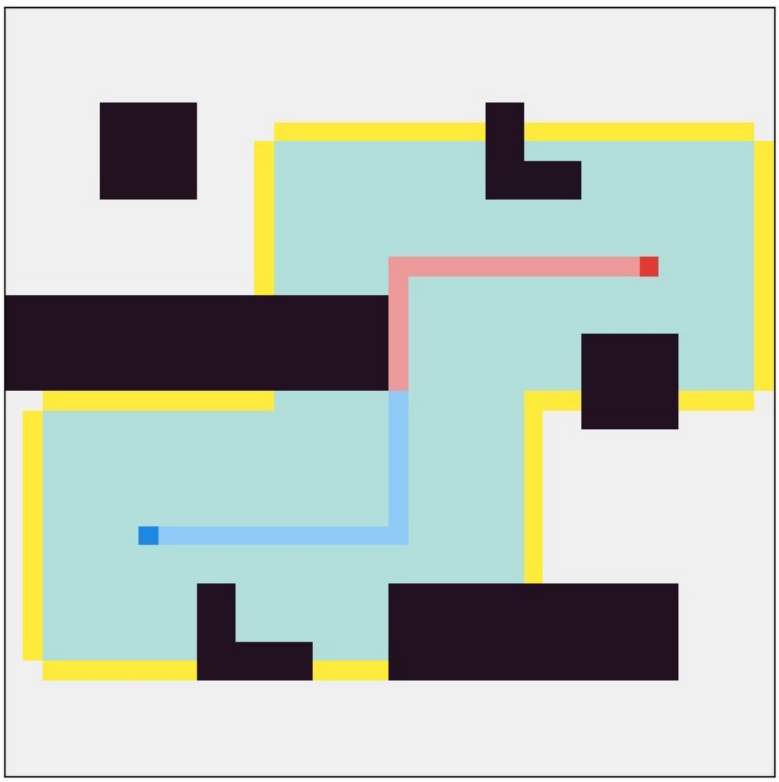

Figure 1: Snapshot of robot paths after 20 steps, explored and unexplored areas, and frontiers. Frontier cells (yellow), explored cells (teal), and unexplored cells (light gray) and the traced paths of both robots are also shown.

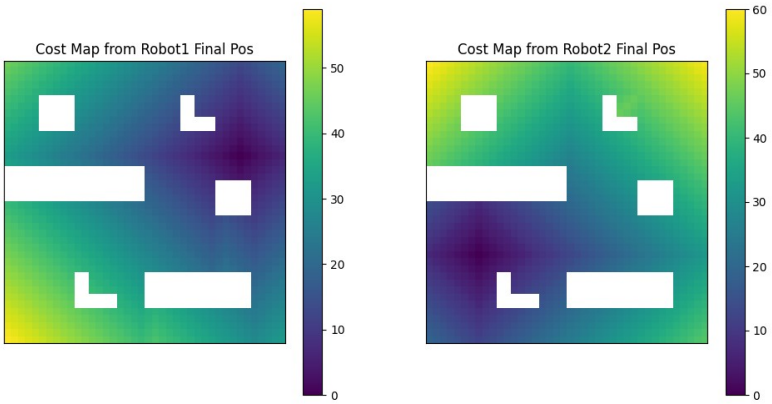

Figure 2: Cost-to-go maps from each robot's final position (after 20 steps)..