Multi-Robot Task Assignment Problem
CMPE 297: Midterm Project Report

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Abstract

This document presents a framework for solving the multi-robot task assignment problem with collision avoidance, detailing the initial conceptual design and plans for future implementation and improvements.

1 INTRODUCTION

The problem addressed is the multi-robot task assignment issue, aiming to optimize the coordination of multiple robots moving from initial to final configurations without colliding. The objective is to ensure efficient, collision-free navigation. Related work includes various strategies in robotic path planning and collision avoidance, such as the use of decentralized algorithms for dynamic environments and the application of A* or D* for optimal pathfinding.

2 SYSTEM DESIGN & IMPLEMENTATION DETAILS

We selected the A* algorithm for pathfinding due to its efficiency and ability to find the shortest path in a weighted graph, making it suitable for real-time robotic navigation. Collision avoidance was handled by implementing a time-stepping simulation where robots' movements are adjusted to prevent position overlap.

The system was implemented using Python for its extensive libraries and ease of prototyping. NetworkX was used to manage graph-based data structures essential for pathfinding, while Matplotlib facilitated real-time visualization of robot movements.

For handling large datasets, the system employs a batching approach where robot configurations and paths are processed in segments, reducing memory overhead and improving computational efficiency. This approach is integrated with parallel processing techniques to further enhance performance.

3 EXPERIMENTS / PROOF OF CONCEPT EVALUATION

3.1 Dataset(s) used

Since the project is in the exploratory phase, synthetic datasets representing graph structures are used. These datasets simulate environments with 4 robots and simple grid-based obstacle scenarios. Each dataset contains about 10-50 instances, with preprocessing involving the generation of valid initial and final robot positions to avoid immediate collisions.

3.2 Datasets details/patterns

The data primarily consists of node and edge configurations within a graph structure. These patterns represent possible movements and positions that robots can take within a constrained environment, helping to test basic pathfinding and collision avoidance algorithms.

3.3 Data/results visualization, online interactive (preferred)

The current visualization is done using Matplotlib to plot robot movements step-by-step in the 2D grid layout. Future plans include enhancing interactivity perhaps through a web-based visualization tool like Plotly or D3.js to allow real-time interaction and observation of algorithm performance.

3.4 Data preprocessing decisions

Initial preprocessing involves assigning distinct starting and ending nodes to each robot to minimize initial conflicts. Edge creation in the graph is restricted to avoid creating paths that could immediately result in collisions, setting up a straightforward scenario for initial tests.

3.5 Evaluation methodology

Currently, the evaluation involves direct observation of the paths generated by the algorithm to ensure they meet basic requirements (no collisions, reach destination). As this project progresses, methods like repeated random sampling of initial and final positions could be used to statistically evaluate performance.

3.6 Graphs showing different parameters/algorithms evaluated in a comparative manner

In future experiments, graphs will compare the efficiency (in terms of path length and computation time) of different pathfinding algorithms like Dijkstra's, A*, and potential field methods. Analysis will focus on the trade-offs between path optimality and computational overhead.

3.7 Analysis of results

Preliminary results indicate that the simple pathfinding approach used can handle basic scenarios but lacks robustness in more complex or densely populated graphs. A deeper analysis with more sophisticated algorithms and larger datasets will be necessary to fully understand the limitations and capabilities of the proposed methods in real-world scenarios.

4 DISCUSSION & CONCLUSIONS

4.1 Decisions made/Things that worked

The decision to use Python along with NetworkX for graph representation and Matplotlib for visualization proved effective for quickly setting up the basic framework and visualizing the robot movements in a 2D space. The simple pathfinding approach using direct paths was useful for establishing baseline functionality.

4.2 Difficulties faced/Things that didn't work well

The simplistic collision avoidance system does not effectively handle complex scenarios where multiple robots have intersecting paths. Additionally, the absence of a sophisticated pathfinding algorithm like A* means that the robots may not move optimally in more crowded or intricate environments.

4.3 Conclusions

This exploratory project has laid the foundational work for a multi-robot task assignment system with basic visualization capabilities. However, significant improvements are needed in both pathfinding algorithms and collision avoidance techniques to handle real-world complexities. Future iterations should include the implementation of advanced algorithms and possibly the integration of more dynamic and interactive visualization tools.

5 FUTURE PLAN / TASK DISTRIBUTION

5.1 Pros and cons of the current method & future plan

The current method is advantageous for its simplicity and ease of implementation, which facilitates quick initial testing and visualization. However, it lacks the robustness required for complex scenarios involving multiple interacting robots. The future plan involves integrating more sophisticated algorithms such as A* for pathfinding and developing a more dynamic collision avoidance system. Enhancing the interactive visualization component using web technologies like JavaScript or a Python framework such as Bokeh or Dash is also planned.

5.2 Break into components and clearly explain

5.2.1 Pathfinding Algorithm Enhancement

I will implement the A* algorithm to replace the current simple pathfinding method. This will potentially include researching and adapting more advanced variations tailored to multi-agent systems.

5.2.2 Collision Avoidance Mechanism

I plan to develop a more comprehensive collision avoidance strategy that includes time-space graph analysis to effectively manage the simultaneous movements of multiple robots.

5.2.3 Visualization and User Interface Development

I will upgrade the visualization component to provide real-time interaction capabilities, facilitating better demonstration and testing of the system's effectiveness in various scenarios.

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APPENDIX

Current Status of Project Code

```python
import matplotlib.pyplot as plt
import networkx as nx
import numpy as np

def initialize_graph(nodes, edges):
    """Initialize a graph given nodes and edges."""
    G = nx.Graph()
    G.add_nodes_from(nodes)
    G.add_edges_from(edges)
    return G

def plot_graph(G, positions, ax, title="Graph"):
    """Plot the graph on a given Matplotlib axis."""
    nx.draw(G, pos=positions, with_labels=True, node_size=700, ax=ax, font_weight='bold')
    ax.set_title(title)

def simple_path_finder(initial_positions, final_positions):
    """
    Generates a simple path from initial to final positions.
    This function assumes that each robot moves independently.
    """
    paths = {}
    for robot, final_pos in final_positions.items():
        start_pos = initial_positions[robot]
        # Create a direct path: This is a placeholder for more complex pathfinding logic
        path = [start_pos, final_pos]
        paths[robot] = path
    return paths

def apply_collision_avoidance(paths):
    """
    Adjusts paths to avoid collisions. This is a very simplistic collision avoidance for illustration.
    """
    adjusted_paths = paths.copy()
    # This is a placeholder for actual collision avoidance logic
    return adjusted_paths

def visualize_movement(paths, initial_positions):
    fig, ax = plt.subplots()
    for step in range(max(len(path) for path in paths.values())):
        positions = {}
        for robot, path in paths.items():
            position = path[step] if step < len(path) else path[-1]
            positions[robot] = position
        plot_graph(initial_graph, positions, ax, f"Step {step+1}")
        plt.show()

# Example initialization
nodes = range(4)  # Suppose we have 4 robots
edges = [(0, 1), (1, 2), (2, 3), (3, 0)]  # Edges representing possible paths

# Initial and final positions of robots, represented as node indices
initial_positions = {0: (0, 0), 1: (1, 0),
```

References

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[3] Lingzhi Luo, Nilanjan Chakraborty, & Katia Sycara, "Distributed Algorithms for Multirobot Task Assignment With Task Deadline Constraints," IEEE Transactions on Automation Science and Engineering, vol. 12, no. 3, pp. 1-13, July 2015, DOI: 10.1109/TASE.2015.2438032.

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