DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

Artificial Intelligence Lab (CS4271)

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Assignment: 3

Question 1

1. A disaster has struck a **futuristic smart city**, and your task is to develop an **AI-powered drone navigation system** to **rescue stranded survivors**. The drone must **autonomously navigate through the city**, avoiding obstacles like collapsed buildings and fire zones while optimizing for the fastest route (equivalent to minimum energy consumption).

   Your objective is to implement the *A Search Algorithm** to guide the drone from its **starting position (S)** to **rescue multiple survivors (G1, G2, ... , Gn) (intermediate states) and return to base (B) (treated as goal state)** while minimizing energy consumption and ensuring safe traversal.

Grid Representation of the City (State Space Representation of the City):

The smart city is represented as a **3D grid** where each $(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z})$ coordinate defined as: (x, y) in the 2D coordinate and z values is the depth of flying at different levels. Each of the depth 'z' is represented by different notations as:

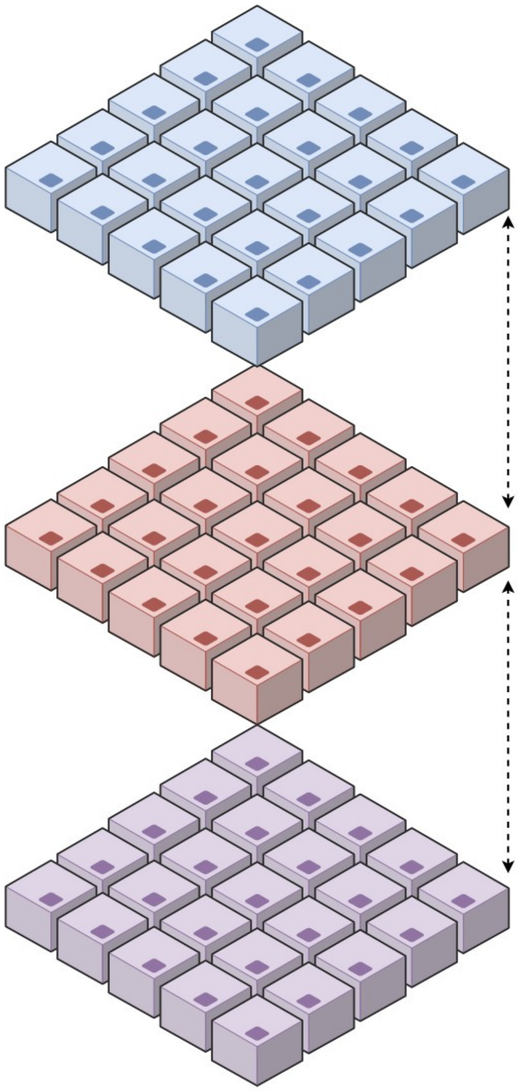
- **Roads & Open Spaces** (`0`) → The drone can fly here.
- **Buildings/Collapsed Structures** (`1`) → The drone **cannot** pass through.
- **Fire Zones** (`F`) → High-risk zones. Passing through **incurs an extra cost**.
- **Survivor Locations** $(G_1, G_2, \ldots, G_n)$ → The drone must **visit and rescue them**.
- **Recharging Stations** (`R`) → The drone can **stop and recharge energy** if needed.
- **Base Station** (`B`) → The drone must **return here after completing the mission**.
- **Drone's Start Position** (`S`) → Where the drone begins.

Drone Movement and Cost Considerations:

a) **The drone moves in 3D space**:
   - **Up** `(x, y, z+1)`, **Down** `(x, y, z-1)`,
   - **North** `(x-1, y, z)`, **South** `(x+1, y, z)`,
   - **East** `(x, y+1, z)`, **West** `(x, y-1, z)`.
   - **Diagonal movements** (like flying at an angle) **are not allowed** for simplicity.

b) **Energy Consumption Factor:**
   - Moving through **clear space (0)** costs **1 energy unit**.
   - Moving through **fire zones (F)** costs **3 energy units** due to turbulence.
   - Moving **upwards (z+1) costs extra 2 energy units**, while descending `(z-1)` costs **1 energy unit**.

c) **Objective:**
   - The drone **must rescue all survivors** before returning to base `(B)`.
   - The **optimal path minimizes total energy consumption**.
   - If needed, the drone can **recharge at (R)**, but stopping at a station adds a **fixed time penalty**.



Sky Level

1	0	0	0	0
0	F	0	1	0
0	0	1	0	F
0	0	0	0	0
0	1	0	0	1

Mid Level

0	0	1	0	0
0	1	1	0	0
F	0	0	0	1
0	1	1	1	0
0	0	0	0	0

Ground Level

S	0	1	0	0
0	F	1	1	G_1
F	0	0	0	F
R	1	1	1	0
B	0	1	0	G_2

Implementation Guidelines:

a) *Use A search algorithm** to compute the most energy-efficient path.
b) **Priority Queue (Min-Heap)** should be used to store nodes with the lowest `f(n) = g(n) + h(n)`.
c) **Heuristic (h(n))**: Use a **3D Euclidean distance** to estimate cost to the goal:

$$h(n) = \sqrt{(x_{current} - x_{goal})^2 + (y_{current} - y_{goal})^2 + (z_{current} - z_{goal})^2}$$

d) **Account for terrain cost penalties** (e.g., fire zones, vertical movement, etc.).
e) **Recharging Logic**: If energy is too low to reach the next goal, navigate to the nearest `(R)` station.
f) **Ensure the algorithm supports multi-goal search**, as the drone must **visit multiple survivors** before returning.
g) **Handle Edge Cases**:
   - No valid path exists to all survivors.
   - Energy depletion before reaching a recharge station.
   - The base `(B)` is unreachable due to obstacles.

```python
import heapq
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

class Node:
    def __init__(self, pos, g=0, h=0, parent=None, energy=100,
time=0):
        self.pos = pos
        self.g = g
        self.h = h
        self.f = g + h
        self.parent = parent
        self.energy = energy
        self.time = time

    def __lt__(self, other):
        return self.f < other.f

class DroneNavigator:
    def __init__(self, grid, start, survivors, base,
recharge_stations, max_energy=100, recharge_penalty=5):
        self.grid = np.array(grid)
        self.start = start
        self.survivors = survivors
        self.base = base
        self.recharge_stations = recharge_stations
        self.shape = self.grid.shape
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        self.max_energy = max_energy
        self.recharge_penalty = recharge_penalty

    def is_valid(self, pos):
        x, y, z = pos
        return (0 <= x < self.shape[0] and
                0 <= y < self.shape[1] and
                0 <= z < self.shape[2] and
                self.grid[x,y,z] != 1)

    def get_neighbors(self, pos):
        x, y, z = pos
        moves = [(0,0,1), (0,0,-1), (-1,0,0), (1,0,0), (0,1,0), (0,-
1,0)]
        return [(x+dx, y+dy, z+dz) for dx, dy, dz in moves if
self.is_valid((x+dx, y+dy, z+dz))]

    def heuristic(self, pos1, pos2):
        return np.sqrt(sum((np.array(pos1) - np.array(pos2)) ** 2))

    def get_path_cost(self, pos1, pos2):
        if self.grid[pos2] == 'F':
            return 3
        elif pos2[2] > pos1[2]:  # Moving up
            return 2
        elif pos2[2] < pos1[2]:  # Moving down
            return 1
        return 1

    def a_star(self, start, goal):
        start_node = Node(start, energy=self.max_energy, time=0)
        open_list = [start_node]
        closed_set = set()

        while open_list:
            current = heapq.heappop(open_list)

            if current.pos == goal:
                path = []
                cost = current.g
                time = current.time
                while current:
                    path.append(current.pos)
                    current = current.parent
                return path[::-1], cost, time

            closed_set.add(current.pos)

            for next_pos in self.get_neighbors(current.pos):
                if next_pos in closed_set:
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                    continue

                cost = self.get_path_cost(current.pos, next_pos)
                next_g = current.g + cost
                next_h = self.heuristic(next_pos, goal)
                next_energy = current.energy - cost
                next_time = current.time + 1  # Each move takes 1 unit
of time

                if next_energy <= 0:
                    nearest_recharge = min(self.recharge_stations,
key=lambda r: self.heuristic(next_pos, r))
                    recharge_path, recharge_cost, recharge_time =
self.a_star(current.pos, nearest_recharge)
                    if recharge_path:
                        next_g += recharge_cost
                        next_energy = self.max_energy - cost
                        next_time += recharge_time +
self.recharge_penalty
                    else:
                        continue

                next_node = Node(next_pos, next_g, next_h, current,
next_energy, next_time)
                heapq.heappush(open_list, next_node)

        return None, float('inf'), float('inf')

    def find_complete_path(self):
        current = self.start
        total_path = [current]
        total_cost = 0
        total_time = 0
        remaining = self.survivors.copy()

        while remaining:
            min_cost = float('inf')
            best_path = None
            best_survivor = None
            best_time = float('inf')

            for survivor in remaining:
                path, cost, time = self.a_star(current, survivor)
                if path and cost < min_cost:
                    min_cost = cost
                    best_path = path
                    best_survivor = survivor
                    best_time = time

            if not best_path:
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                print("No valid path to remaining survivors")
                return None, None, None

            total_path.extend(best_path[1:])
            total_cost += min_cost
            total_time += best_time
            current = best_survivor
            remaining.remove(best_survivor)

        base_path, base_cost, base_time = self.a_star(current,
self.base)
        if not base_path:
            print("No valid path to base")
            return None, None, None

        total_path.extend(base_path[1:])
        total_cost += base_cost
        total_time += base_time

        return total_path, total_cost, total_time

    def visualize_path(self, path=None):
        fig = plt.figure(figsize=(10, 10))
        ax = fig.add_subplot(111, projection='3d')

        ax.set_xticks(range(self.shape[0]))
        ax.set_yticks(range(self.shape[1]))
        ax.set_zticks(range(self.shape[2]))

        x, y, z = np.where(self.grid == 1)
        ax.scatter(x, y, z, c='gray', marker='s', label='Obstacles')
        for obs in zip(x, y, z):
            ax.text(*obs, f'({obs[0]},{obs[1]},{obs[2]})',
color='gray')

        x, y, z = np.where(self.grid == 'F')
        ax.scatter(x, y, z, c='red', marker='s', label='Fire')
        for fire in zip(x, y, z):
            ax.text(*fire, f'({fire[0]},{fire[1]},{fire[2]})',
color='red')

        surv_x, surv_y, surv_z = zip(*self.survivors)
        ax.scatter(surv_x, surv_y, surv_z, c='green', marker='^',
s=200, label='Survivors')

        recharge_x, recharge_y, recharge_z =
zip(*self.recharge_stations)
        ax.scatter(recharge_x, recharge_y, recharge_z, c='blue',
marker='s', s=100, label='Recharge Stations')
```

```
        ax.scatter(*self.base, c='orange', marker='*', s=200,
label='Base')

        if path:
            path_x, path_y, path_z = zip(*path)
            ax.plot(path_x, path_y, path_z, c='blue', linewidth=2,
label='Drone Path')
            ax.scatter(*self.start, c='brown', marker='o', s=100,
label='Start')
            for i, pos in enumerate(path):
                ax.text(*pos, f'{i}:({pos[0]},{pos[1]},{pos[2]})',
color='blue', fontsize=8)

        ax.set_xlabel('X')
        ax.set_ylabel('Y')
        ax.set_zlabel('Z')
        ax.legend()
        plt.title('Drone Navigation Path')
        plt.show()

# Example usage
grid = np.zeros((5, 5, 3), dtype=object)
obstacles = [(0,0,2), (1,1,1), (2,2,1), (3,3,1), (4,4,1)]
for obs in obstacles:
    grid[obs] = 1
grid[0,1,1] = 'F'
grid[2,1,1] = 'F'

start = (0,0,0)
survivors = [(1,4,0), (3,3,2), (4,4,2)]
base = (4,0,0)
recharge_stations = [(2,2,0), (4,3,1)]

navigator = DroneNavigator(grid, start, survivors, base,
recharge_stations, max_energy=100, recharge_penalty=5)
path, cost, time = navigator.find_complete_path()

if path:
    print(f"Path found with total cost: {cost}")
    print(f"Total time taken: {time}")
    print("Path:", path)
    navigator.visualize_path(path)
else:
    print("No valid path found")
```

```
Path found with total cost: 20
Total time taken: 18
Path: [(0, 0, 0), (0, 1, 0), (0, 2, 0), (0, 3, 0), (0, 4, 0), (1, 4,
0), (2, 4, 0), (2, 4, 1), (3, 4, 1), (3, 4, 2), (3, 3, 2), (4, 3, 2),
```

```
(4, 4, 2), (4, 3, 2), (4, 3, 1), (4, 2, 1), (4, 1, 1), (4, 0, 1), (4,
0, 0)]
```