CS 357 Project Proposal

Optimal way-point assignment for designing drone light show formations

19.10.2024

[Research Paper Reference]

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Overview

A swarm drone light show uses multiple drones, typically quadrotors, flying together to create stunning displays. Each drone is equipped with LEDs, and the show is held at night. The drones arrange themselves into different formations, creating beautiful designs, images, and transitions.

These shows are an eco-friendly and reusable option for advertising, celebrations, and entertainment. As the number of drones increases, coordinating them becomes more complex. To manage this, an intelligent assignment system is needed to allocate way-points for each transition between formations. The proposed solution, called the Constrained Hungarian Method for Swarm Drones Assignment (CHungSDA), adapts the Hungarian algorithm with added constraints to optimize this process.

Problem Description

To design and simulate a drone light show, we first decide the number of drones to use, considering costs. Then, way-points are created for each formation, assigning one to each drone. This assignment is key, as it impacts how smoothly drones move and how long the show can last. Given drones' limited flight time, minimizing the total distance they travel helps extend the duration of the show.

Our goal is to develop a method that efficiently assigns way-points to drones, covering all formations while minimizing the distance traveled during transitions. This optimization will lead to smoother, longer-lasting drone shows.

Constraints of the Optimization Problem

- Only one way-point should be assigned to each drone in each formation.
- All the drones in the swarm should be assigned a way-point for creating a formation.

The above two constraints imply that the number of drones used for the light show is exactly equal to the number of way-points.

- The distance between any two drones must be greater than a fixed minimum, called δ_{min}.

This constraint checks if all the way-points in the design are unique and maintain minimum collision avoidance distance between each other. Next, the objective is defined as:

- The cost, i.e., sum of the distances of all the trajectories of drones for transforming into each new formation should be minimum.

Develop an optimized approach for way-point allocation to drones during each intermediate transformation in swarm drone by minimizing the total distance traveled by drones in order to enhance the efficiency and smoothness of transitions between formations.

Proposed Solution - Specifications

The following algorithm will be used to solve the drone assignment problem. We first describe the standard Hungarian algorithm to solve the assignment problem.

Algorithm - The Kuhn's (Hungarian) Algorithm

The Hungarian algorithm is a combinatorial optimization algorithm that solves the assignment linear-programming problem in polynomial time. The Hungarian Algorithm locates maximum-weight matchings or minimum-weight matchings in the bipartite graph to discover the optimal solution to the assignment or association problem. The algorithm works by finding the best possible matches between two sets of objects, such as a set of workers and a set of tasks to be assigned to each of the workers, to ensure an optimal solution. It does this by solving the problem in polynomial time $(O(N^3))$, hence finds the solution quickly and efficiently, even for larger problems.

Compatibility with the Problem at Hand

The above-mentioned method is compatible with the problem at hand with the following provided as input, along with additional constraints. In this case, the matrix representation will have rows corresponding to the drones and columns representing the way-points.

The availability of each drone is exactly one, meaning each drone can be assigned to one and only one way-point. Let $x_{ij} = 1$ represent the assignment of drone to way-point. The value of indicates that the drone is assigned to way-point, while means that the drone is not assigned to way-point.

$$\text{minimize Z} = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$$

$$\text{subject to constraints:}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \quad \text{for} \;\; i = 1, \ldots, n \qquad (1)$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad \text{for} \;\; j = 1, \ldots, n \qquad (2)$$

1. An array $D = [[p_x^{d_1}, p_y^{d_1}, p_z^{d_1}], [p_x^{d_2}, p_y^{d_2}, p_z^{d_2}], \ldots [p_x^{d_n}, p_y^{d_n}, p_z^{d_n}]]$ — representing the coordinates of each drone. $p_x^{d_i}, p_y^{d_i}, p_z^{d_i}$ represent the x, y and z coordinates of the drone i respectively.
2. An array $W = [[p_x^{w_1}, p_y^{w_1}, p_z^{w_1}], [p_x^{w_2}, p_y^{w_2}, p_z^{w_2}], \ldots [p_x^{w_n}, p_y^{w_n}, p_z^{w_n}]]$ — representing the the coordinates of the way-points. $p_x^{d_j}, p_y^{d_j}, p_z^{d_j}$ represent the x, y ,and z coordinates of way-point j respectively.
3. δ_{min}: the minimum distance to be maintained between any two drones.

We can calculate the optimal assignment using the Hungarian algorithm by considering the following matrix:

	w_1	w_2	w_3	w_4
d_1	c_{11}	c_{12}	c_{13}	c_{14}
d_2	c_{21}	c_{22}	c_{23}	c_{24}
d_3	c_{31}	c_{32}	c_{33}	c_{34}
d_4	c_{41}	c_{42}	c_{43}	c_{44}

The cost of assigning drone i to way-point j is denoted as c_{ij}. It is calculated from the Euclidean distance between the drone and the corresponding way-point, multiplied with a constant factor that takes into account the different types of drones that may be used for the show.

The objective function here is F representing assignments of i^{th} drone to j^{th} way-point such that the total cost is minimized, or, mathematically,

$$F = \min \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$$

The output of running the algorithm is expected to be the entries $x_{ij} = 0 \text{ or } 1$ of the matrix x. Constraints (1) and (2) described previously require that in each row and in each column of the output matrix, there is **exactly one** entry equal to 1 and the rest of the entries in the corresponding row/column are equal to 0.

Ideas for Future Work

1. **Individual drone battery capacity constraint:** While the current algorithm focuses on minimizing the total distance, it does not account for individual drone battery capacities—a critical practical consideration. Thus we would like to modify the constraints to take into account the limits of each drone in terms of the maximum distance it can travel in one flight.
2. **An alternative optimization approach:** while the total distance minimization is discussed in this paper, another potential approach could prioritize minimizing the **time interval** between consecutive transitions, which adds to the visual appeal of the show.

3. **AI-based assignment:** Wind conditions can alter the initial positions of the drones and hence their trajectories. This leads to the risk of close proximity and/or collisions. AI is essential to detect various such factors and also take into account any obstacles around. However this field of improvement is of not enough scope as it's less relevant to the course.