Task Scheduling for UAV: A Finite State Machine Based Clustering Algorithm

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Abstract. This paper concerns the Unmanned Aerial Vehicle (UAV) task scheduling problem. While some approaches offer the optimal solution, due to the combinatorial nature of this problem, many research suggest the heuristic algorithm to obtain sub-optimal solution within a reasonable time. In this paper, we propose a novel heuristic algorithm that accelerates UAV task scheduling based on Finite State Machine (FSM) and clustering method. First, we reformulate the original problem using FSM. In this reformulation, we define the start and end points of tasks as states, and tasks as transitions between these states. This approach can reduce the problem size in terms of the number of states considered. Second, we cluster tasks and connect these clustered groups which yields the complete task schedule. To enable effective clustering, we introduce a novel distance metric to determine the distance between tasks in the reformulated problem, implying the minimum time required for transit between tasks. Simulation results demonstrated the excellence of the proposed method in terms of tasks completion time and total travel time compared to the existing heuristic algorithm.

Keywords: Task Scheduling Problem, Finite State Machine, Heuristic Algorithm, Clustering Algorithm, UAV

1 Introduction

In recent years, the use of unmanned aerial vehicles (UAVs) has been increased in various fields. As the use of UAVs increases, research on methods for finding an optimal task scheduling for an efficient work are also actively being conducted. Among which, (Mixed) Integer Linear Programming (MILP) has been widely used to seek the optimal scheduling of task. However, since the optimal task scheduling problems are combinatorial problems, MILP may cause intractable computational complexity, and thus many researchers have proposed heuristic algorithms instead [1].

This paper proposes a new heuristic algorithm to solve the UAV task scheduling problem. First, by utilizing the feature of the task, which consists of a starting point and an ending point, the problem is reformulated using a Finite State Machine (FSM) [2]. After that, the distance metric, which means the minimum distance between the two tasks, is defined based on the FSM. Using this metric, tasks are clustered to form several task groups. Lastly, the entire UAV task scheduling solution is obtained by connecting the cluster groups that conform to the minimal distance metrics. Through simulations, we evaluate the performance of proposed algorithm, against the existing heuristic algorithm, Particle Swarm Optimization (PSO) algorithm. We compared execution time and performance by incrementally increasing the number of tasks. The result demonstrates the superiority of the proposed algorithm over PSO.

2 Problem Formulation

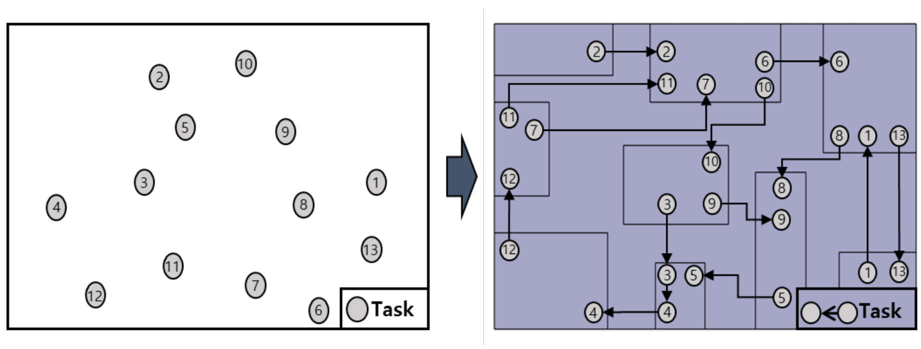

Fig. 1. Reformulation of Task Scheduling Problem

The problem addressed in this paper is finding the task order that allows single UAV to complete all given tasks within minimum flight time. This problem can be mathematically expressed as follows:

$$\min \left(\sum_{i} t_i x_i + \sum_{i,j} t_{ij} x_{ij} \right) \tag{1}$$

Here, t_i represents the time taken to complete task i, and x_i represents whether task i is performed or not. Additionally, t_{ij} represents the time required for execution of task j after completing task i, and x_{ij} indicates whether task j is performed after task i.

In this problem, the tasks are characterized by predetermined starting and ending points. By utilizing these characteristics, the problem can be reformulated, enabling the derivation of solutions.

2.1 Problem Reformulation

As depicted in Figure 1, the features of tasks along with FSM can be used in reformulating the problem [2]. While performing the task, traversed points are represented as state, s_i. Tasks are then expressed as transitions between these states.

$$\text{task}_i := \{s^i_{\text{init}}, \ldots, s^i_{\text{fin}}\} = s^i \tag{2}$$

Here, task_i indicates that task i is defined by a transition from s^i_{init} to s^i_{fin}. Therefore, (1) is redefined as follows:

$$\min \left(\sum_i t_i x_i + \sum_{s_i, s_j} t(s_i, s_j) \cdot \text{tr}(s_i, s_j) \right) \tag{3}$$

In equation (3), $t(s_i, s_j)$ represents the time taken for transition from state i to state j, and $\text{tr}(s_i, s_j)$ represents the number of transitions from state i to state j.

3 Algorithm Development

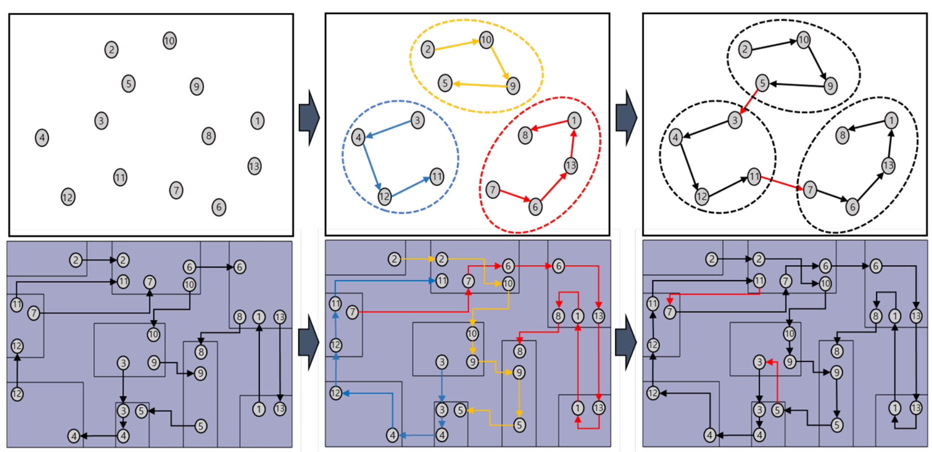

Fig. 2. Overall Algorithm Structure

Figure 2 illustrates the proposed algorithm. The upper section depicts the general scheduling problem, while the lower section presents the reformulated problem. To tackle the reformulated problem, we define a new distance metric and apply the proposed algorithm, which consists of two steps. First, we cluster the tasks into new groups using the distance metric. Then, we connect these clusters to find the solution.

3.1 Distance Metric

Before explaining the algorithm, a new distance metric is proposed. The distance between tasks that can be used in reformulated problem is defined as follows:

$$d(\mathrm{task}_i, \mathrm{task}_j) = \begin{cases} t(s^i_{\mathrm{fin}}, s^j_{\mathrm{init}}) & \text{if } s^j_{\mathrm{init}} \neq s^j_{\mathrm{fin}} \\ \min t(s^i_{\mathrm{fin}}, s^j) & \text{if } s^j_{\mathrm{init}} = s^j_{\mathrm{fin}} \end{cases} \tag{4}$$

This metric can be divided into two cases. Firstly, if the starting point and ending point of task j are not the same, it refers to the time taken to move from the ending point of task i to the starting point of task j. However, if the starting point and ending point of task j are the same, it signifies the shortest time after comparing all states of s^j.

3.2 Task Clustering

Following that, the clustering process is carried out using defined distance metric. The clustering process involves merging tasks into clusters to create new clustered tasks where the distance according to metric (4) is 0. These clustered tasks retain the same attributes as the original tasks, allowing the same application of the distance metric.

3.3 Connecting Clustered Tasks

Finally, a solution is found by connecting clustered tasks created earlier with distance metric. To achieve this, the process begins by considering the starting state and selecting the closest clustered task. Subsequently, the selection continues by choosing the task closest to the previously selected clustered task, thereby determining the entire order of tasks.

4 Numerical Simulation

Through simulations, this study compared proposed algorithm with the existing heuristic algorithm, Particle Swarm Optimization (PSO) [1]. The comparison included increasing the number of tasks and evaluating computation time and performance. The results showed that the proposed algorithm consistently achieved better computational time, which is attributable to its avoidance of iterative computations. Additionally, the algorithm achieved better performance by effectively clustering tasks using a distance metric to minimize UAV travel distance.

5 Conclusion

This paper proposes a new heuristic algorithm to solve the task scheduling problem using the UAV. The proposed algorithm demonstrates its superior performance by achieving lower execution times and shorter task completion durations compared to the existing heuristic algorithm, PSO.

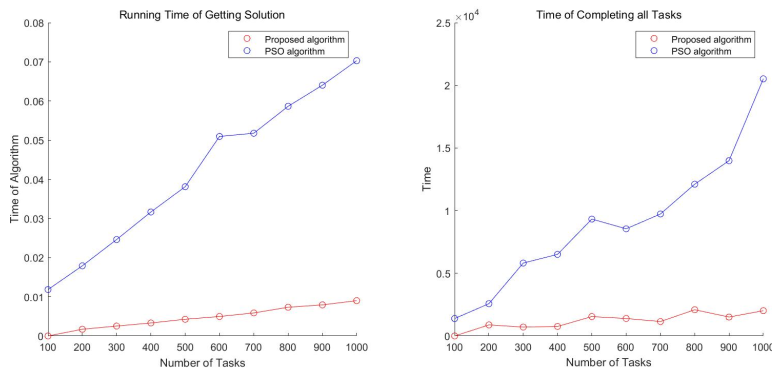

Fig. 3. Results of Simulations

This work opens opportunities for UAV task scheduling by suggesting an approach that could be extended to consider factors like drone battery life and payload capacity, expanding the algorithm's use.

6 Acknowledgement

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