Formulation and a MOGA Based Approach for Multi-UAV Cooperative Reconnaissance

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Abstract. Multi-UAV cooperative reconnaissance is one of the most challenging research area for UAV operations. The objective is to coordinate different kinds of sensor-bearing UAVs conducting reconnaissance on a set of targets within predefined time windows at minimum cost, while satisfying the reconnaissance demands, and without violating the maximum permitted travel time for each UAV. This paper presents a multi-objective optimization mathematical formulation for the problem. Different from previous formulations, the model takes the reconnaissance resolution demands of the targets and time window constraints into account. Then a multi-objective genetic algorithm CR-MOGA is put forward to solve the problem. In CR-MOGA, Pareto optimality based selection is introduced to generate the parent individuals. Novel evolutionary operators are designed according to the specifics of the problem. Finally the simulation results show the efficiency of our algorithm.

1 Introduction

Unmanned Aerial vehicles (UAVs) plays an important role in air base reconnaissance operations. However, single UAV conducting reconnaissance in complex battlefield will encounter many problems. For example, one UAV alone cannot conduct reconnaissance on targets located in different sites simultaneously. Therefore, coordinating a fleet of sensor-bearing UAVs to conduct air reconnaissance is an important problem for employing UAVs effectively.

The mathematical modelling and solving for multi-UAV cooperative reconnaissance problem is one of the challenging areas in UAV studies. Ryan[1] formulated the problem as a multiple travelling salesman problem(TSP) with time window constraints and solved by tabu search algorithm. Hutchison[2] proposed a method which divided the operations area into identical sectors and allocated the targets in one sectors to a given UAV. Then TSP defined to find the shortest path connecting each target for each UAV is solved using simulated annealing algorithm. Ousingsawat[3] divided the problem to minimum-time trajectory problem and task assignment problem. A* search is used to find the shortest path between two points, then the task assignment problem is expressed as a mixed integer linear program(MILP) solved using the MATLAB optimization

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toolbox. While in these previous studies, the specifics of reconnaissance mission are not considered thoroughly. For a certain ground target, the imaging resolution on it should reach a certain level for the commander to recognize it or even classify it. Otherwise the reconnaissance is failure. And the information about the target should be timely and reflect the situation in a certain period. If the UAVs are tardy, the reconnaissance mission is also failure. At the same time, the cost to employ UAVs conducting reconnaissance should also be minimized while meeting all the reconnaissance needs.

The main contribution of this paper is to present a mathematical model for multi-objective cooperative reconnaissance problem(MOCRP). The model takes the reconnaissance resolution demands and time window constraints of the targets into account. Then a novel multi-objective genetic algorithm CR-MOGA is proposed to solve the problem. The rest of the paper is organized as follows. Section 2 presents the mathematical model of MOCRP. The proposed CR-MOGA is described in detail in section 3. Section 4 shows the simulation results and section 5 concludes the paper.

2 Cooperative Reconnaissance Problem Formulation

In previous formulations of the problem, such as TSP in [1][2] and MILP in [3], the reconnaissance resolution and time windows of the targets, which are important factors, are not considered thoroughly. And the number of UAVs is often fixed and not be optimized. In this paper, we present a mathematical formulation for the problem, which takes more specifics of the reconnaissance mission into account.

The reconnaissance targets set is denoted by $T_0 = \{1, 2, ..., N_T\}$, where N_T is the number of targets. R_i is the reconnaissance resolution demand of target i. Each target i has a time window $[e_i, l_i]$, where e_i is the earliest time allowed for reconnaissance on it and l_i is the latest time. T_i is the time to begin reconnaissance on target i. An UAV may arrive before e_i, which incurs the waiting time w_i until reconnaissance is possible. No UAV may arrive past l_i. The set $T = \{0, 1, ..., N_T\}$ denotes the extended targets set, where 0 indicates the base that UAVs depart from and return to. $V = \{V^1, V^2, ..., V^{N_V}\}$ denotes UAVs set with different capabilities, where V^k denotes the k-th kind of UAVs set and v_q^k is the q-th UAV in V^k. The reconnaissance resolution is r_k for UAVs in V^k, and for $V = \{V^1, V^2, ..., V^{N_V}\}$, $r_1 < r_2 < ... < r_{Nv}$ holds. TL_k is the maximum travel time permitted, and c_k is the cost to employ one UAV in V^k. s_i^k denotes the time duration for an UAV in V^k conducting reconnaissance on target i. The routes set between target pairs is denoted by $A = \{(i, j) | i, j \in T, i \neq j\}$, which can be calculated by classical routing algorithms such as A*. Each route $(i, j) \in A$ is associated with a distance d_{ij} denoting the length of (i, j) and a travel time t_{ij}^k denoting the travel time for UAV in V^k between target i and j. The decision variable of MOCRP is

$$x_{pij}^k = \begin{cases} 1 & \text{if route } (i, j) \text{ is used by UAV } v_p^k \\ 0 & \text{otherwise} \end{cases} \tag{1}$$