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Use of Co-operative UAVs to Support/Augment UGV Situational Awareness and/or Inter-Vehicle Communications

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Abstract: This paper presents the development of a path-planning algorithm for Unmanned Aerial Vehicles (UAVs) in order to increase the situational awareness for platooning vehicles. The scenario considers a team of cooperative UAVs, initially docked on moving Unmanned Ground Vehicles (UGVs). In particular, the goal consists in finding the best routing plan for the UAVs in order to visit some designated targets in a wide search area to augment the UGVs' situational awareness. Taking into account the maximal endurance constraint of the UAVs, this problem becomes equivalent to a time-constrained multiple depot vehicle routing problem with moving depots. To tackle this variant of the well-known vehicle routing problem, a methodology based on a TABU search meta-heuristic is implemented. While respecting the endurance constraint, this methodology tempts to optimize multiple objectives: the number of UAVs required, the total length of the routing and the balance of the lengths of the different routes within the routing plan. The proposed approach based on a meta-heuristic gives relevant results in a relatively short period of time.

Keywords: Co-operative UAVs; Multiple-depots vehicle routing problem; path planning; vehicle routing problem with moving depots; TABU search meta-heuristic.

1. INTRODUCTION

The use of robots has many applications in the military as well as in the civilian areas. In particular, unmanned vehicles can carry out hazardous and difficult tasks in hostile or dangerous environments. Removing the operator from the vehicle is a very promising challenge to reduce the risk to human life in these types of missions. In case of extreme situations such as natural disasters or critical battlefields, part of the missions could be entirely dedicated to a cooperative team of aerial and ground unmanned vehicles. These unmanned vehicles, tasked as a team at a high level, can efficiently perform an aerial ground mapping of large predefined areas for missions such as exploration, surveillance, target detection, tracking and search and rescue operations. Indeed, the deployment of such a team is well suited to achieve these missions since the cooperation of ground and aerial vehicles exhibit strong and complementary characteristics, leading to efficient synergies and greater reliability. Unmanned Aerial Vehicles (UAVs), such as small rotorcrafts, are easily transportable and can be launched quickly to explore a large area and search for targets. However, these small UAVs cannot carry heavy payloads such as large LIDAR and cameras. Therefore, sensors requirements, combined with other uncertainties, may limit the UAVs capabilities of precise detection and localization of targets on the ground. On the other hand, Unmanned Ground Vehicles (UGVs), such as Armed Forced Vehicles (AFVs), benefit from high resolution sensor capabilities but they may be limited by their short range due to obscured field of view in the presence of ground obstacles. Then, the use of cooperative aerial and ground vehicles is challenging and much effort and research work have been pushed into exploiting the complementarity capabilities of UAVs and UGVs. The deployment of autonomous vehicles is gaining ground thanks to many achievements and current progress in modern technologies such as flight controls, sensors and computing capabilities. UAVs and UGVs can be highly automated and do not require the direct control of the operator during the missions. Path-planning algorithms can efficiently plan in advance optimal trajectories for the unmanned vehicles to follow. Path-planning algorithms also aim to find a specific trajectory which optimizes a specific objective function such as the shortest path in terms of time or energy supply requirements. In this paper, the path-planning problem is investigated for UAVs docked on AFVs and tasked as a cooperative team to cover a large area and visit some designated targets. This problem is finally equivalent to solve the well-known Multiple Depot Vehicle Routing Problem. It also focuses on the deployment of a fleet of UAVs during a surveillance mission in a realistic and dynamic environment. It is assumed that UAVs are first stored on the ground vehicles and docked on recharging stations, before being launched to visit some predefined targets.

This work continues the efforts of Leonard (2015) in solving the dynamic multiple travelling salesmen problem. Leonard's Ant Colony optimization provides near-optimal routing accounting for multiple ground vehicles with only one UAV docked on each UGV and a dynamic set of targets. The present paper takes a slightly different approach and uses different algorithms in order to extend Leonard's results. First, TABU search optimization is used to solve the problem. Then, several constraints are added to the framework: UAVs capabilities are limited by their endurance, more than one UAV can be launched from an UGV. Although the constraint of a dynamic

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set of targets is released, the possibility to add a new target during the optimization process is permitted in the present work. Moreover, the UGVs are considered here as dynamic and can move forward while the UAVs are flying. The minimization of an objective function in a realistic and dynamic environment where the ground vehicles are moving is the main contribution of this work.

This paper is organized as follows: first, a literature review on Multiple Depot Vehicle Routing Problems and related resolution methodologies, pertaining to this research, is conducted in Section 2. Then, Section 3 defines mathematically the problem for which Section 4 offers a resolution methodology. Section 5 highlights the performances of the proposed algorithms based on the analysis of the test results.

2. RELATED WORK

2.1 Vehicle Routing Problems

The Vehicle Routing Problem (VRP) consists of a multiple tasks allocation problem. It aims to assign a cooperative team of vehicles a set of orders, which constitute geographically spread targets to visit, in the most optimal way based on a predefined objective function while conforming to various constraints. In the multiple Travelling Salesmen Problem (m-TSP), the aim is to allocate each moving vehicles a list of targets while minimizing an objective function such as the maximum length of one route. Each vehicle visits the targets as ordered in its own list and then returns to its starting position. Each list of targets consists then in a tour or a route. The VRP extends the m-TSP, by adding some capacity constraints to the vehicles. A wide part of the literature tackles this problem in the context of a supply chain problem. For instance, the first original formulation of the VRP was proposed by Dantzig at al. in 1959, who focused on the computation of a set of optimal routes for a fleet of gasoline delivery trucks. The analogy is relatively straight forward. Indeed, while the UGVs are equivalent to the depots or factories, the UAVs can represent the vehicles, such as trucks, doing the delivery or the collection by some customers which are by analogy similar to the targets.

Depending on the assumptions and constraints, many variants of the VRP exist and for each sub-problem a specific mathematical model can be developed. A generic mathematical description for a standard VRP with capacity constraints is given by Freitas (2012). A large panel of problem variants can be generated by adding or relaxing different constraints to the original formulation. Carlton, in 1995, has proposed a hierarchical classification scheme of the main variants of the Vehicle Routing Problem. His classification highlights the Capacited Vehicle Routing Problem (CVRP), the Periodic Vehicle Routing Problem (PVRP), the Distance-constrained Vehicle Routing Problem (DVRP), the Vehicle Routing Problem with Time Windows (VRPTW), the Vehicle Routing Problem with Back-hauls (VRPB), the Vehicle Routing Problem with Pick-up and Delivery (VRPPD) and the Multiple Depot Vehicle Routing Problem (MDVRP). Hybrids of these variants are also sometimes investigated such as the Capacited and Distance-constrained Vehicle Routing Problem (DCVRP). This classification is well represented in the diagram presented in Fig. 1 (Montoya-torres at al., 2015).

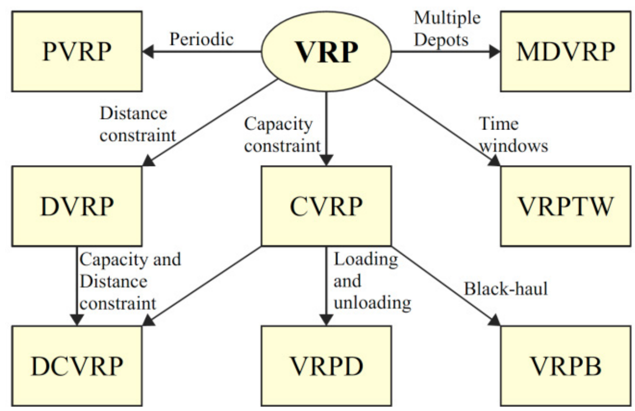

Fig. 1. Classification of the different variants of the Vehicle Routing Problem (VRP).

2.2 Resolution Methodologies

The VRP is a well-known combinatorial optimisation problem. A wide panel of possible resolution methodologies exists for this kind of problems. The potential optimization strategies include exacts methods, heuristics algorithms and meta-heuristics algorithms. The VRP has been classified as an NP-hard problem. Winston at al. (2003) have highlighted that this class of problems cannot be solved efficiently to optimality in terms of computational load. A problem is also qualified as NP-hard if the computational load required to solve the problem increases exponentially with the size of the problem. Therefore, exact methods which aim to find out the optimal solution become quickly inoperative for bigger size problems because of the high computational load requirements. Consequently, the majority of papers found in the open literature regarding VRP have investigated the use of resolution methodologies which give a promising compromise between the near-optimality of the solution and the computational load. Indeed, from a more realistic and operational point of view, operators, which implement such strategies, often prefer having an approximate but good enough solution in a relatively short period of time. This explains the interest of researchers in the development of heuristics algorithms and meta-heuristics strategies.

Meta-heuristics are powerful and efficient techniques used to solve a large panel of NP-hard combinatorial problems. The aim of the meta-heuristics is similar to the one of the heuristics: find out a feasible solution whose quality is acceptable in a short period of time. Contrary to classical heuristics, meta-heuristics use a generic scheme which is completely independent of the specific problem. A meta-heuristic consists in an iterative decision making process that guides and leads the operations of subordinate heuristics by rigorously analysing the situation at each iteration to generate the best exploration of the solution space in a very short period of time. Moreover, meta-heuristics often involve mechanisms and algorithms which enable the solution search to avoid being trapped in a local minimum. Several types of meta-heuristics