RPAS Swarms in Disaster Management Missions

Efficient Deployment through Optimized Mission Planning

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***Abstract*—The use of Remotely Piloted Aircraft Systems (RPAS) in civil applications is becoming increasingly popular. At the moment, several R&D projects focus on the topic of RPAS deployment in crisis management. The number of conceivable tasks in a disastrous event is high and still rises with the increase in the level of automation. In this context, efficient deployment is a decisive point and requires particular emphasis on an optimized mission planning process. This research aims to address the problem of cooperative mission planning and control for the deployment of RPAS swarms in disaster management. To that aim, uncertainties and environmental changes must be taken into account. The following contribution describes the specific problems that arise in in disaster management missions. Important steps towards the development of a set of optimization techniques that enables dynamic cooperative mission planning are outlined.**

RPAS swarm, cooperative mission planning, cooperative RPAS control, disaster management;

I. Introduction

Deploying Remotely Piloted Aircraft Systems (RPAS) in disaster management is a promising concept. RPAS can be used in inhospitable environments to give a comprehensive picture of the existing situation without endangering human life. Besides small and rotor-wing RPAS, High Altitude Long Endurance (HALE) and Medium Altitude Long Endurance (MALE) systems can also make an important contribution in the context of disaster management. Due to their long endurance and their larger payload capacity, these systems are best suited to support missions which concern large areas. Such large scale disasters include among others earthquakes, forest-/wildfires, tsunamis/floods and volcanic eruptions.

Optimal mission planning techniques are an important element, to ensure the most efficient use of RPAS. An optimized planning process can lead to several positive effects for the entire mission, e.g., by faster acquisition of required information, greater resource efficiency, or maximized surveillance benefit. During major disasters the parallel use of several RPAS is likely, since multiple tasks can be executed at the same time. It is known from several battlefield applications that the performance of the whole team will improve if all members of an RPAS swarm work cooperatively [1]. Therefore, the aim of this research is to investigate and develop optimization techniques that allow dynamic cooperative mission planning for the deployment of RPAS swarms in disaster management. We will identify different optimization problems, which are to be solved during the mission planning process. The next step is to explore whether and to what extent existing algorithms are applicable to the specified problems. This paper describes the general research background and outlines initial considerations.

II. Background

A. *Research Context*

Existing research on the problem of cooperative RPAS mission planning and control is mostly related to military applications. Conceivably, suggested approaches and algorithms are applicable or at least transferable to the specific problems in disaster management missions. We give a few selected examples of related work in the following paragraph.

Several studies have focused on decentralized model predictive control and particle swarm optimization algorithms to solve cooperative planning and control problems [2],[3][4]. It is important to note that group dynamic solutions are rather difficult to apply to groups of MALE or HALE systems, since motion of large fixed-wing RPAS is restricted by strong flight dynamic constraints [2]. Reference [1] addresses several U.S. Air Force relevant RPAS cooperative decision and control problems that arise in military operations. In this work different algorithms for cooperative control problems are outlined. The methods presented include mixed integer linear programming, stochastic dynamic programming, vehicle routing, and genetic algorithms. The idea of formulating the swarm routing problem as a variant of the vehicle routing problem was also pursued by [5]. The work includes a detailed description of the design of a multi-objective evolutionary algorithm to solve the problem. While [1] puts more emphasis on different variants of the task assignment problem, a comprehensive overview of cooperative path planning algorithms is given by [6].

B. *Long Endurance RPAS in Disaster Management*

Prompt situation assessment is a critical point for the success of a disaster management mission. Common MALE and HALE Remotely Piloted Aircraft (RPA) can provide a payload capacity of up to 1360 kg [7] to carry multiple sensors. Presently, available sensors range from advanced Electro Optical (EO) and Infrared (IR) camera systems, to radar or gas sensors [8]. Adequately equipped RPAS can execute complex reconnaissance and surveillance missions. Thermal imaging devices support rescue forces to find victims buried under rubble, and enable the forces to continue missions during night. The extensive data is used to support fast and efficient deployment of rescue forces or distribution of relief goods. Remaining payload capacities provide the opportunity to transport special loads to areas with limited access. Conceivable loads range from disaster relief material and humanitarian aid cargo to ground-based sensors that can be deposited in certain areas.

While several studies focus on the deployment of small, or rotor-wing systems, this contribution is devoted to the use of HALE and MALE systems for large-scale disaster management. These systems are particularly useful during major disasters, because of their capability to cover very large areas during reconnaissance and surveillance missions. In addition, the maximum flight duration of HALE/MALE systems exceeds the possible flight duration of manned aircraft. To give an example: The Block 10 production version of the RQ-4 Global Hawk can image an area of a size up to 40,000 nautical square miles during a 24 hours reconnaissance mission and is capable to fly for as long as 35 hours without a break [7].

The best known MALE system is most certainly the U.S. RPAS RQ-1 Predator and its successor the MQ-9, formally called Predator B. An equally prominent member of the family of HALE systems is the RQ-4 Global Hawk. Primarily known for their use in military applications, both systems have already been successfully employed in disaster management missions. Global Hawk’s first humanitarian mission was to assist firefighters and rescue teams during the wildfires in Southern California in 2007 [9]. Further participations of both systems in disaster management are summarized in Table I.

III. Methodology

To meet the specific requirements we have to include various approaches and methodologies in the model development. In this section an overview on the new model design and its basic concepts is given.

A. *Cooperative Control*

Cooperative control is defined as the problem to command several RPAS to cooperatively perform multiple tasks [1]. In order to maximize the performance of the whole group, shared use of information and utilization of resources is an important factor [6]. Depending on the organization structure, swarm members can exchange state information and collected data directly between each other, or disseminate all information to a central decision-maker. In the second case, all information is processed by a large decision and control program. This variant is called a classical centralized control problem [1]. We base our model design on a centralized control scheme.

B. *Database Incorporation*

An important prerequisite for optimal mission planning is to keep the decision-maker constantly informed. Reliable real-time information improves planning in uncertain and changing environments. In [10] it was first suggested to incorporate a coverage database to store reliable up-to-date information about the availability and quality of already collected data. This database is used to provide coverage awareness to the operator and to enable efficient re-planning during the mission. The area of interest is represented with a cellular grid where each cell contains specific information regarding surveillance priority and data quality. We extend the idea of the coverage database and include pre-disaster information on infrastructure and population density. This information will enhance targeted search for possible landing spaces and survivors. During mission execution, the information of each cell is continually updated and expanded with the latest collected data. This will indicate new tasks and support reasonable re-planning of the mission.

C. *Mission Planning*

A very general formulation of the problem of interest was

TABLE I.

Natural Disaster	**Examples of HALE/MALE System Use in Disaster Management**	
	RQ-4 Global Hawk	***RQ-1/MQ-9 Predator/ Predator B***
Wildfires, Southern California (2007)	Flew over 157 hours to support fire-fighting efforts. The use of infrared imagery allowed data collection even through smoke and at night [9].	NASA’s Ikhana (additionally equipped Predator B) flew over the wildfire areas and provided high quality images of the hot spots with use of thermal- infrared imaging equipment [9].
Earthquake, Haiti (2010)	Flew 6 missions in support of relief operations and provided among others images on hospitals, distribution points, ID (Internally Displaced People) Settlements [9]. Provided imagery of places where soldiers are to be deployed [11].	Several Predator RPAS operated from Puerto Rico and provided real-time full motion videos across Haiti. The mission provided 24 hour a day coverage [12].
Earthquake and Tsunami, Japan (2011)	Flew over 20 missions and over 500 hours and surveyed the damaged areas with focus on infrastructure, damage assessment and nuclear power plant status. Surveillance through obscuring clouds was possible with use of Synthetic Aperture Radar (SAR), as well as infrared and electro optical camera systems [9].	-

given by [13]:

Given: V non-identical RPAS (v_k for $k \in \{1,\ldots,V\}$) of limited capacity initially located at depot, S sources with limited resources ($i \in \{1,\ldots,S\}$), and G targets (goal points) (g_i for $i \in \{1,\ldots,G\}$), with known demand and specific service time window.

Find: Necessary number of vehicles, their payload profile, and feasible tours of minimal travel to all targets, respecting capacity constraints on targets.

In this formulation, we identify three different optimization problems: Task assignment, payload planning and path planning. All three problems are inextricably linked, since tasks that can be executed depend on the established payload and the estimated cost for a task on the resulting flight path. However, we intend to solve the problems in two steps. Firstly, the task assignment and payload planning problem are solved with the use of estimated cost for the execution of each task. Afterwards, the path planning process is carried out to provide a flight path for each swarm member. Our model design is based on the assumption that future RPA will be able to follow an assigned trajectory automatically. Therefore, the desired outcome of the optimization process consists of a set of 4D trajectories associated with a specific cost for each RPAS.

As the mission proceeds, the system has to constantly respond to arising demands and unexpected events. We therefore distinguish between mission planning at planning stage and execution stage during the development of optimization techniques. Fig. 1 gives a rough overview of the planned system architecture.

1) Mission Planning Stage All tasks are known a priori and we have to assign multiple task tours to each vehicle. The problem of uncertainties is addressed with use of stochastic programming approaches. This means to calculate the expected future value of a decision or action taken now [1]. The introduced database will be of great support for an improved probability assessment. The generated solution will serve as a reference solution during mission execution.

2) Mission Execution Stage The system has to deal constantly with newly arising tasks. Each decision must be taken without knowledge of future demands. We can model the input data to the task assignment and payload planning problem as a finite request sequence which is revealed step by step to the system. This problem formulation corresponds to the definition of an online optimization problem [14]. Online algorithms are especially developed to serve the requests according to the specific online paradigm.

D. Path Planning

The final step in mission planning is to create a flight path for each RPAS, based on the assigned tasks. A path consists of a number of waypoints together with altitude and time constraints, which form a flyable 4D trajectory. During the path planning process, the specific technical constraints of each RPAS will be taken into account. The purpose is to generate collision-free trajectories that enable the most efficient mission execution. At this stage, we will not only generate trajectories for individual flights, but also for flight in formation. Recent development successes have shown that automatic flight in close formation is conceivable to become possible for

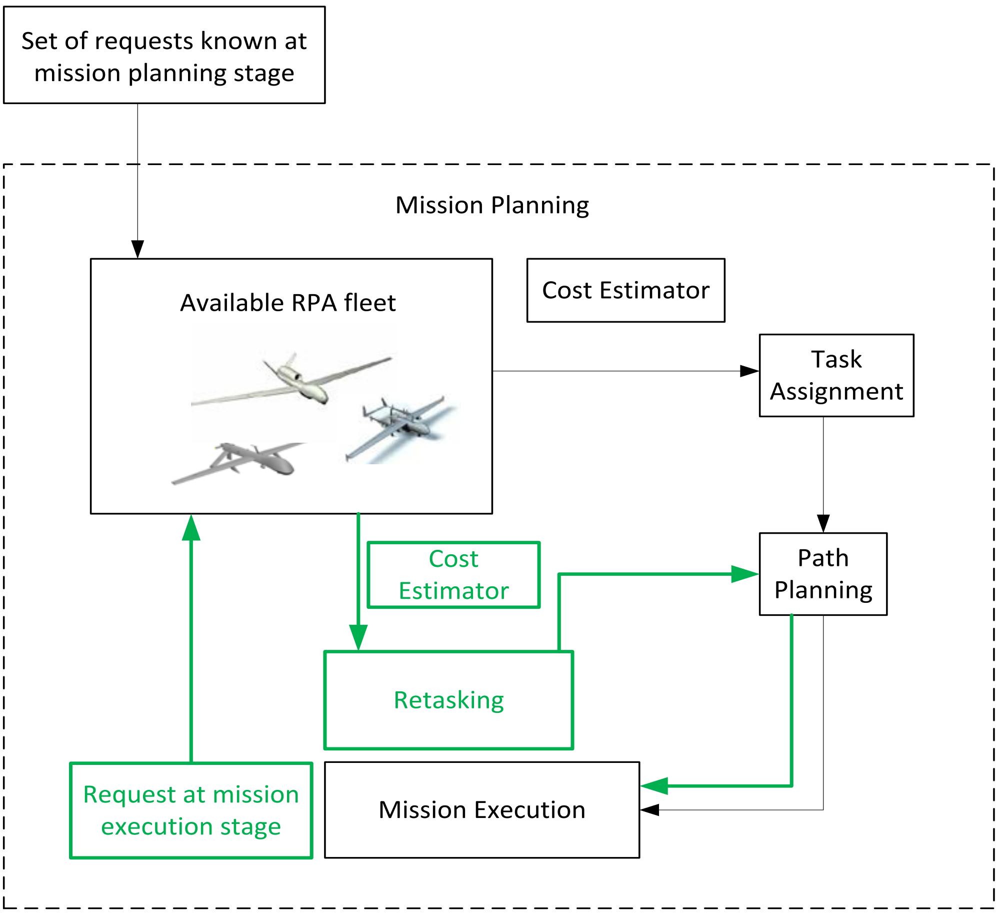

Figure 1. System Architecture

RPAS in the near future [15]. This could decrease the operator vehicle ratio rapidly and simplify the process of mission planning and control. For example, it will be easier to oversee the whole swarm during a close formation flight or to generate trajectories for collision avoidance if the entire swarm is treated as a single object. In addition, close formation flight is known to potentially reduce fuel consumption of following aircraft since the leader's wing can be used for drag reduction [16].

IV. Research Objectives

This research aims to develop a set of optimization techniques for the cooperative mission planning and control of multiple RPAS. To that aim we will make use of existing approaches to RPAS deployment in disaster management missions and existing research on cooperative mission planning and control. The principal work steps will be as follows:

- Analysis of past disastrous events against the background of RPAS deployment
- Investigation of existing research and solution approaches in the field of RPAS swarming
- Realistic scenario design to create a test-bed for the developed solutions
- Mathematical formulation of identified optimization problems
- Development and examination of different algorithms
- Report of simulation results

The developments of this research will be integrated into DLR's existing simulation environment and contribute to ongoing research projects.

V. Conclusion

RPAS have already proven their potential to support mission management during past major disasters. The specific advantages and challenges of using RPAS swarms in disaster management missions advise to put more research effort on optimal mission planning. We presented early considerations on the development of a new mission planner for the deployment of multiple large fixed-wing systems in disaster management. The concept includes the use of dynamic and stochastic programming approaches to handle uncertain and changing environments. A special coverage database is incorporated to provide reliable up-to-date information of the area of interest. Based on this information the response capacity of first and second responders to disastrous events can be considerably improved.

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