AERIAL: Hypothetical Trajectory Planning for Multi-UAVs Coordination and Control

(Demo Paper)

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ABSTRACT

This paper presents a distributed application named *AERIAL* which allows coordination and control of multiple Unmanned Aerial Vehicles (UAVs) engaged in temporally constrained missions. This application combines multiagent paradigm and trajectory planning techniques and relies on a coordination model taking both deliberation and planning durations into account.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Intelligent agents, Multiagent Systems*

General Terms

Algorithms

Keywords

Multiagent Software Systems, UAV, Coordination, Trajectory planning

1. INTRODUCTION

Recent advances made in the field of autonomous Unmanned Aerial Vehicles (UAVs), suggest that fleets of UAVs will be deployed in order to achieve various temporally constrained missions such as surveillance, intelligence or suppression of enemy air defences.

Thus, new algorithms and architectures have to be proposed to ensure a coordinated control of the fleet. Many were already proposed [5] [4], but there is still a lot to do, in particular when the duration of the planning or deliberation process has to be taken into account, which is always the case in real applications. Indeed, in most approaches, strong assumptions about durations are made, such as planning or decision are instantaneous.

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From an operational point of view, those assumptions are problematical because in reality both planning and deliberation processes take time, and have to be handled.
We decided not to elude this problem, and that is why this paper presents a distributed application, combining multiagent and trajectory planning techniques, which in addition to allow coordination and control of several UAVs involved in temporally constrained missions, takes both deliberation and planning durations into account.

2. SYSTEM ARCHITECTURE

It is now admitted that Distributed Systems of Agents, also called Multiagents Systems (MAS) [2] are well suited to design large scale distributed systems made of multiple autonomous entities engaged in one or more activities, and where coordination is a major issue. Indeed, the different properties i.e. *modularity, flexibility, robustness, scalability and decentralization*, required by such systems, are inherent characteristics of MAS. That is why we decided to base our work concerning multiple UAVs coordination on the multiagent paradigm.

In AERIAL, two types of intelligent entities interact, the first one is *Human* (Operator) and the second is *computational* (UAVs and Ground Control Station (GCS)). The human operator plays the role of a chain of command. Its purpose is to enact mission orders, to monitor UAVs during coordination tasks, but also to make decisions. It should be noted that in AERIAL, final decision remains to Human. Computational entities are modelled by agents. More specifically, the GCS agent takes responsibility for transmitting orders enacted by the human operator to the UAVs (such as a new temporarily constrained mission). Besides being a simple interface between the human operator and the UAVs, the GCS agent plays a predominant role during the task assignment process. An UAV agent is cognitive, cooperative, has his own representation of the environment according to its capabilities, can communicate with others and embeds its own trajectory planner.

The on-board planner we developed computes time-optimal trajectories using a path/velocity decomposition [7]. First, a path is computed thanks to a wavefront expansion algorithm [8]. Then, the velocity of the UAV is tuned on this path, allowing to deal with moving obstacles avoidance and synchronization with others UAVs in a unified way. This decomposition is computationally very efficient, and allows an UAV agent to dynamically in-flight re-plan its trajectory in a few seconds. In particular, for each request emitted by the GCS agent, an UAV agent, while following its current trajectory (denoted $\tau_{current}$), is able to produce a hypothetical trajectory, in order to evaluate the consequences of the addition of a new objective to the current plan.

3. COORDINATION MODEL

Like many coordination models, our approach is based on a goal assignment/trajectory computation decomposition. Our approach solves the goal assignment problem via the *Contract Net Protocol* (CNP) [6], and the trajectory computation problem is handled in a distributed manner by the UAVs.

As we mentioned before, and even if both goal assignment and trajectory computation are efficient, coordination takes time. We decided neither to elude this problem, nor to make strong assumptions such as *planning is instantaneous*. In order to provide a coordination model taking into account both deliberation and planning durations, we propose to adapt a mechanism commonly used in human coordination: the specification of a date of commitment (denoted d_{commit}). At the coordination level, with the addition of such a date, no assumption is made on durations. It only implies that the different processes involved in the coordination have to end before d_{commit}. At the agent level, this commitment date represents the starting point of plan changes.

Hence, our coordination model relies upon the combination of trajectory planning, CNP and the concept of commitment date.

Let's consider n UAVs in flight and a human operator who wants to plan a new temporally constrained mission such as a joint observation of a target X between T_{min} to T_{max}. First, the human operator needs to know which forces (i.e. UAVs) could handle the mission. Therefore, via the GCS agent, he broadcasts a request formatted as: *observe X between T_{min} to T_{max} commit d_{commit}* and waits for answers.

When an UAV receives a request while following $\tau_{current}$, it evaluates its feasibility, generating an hypothetical trajectory derived from $\tau_{current}$. To do this, the UAV locates its future position p on $\tau_{current}$) at time d_{commit} and computes a trajectory including the new task whose starting point is p. If the mission is feasible then the UAV informs the GCS agent of its estimated time of arrival (ETA) on the target. Otherwise, it ignores the task, removes the hypothetical trajectory associated and informs the GCS that it cannot perform the mission.

Once informed, the operator, according to different criteria depending on the application, forms a team of UAVs to accomplish the mission. When the mission is coordinated (i.e. UAVs have to observe the target at the same time), UAVs have to be synchronized. But ETA can differ between UAVs. To finalize the synchronization, the UAV which ETA is highest, is designated as leader. It asks the others to refine (thanks to on-board planer velocity tuning mechanism) their hypothetical trajectories in order to be synchronized with it. This refining process, consisting in slowing down the fastest UAVs, might require additional planning if some constraints (e.g. fuel consumption) do not hold anymore.

To finish, when commitment date is reached, each agent involved activates the hypothetical trajectory associated to the mission.

4. IMPLEMENTATION

The whole system is based on Alba [1], a proprietary generic library dedicated to the commissioning of mobile agents written in Prolog.

5. CONCLUSION AND FUTURE WORKS

AERIAL is a distributed application combining both Multiagent and trajectory computation techniques, and is able to ensure coordination and control of a fleet of UAVs involved in temporally constrained mission. Since our approach is experimental, further work will be done. Different fields of research were already identified, and studies are carried out. In particular on the formal framework related to the concept of date of commitment. But also on the trajectory planner, so that it can handle time-varying environment and provide a more flexible velocity tuning mechanism. Finally, studies are carried out on the various processes able to manage concurrent mission requests i.e. concurrent hypothetical trajectories. An extended description of the AERIAL system can be found in [3].

6. REFERENCES

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