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UAV Multilevel Swarms for Situation Management

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ABSTRACT

The development and usage of Unmanned Aerial Vehicles (UAVs) quickly increased in the last decades, mainly for military purposes. Nowadays, this type of technology is used in non-military contexts mainly for civil and environment protection: search & rescue teams, fire fighters, police officers, environmental scientific studies, etc. Although the technology for operating a single UAV is now mature, additional efforts are still necessary for using UAVs in fleets (or swarms).

This position paper presents the ASIMUT project (Aid to Situation Management based on MULTimodal, MUltiUAVs, MULTilevel acquisition Techniques). The challenges of this project consist of handling several fleets of UAVs including communication, networking and positioning aspects. This motivates the development of novel multilevel cooperation algorithms which is an area that has not been widely explored, especially when autonomy is an additional challenge. Moreover, we will provide techniques to optimize communications for multilevel swarms. Finally, we will develop distributed and localized mobility management algorithms that will cope with conflicting objectives such as connectivity maintenance and geographical area coverage.

CCS Concepts

•Computing methodologies → Multi-agent systems;
Cooperation and coordination;

Keywords

cooperative UAV; multilevel swarm; mobility model; decisional autonomy

1. INTRODUCTION

The development and usage of Unmanned Aerial Vehicles (UAVs) quickly increased in the last decades, mainly for military purposes [10]. Nowadays, this type of technology is used in non-military contexts mainly for civil and environ-

ment protection: search & rescue teams, fire fighters, police officers, environmental scientific studies, etc. Although the technology for operating a single UAV is now mature, efforts are still necessary for using UAVs in fleets (or swarms).

This position paper presents the ASIMUT (Aid to Situation Management based on MULTimodal, MUlti-UAVs, MULTilevel acquisition Techniques) project that aims at developing surveillance services relying on multiple fleets of UAVs. It is planned to have collaborations among UAVs evolving at different altitudes: large (typically fixed-wing) UAVs covering the area from a high altitude with coarse grain acquisition capabilities, and low altitude multi-rotor UAVs in charge of precise close to the field measurements. Additionally, the considered scenario targets multimodal data collection, i.e. acquisition achieved with different types of sensors (e.g. electro-optical or infrared) and will thus allow retrieving meaningful information from the surveyed field. The ASIMUT consortium's vision entails a model proposing a balanced combination of different measures, framed by the types of threats and operator's reaction capabilities. The ASIMUT project aims at increasing detection, high-level data fusion capabilities and UAV autonomy, by using innovative algorithms permitting to decrease the operator workflow by providing tools to enhance the capabilities of the system.

The remainder of the article is organized as follows. In section 2, a description of the ASIMUT project is given. Then in section 3 we provide a state-of-the-art on swarm decisional autonomy and on mobility management. Merging the latter fields, section 4 presents the innovations developed and implemented for the ASIMUT project. Finally, section 5 presents our conclusions.

2. ASIMUT PROJECT

The main goal of the ASIMUT project is to address scenarios where a mission is to be achieved based on data fusion coming from different sensors in a number of UAVs that constitute a swarm. The ASIMUT project aims at developing innovative algorithms based on learning techniques dedicated to fusion of data. From early warning process where data are provided by the UAV swarm payload, the target localization, monitoring and classification processing are performed using these techniques. These will improve the quality and significance of the pieces of information provided to an operator through detection and identification processes. It will be typically necessary to combine the information about multiple objects, events and their relations with con-

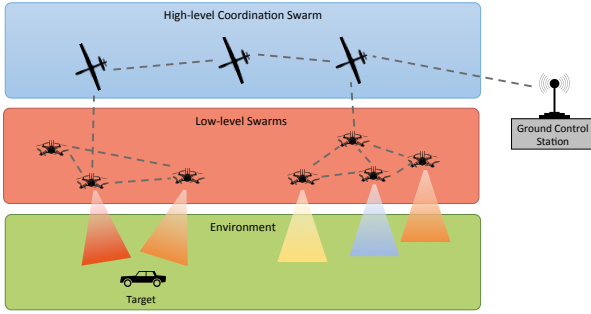


Figure 1: Multi-level swarms of UAVs.

textual information. To this end, the ASIMUT model concept integrates different approaches in three layers:

UAVs Collaboration: UAV swarm flight plan optimization according to external environment;

UAVs Detection: each UAV carries a specific payload to perform detection for air-ground surveillance. The autonomy of the UAV swarm permits to define which UAV(s) is(are) relevant to perform the analysis required by an operator;

Data Exploitation: automatic detection of targets in particular in a real-time FMV (Full Motion Video). The data fusion can be improved so as to decrease the workflow for an operator (Smart Information Management).

The ASIMUT system is composed of a Ground Control Station (GCS) and UAVs that constitute swarms (Figure 1). The GCS role is to communicate and transmit data between the swarms and the person(s) in charge of the situation management. Two types of swarms are distinguished: High Level Coordination Swarm (HLCS) and Low Level Swarm (LLS), composed of fixed-wing and multi-rotor UAVs respectively. The role of the HLCS is to manage the tasks assigned by the GCS or autonomously created by the HLCS itself in reaction to an event occurring in the environment. Finally the LLS role is to collect data and track vehicles in specific areas of this environment.

This distinction implies a multilevel cooperation between UAVs to achieve their missions. In this description the GCS is considered as global entity dealing with situation awareness, high-level data fusion and mission management of the ASIMUT project. The considered system targets multimodal acquisition, i.e. acquisition achieved with different types of sensors (e.g. electro-optical or infrared) and will thus allow retrieving meaningful information from the surveyed field. These data are transmitted to the GCS using a multilevel of collaboration between UAVs to ensure the communication performance. Figure 2 illustrates these relations between the GCS, the swarms (HLCS and LLSs) and the components of the system. This figure also underlines the autonomous capacity of the HLCS to take decisions facing critical situations identified from data collected by the LLSs.

Every considered aircraft will be equipped with a wireless transceiver to communicate with its neighbors, i.e. the aircrafts that are currently in the transmission range of the transceiver. Each UAV will thus be able to exchange information with its neighboring UAVs and for instance determine its flight plan solely based on the knowledge of its

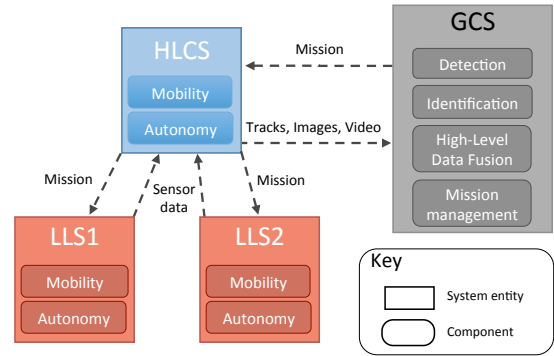


Figure 2: Interaction between system modules.

local environment and an estimate of the global situation. Indeed gathering a complete precise knowledge of the overall system would decrease the scalability of the approach, since in such networks this would require a continuous broadcasting process of all the aircrafts and no communication failure to maintain everyone updated. If feasible this would dramatically reduce the available bandwidth for other types of communications.

One of the addressed challenges in this project is therefore to handle several fleets, or swarms, of UAVs including their communications, networking and positioning. This thus motivates the development of multilevel cooperation algorithms which is an area that has not been widely explored, especially when autonomy is also a challenge. Moreover, we will provide techniques to optimize communications within a swarm and between swarms (including multilevel swarms). Finally, we will develop distributed and localized mobility management algorithms that will cope with conflicting objectives such as connectivity maintenance and geographical area coverage.

3. SWARM DECISIONAL AUTONOMY AND MOBILITY MANAGEMENT

This section first contains an analysis of the related work in UAV swarm decisional autonomy, followed by a survey on UAV swarm mobility management. In the first part we consider existing projects under the criteria of the swarm's decisional autonomy and on the fact that they rely, or not, on an existing communication infrastructure. We believe that the CARUS project [2] went a step further than a state-of-the-art to deal with autonomous swarms of UAVs. In this project, five UAVs share the supervision of a grid of fifteen points of potential ground incidents. Although often using a motion capture system to localize the drone, the GRASP Laboratory generally supports a high level of autonomy in terms of decision as evidenced by their decentralized flight formation work [9], their achievement in collaboratively grasping different kinds of objects [6]. The most remarkable achievement is a collaborative mapping experiment of an earthquake-damaged building of the Tohoku University by two rovers and one UAV carried by one of them [7]. When the rovers have covered every part of the building they could reach, the UAV is autonomously launched at the right spots by the rover to map the specific parts that are only reachable by the UAV (which has less endurance than rovers).

The mobility management aspects of this project tackle issues encountered in both the robotic and the mobile networking domains, since for instance coverage and connectivity are shared objectives. Nowadays, these two scientific communities are working on very close problematics, sometimes without noticing it. In the mobile ad hoc networks domain, influencing the mobility of a device and its network equipment in order to enhance some networking-related quality metrics is currently being investigated due to advances in technology. In the robotic networking domain, the maintenance or the reinforcement of the connectivity has always been an important issue, as it greatly influences the fault tolerance of a system. When it comes to controlling the mobility of UAV swarms, many proposals exist in the literature. One can classify them as centralized/distributed and online/offline techniques. Historically, the first flight plan computation techniques are centralized and offline, meaning that the UAVs trajectory is computed by one single entity and distributed before the start of the mission [1]. However, these are not suitable due to the unpredictability of the potentially hostile environment in which the aircrafts will be deployed, e.g. harsh weather conditions or technical and mechanical problems.

Centralized and online mission planning techniques have therefore been investigated, allowing to recompute the swarm's flight plan at runtime, which is highly desirable when considering surveillance and tracking missions like in this work. However, updating the whole swarm flight plan via a unique access point, such as satellite connection, also has drawbacks in terms of scalability, robustness and communication costs. Indeed, what would happen if the central entity fails or is not able to communicate with the fleet frequently enough?

This work is thus interested in online and distributed mobility control techniques. In that case, UAVs are equipped with wireless communication interfaces that allow them to exchange information in a peer-to-peer fashion, i.e. no (costly) infrastructure is required. Such networks are a novel type of Mobile Ad Hoc Networks (MANETs) referred to as Flying Ad Hoc Networks (FANETs). That way, each UAV determines its flight plan solely based on aggregated knowledge from neighboring UAVs.

Some promising approaches are inspired by nature, and more precisely by ant colonies. Ant Colony Optimization (ACO) is a set of probabilistic techniques for solving computational problems, which can be reduced to finding good paths through graphs. Initially proposed by Marco Dorigo in 1992 in his PhD thesis [3], ACO has found applications in many domains. The main idea is that ants use the environment to exchange information via pheromone deposit which concentration influences their behavior. This process is called stigmergy. UAVs deposit repulsive pheromones in visited geographical areas so as to prevent other UAVs to revisit the same places too rapidly [5]. However many of the proposed approaches are not realistic since they consider global pheromone maps while each UAV can only have a partial knowledge of the environment, i.e. a local pheromone map. Communicating this information therefore remains a challenge to ensure scalability, i.e. which information and when to broadcast it.

Additional objectives are to be considered such as network connectivity as recently proposed by Schleich *et al.* for surveillance scenarios [8]. This is motivated by most

safety-related regulations that currently require any UAV to be reachable at any moment in case of an emergency. That way maintaining a connected network would ensure that the furthest UAVs can still be controlled via multi-hop communications. However none of these existing works has considered multilevel swarms as proposed in the ASIMUT project. Novel mobility management techniques have thus to be developed to address the aforementioned objectives: coverage/tracking, communication, connectivity, and additionally energy-efficiency.

4. INNOVATION

The ASIMUT project innovates in several fields, including distributed load sharing, autonomous retasking, multilevel and global cooperation, and bio-inspired swarms mobility models. These are detailed in the following section.

In the ASIMUT project the system is fully decentralized. The GCS only sends missions requirements to the HLCS. The latter has the capability to first decide who will achieve this mission: the HLCS itself or in collaboration with one LLS. After that, the UAVs of the considered swarms will decide autonomously the actions they have to plan to complete this mission including communications. If the HLCS received too many missions, it has to decide to stop one or more missions or to wait until another mission ends before it can assign new ones. As a consequence: the swarms control the load-sharing. They are chosen depending on their capabilities, mainly based on the sensors they embed, and their relative position to the objective. This is done in order to reduce the number of communications and to optimize the system as a whole.

The Figure 3 details the global scheme of the autonomous retasking of swarms. In this diagram, the key point is that a UAV always receives information from the other UAVs and stores them. This information is regularly analyzed by the UAV before it takes a decision. This is the way UAVs collaborate at both levels because information can come from any swarms. The last steps are dedicated to the information of the other UAVs (position of an UAV, ongoing action, ...). We will also implement algorithms to select relevant information depending on their meaning and their duration impact. This participates to the communication optimization of the model.

In terms of communication optimization swarm members autonomously elect one of them to take care of the communication with other swarms. This election occurs regularly. Critical situations that the ASIMUT system faces might require collecting information far from the current position of the HLCS. Thus the HLCS can send several LLS to collect data while it remains over the critical situation area and help other LLS to handle it by directly post processing data to help them. This multilevel cooperation between swarm permits to face critical situations with massive amount of ressources involved while routine missions are still accomplished.

ASIMUT will focus on online and decentralized mobility management techniques. More precisely it will rely on bio-inspired techniques, to ensure the optimization of the autonomous UAV swarms movements. In order to comply with the targeted scenario, several possibly conflicting objectives and constraints should be respected by the UAVs, i.e. coverage, connectivity, randomness and energy efficiency.

Mission Decision and Execution

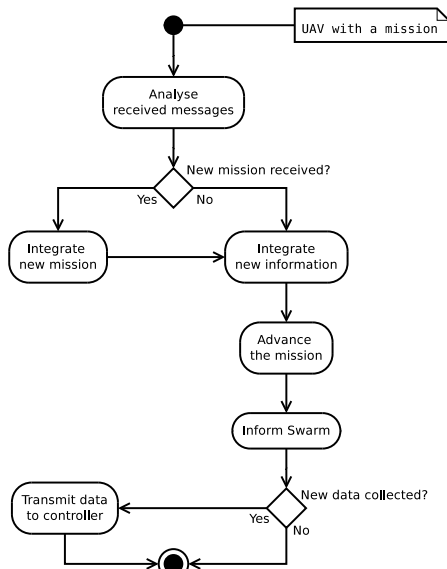


Figure 3: Activity Diagram describing the communication process of a UAV.

First of all, as the assigned mission is about surveillance, the considered area should be covered completely and on a sufficiently frequent basis. The exploration process will be based on Ant Colony Optimization (ACO). Its design should be light enough to represent the known environment accurately and be efficiently exchanged in a wireless ad hoc fashion between aircrafts. Extensions to this model will be proposed to optimize the mobility of the higher-level fleet, to maintain and optimize the connectivity between the two levels. Although this mechanism is antagonist to the exploration process, we will research how to limit its inhibition impact. In addition, the UAVs mobility should be as hard to predict as possible to prevent possible attacks. Two approaches are considered, either using stochastic or deterministic processes. For the surveillance movement, we plan to compare the usage of randomness to a behavior obtained from chaotic dynamical systems inspired by the mobile robots domain [4]. It should also be noted that in real conditions degraded modes must be considered. Loss of a UAV or loss of messages are to be taken into account not only in a military context but also in a civilian context such as disaster relief areas.

5. CONCLUSION

The ASIMUT project aims at developing surveillance services based on fleets of UAVs flying at different altitudes and equipped with various sensors (e.g. EO, IR, ...). The required processing of the collected information can be done at the level of each individual UAV, at the level of a higher altitude one or even on the ground. This thus requires intra-level and inter-level cooperation; the latter being without doubt an area that has not been widely explored, especially when autonomy is also a challenge. Therefore one of the innovations will be in the management and the optimization of the interactions between the swarms that participate in the mission and how their local decisions and work impact the behavior of the other swarms, i.e. of the global system.

Other innovations reside in the development of distributed and online mobility management algorithms. The latter deal with potentially conflicting objectives such as coverage, connectivity preservation and bandwidth efficiency. These innovations will be combined as a global framework for the ASIMUT project and evaluated via state-of-the-art simulations; a preliminary step before its real-world deployment.

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