Control System Algorithms for Groups of UAVs

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***Abstract*—The paper deals with the research of control system algorithms for the groups of unmanned aerial vehicles. When UAVs are on mission, it's suitable to control them using less amount of pilots, and control them as a swarm. Using the ad-hoc communication between the agents, and remote control of one master relatively to the group of slave-type vehicles, this type of system is quite usable for the list of actually necessary tasks. This work describes 4 novel control system algorithms for a group of UAVs.**

***Keywords*—UAVs; multi-agent system; tasks distribution; single-master-multi-slave system**

I. Introduction

First aerial vehicles were controlled strongly by the pilot, or pilots. But with the development of automatics, new ways of control were investigated, especially, remote control which allows to operate the aircraft distantly. It has a lot of benefits, for example, absence of threat to pilot's life, small sizes, so UAVs are widely used for intelligence aims, to control the borders, etc. [4]

When the UAV is in the air on a mission, one important thing is to ensure that the whole group and a single UAV receive tasks, perform them accurately. They also should detect and avoid the obstacles, and communicate with the master unmanned vehicle.

An essential feature of the formation control problem for meter-scale UAVs is that "autonomy" is limited by cost and payload constraints. Consequently, identifying a few specific objectives, and attempt to formulate and implement a control law to meet these basic objectives is strongly required. These objectives are to avoid collisions between UAVs, maintain the cohesiveness of the formation, be robust to loss of individuals, and scale favorably for large swarms. [1] The challenge is that the physics of sensing, actuation, and communication cannot be neatly separated from the problem of coordination and control. [4] [9] Rather than simply extra payload, the automatic control system for formation control becomes an integral part of vehicle design.

The urgency of the work is connected with necessity of military area, or civil patrolling firms to increase the investigation area, and consequently the amount of data, that can be received on less time period. The implementing of such a system significantly increases the reaction time of group.

The primary investigation area of this paper is the problem of control distribution algorithms developing. When using a group of UAV to perform some task, it's necessary to investigate some new approaches of control algorithms for such groups. This paper proposes an approach that enables both centralized (i.e. human-centered, in a ground station) and distributed (i.e. delegated to UAVs) configurations of the decision.

II. Problem Statement

This paper is dedicated to studying some of the existing algorithms of UAVs collective behavior in a formation and synthesize a new approach basing on the related works in this area. Based on the structural and algorithmic schemes of other works, the master-to-slaves type of control and communication was chosen.

III. Previous Researches

There is a variety of systems which are aimed to control both single vehicle and also some groups and automatically controlled formations. However, nevertheless all these systems exist, there are some difficulties, connected with the adapting of generalized systems for certain task, and this problem complicates a lot the algorithms designing and software developing for such a system. Generally, the problem statement of the task is to develop some algorithms, which should be working for the systems with multi-agent structure. The proposed system allows to change the tasks queue dynamically to separate a part of group (even up to a single performer) to complete a detached task.

Cooperative control of multi-robotic systems has been studied extensively in recent years, especially for some tasks that cannot be handled by one single robot. It can improve dexterity of robots and enlarge application fields of robots. Thus, many cooperative control algorithms have been proposed so far. For example, A. Karimoddini and his team in "Hybrid formation control of the unmanned aerial vehicles" describes another, hybrid type of controlling the huge formations; taking into account that it doesn't include obstacles avoiding it has the disadvantages, and it's required to develop deeper in this area.

Automation bias was operationally seen in the 2004 war in Iraq when the U.S. Army's Patriot missile system, operating in a management-by-exception mode, engaged in fratricide, shooting down a British Tornado and an American F/A-18, killing three. The system was designed to operate under management-by-exception and operators were given approximately 15 seconds to veto a computer solution. Automation bias is a significant concern for command and control systems so it will be critical to ensure that when higher levels of automation are used, especially at the management-by-exception level, that this effect is minimized [7].

IV. Generic Model of Single UAV Agent

A generic UAV model provides information about flight capabilities and available resources. The perception model contains characteristics such as the expected coverage of the perception device, and reports the sensors availability. Finally, a (quite simple) line of sight-like communication model is exploited to estimate the "communicability" between two entities, and to compute the communication coverage.

According to these models, various "services" can be provided: the next section provides a few algorithmic details related to some of these features.

Algorithms:

a) Perception planning: given a location to be perceived, the refiners compute the best locations for a given UAV to perform useful perceptions, according to the environment model (considering obstacles such as hills or no-flight zones) and the perception task model. A measure of the utility is compared over a discrete set of positions in a 3D radius around the location to be perceived.

b) Path planning and TSP: path planning is performed in a simple way (A* based) to compute paths in the discretized 3D environment. Then we exploit this simple path finding to compute the shortest path between several points (TSP): an approximated solution of the TSP is computed using a simple stochastic algorithm with two operations: insertion and permutation of locations.

c) Mapping: the mapping task aims at covering a whole given area in the shortest time. In this problem, we try to minimize the number of turns. The principle of the algorithm is to select a favored direction (along the longest straight line inside the area), and then to apply a sweeping pattern accordingly, assuming that areas are (or can be divided into) convex polygons.

d) Detection: this activity requires the UAV to fly over an area during a certain time, trying to minimize the time between two flights over a given ground cell. In the COMETS context, different priority values are attached to the cells, according to their burning risk factors, and detection considers this terrain's burnability. We implemented for this purpose an potential fields-based algorithm. Each cell of the ground is associated to a potential, initiated to a maximum value, and decreasing with time according to the a specific law. Perception coverage depends on the perception device's aperture, and flying altitude. Perceiving areas makes the corresponding potential raise according to the perception model (i.e. well perceived regions have their potential raised to their max, whereas badly perceived regions' potential is only slightly raised). At each increment, the move follows the steepest gradient in the potential field. Even for very low risk fareas, the potential slowly decreases until reaching a low value that eventually attracts the UAV after a lapse of time.

When a UAV operates as an individual – that is, when flocking and TA are disabled – each UAV randomly selects a flying heading and continues to fly in this direction until one of the following happens.

1) The sensors detect a potential object to intercept. In this case, the UAV will select an optimal route in order to intercept the target. The process of calculating the route is performed under the UAV flight and maneuvering limitations.

2) The UAV reaches the border of the theater. In this case, UAV selects one of the following.

a) Return back to the theater using the same heading angle ψ.

b) Return with a random heading angle.

c) Return to the field using the heading angle of π-ψ.

3) The UAV randomly changes its flying direction with a probability of 10–5 per simulation cycle.

V. Supervisory Control of UAVs

All UAVs in the DoD inventory operate at some level of supervisory control as depicted in Fig. 1.

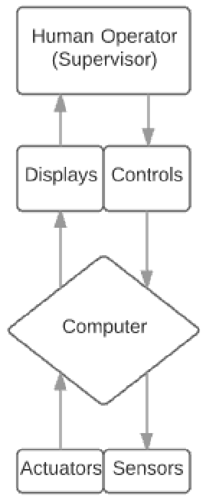

Fig. 1. Supervisory Control of UAVs.

Human supervisory control in UAV operation is hierarchical, as represented in Fig. 2.

The innermost loop of Fig. 2 represents the basic guidance and motion control, which is the most critical loop that must obey physical laws of nature such as aerodynamic constraints for UAVs. In this loop, operator actions are focused only on the short term and local control (keeping the aircraft in stable flight), and generally human control in this loop requires skill-based behaviors that rely on automaticity [11].

The second loop, the navigation loop, represents the actions that some agent, whether human or computer-driven, must execute to meet mission constraints such as routes to waypoints, time on targets, and avoidance of threat areas and no-fly zones [5].

The outermost loop represents the highest levels of control, that of mission and payload management. In this loop, sensors must be monitored and decisions made based on the incoming information to meet overall mission requirements. In this loop, decisions require knowledge-based reasoning that includes judgment, experience, and abstract reasoning that in general cannot be performed by automation.

Finally, the system health and status monitoring loop in Fig. 2 represents the continual supervision that must occur, either by a human or automation or both, to ensure that all systems are operating within normal limits. [3] The control loop line is dashed as it represents a highly intermittent loop in terms of the human, i.e., if the human is engaged in another task, with the highest priority given to the innermost loop, health and status monitoring becomes a distant, secondary task.

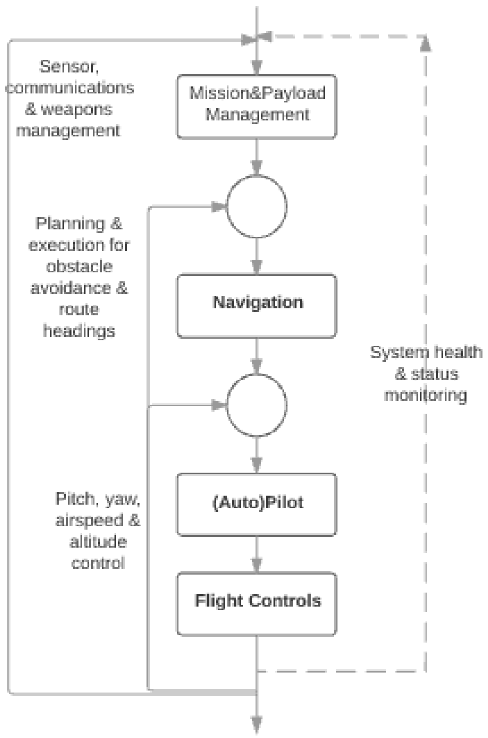

Fig. 2. Hierarchical control loops for a single UAV.

VI. Types of Cooperative Behavior

Considering the multi-agent system with master-slave cooperative principle, we can determine four main types of behavior of a group, which will be described below.

- Slave unit behavior.

This type of behavior is rather simple (Fig. 3), comparing to the masters control and decision making. The main task of the slave unit – to keep the required controlling values in the certain range, which's prescribed by the master's signal. The operator enters the mission data into the Mission Planner block, which compiles the task into the required form and sends it to the master UAV. Then it generates the control signal and sends the data to certain slave unit. Slave unit on receiving task event performs the task, comparing its own path to the required, separates if necessary. Path generating uses obstacle avoiding algorithm. While the formation is keeping, slave unit sends reports to the master UAV about its flight condition and telemetry data.

- Separated unit behavior.

The principle of action of such an algorithm (Fig. 4) is quite similar to the previous one, but it describes more scrupulously the actions of slave, if it has been separated from the group. That's why keeping the formation block is neglected. It also needs to use obstacle avoiding algorithms to perform its own task. After performing the distanced task, it needs to send the report to master unit.

- Master unit behavior in task performance.

This type of control (Fig. 5) requires more accuracy in the collecting UAVs data. After receiving of the distances to certain target, the computation unit forms an array with distances, sorts it using bubble sorting, and sends to the UAV, which has less distance to target. In decision block it chooses the vehicle, which's preferred to perform the task. After the successful selection, the master generates the data signal for the UAV, aimed to the certain task. After it, the UAV listens the reports and on successful report allows the slave to reunite the formation.

- Master unit behavior in formation controlling.

This type of system (Fig. 6) is similar to the previous, but it requires more data computation. The master sends the control signal to all the UAVs to keep certain formation, receives the telemetry/sensor data from each of them, corrects path if it's necessary by synchronizing data with mission planner. It also sends this data to GCS, if it is in the action range of any of the UAVs.

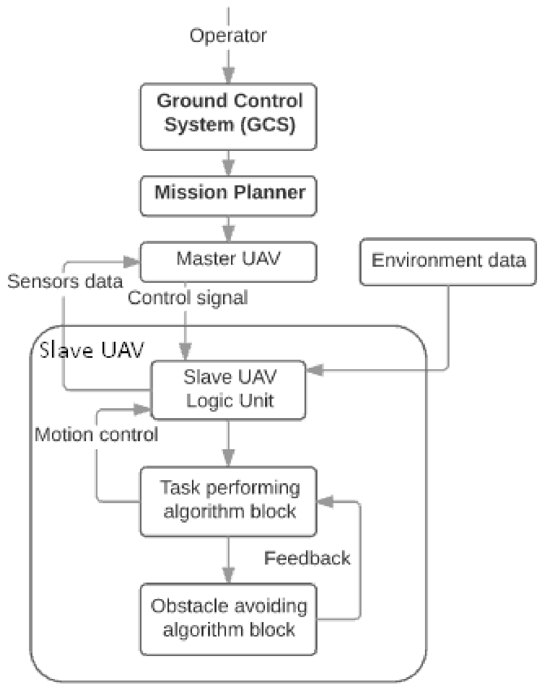

Fig. 3. Slave unit behavior algorithm.

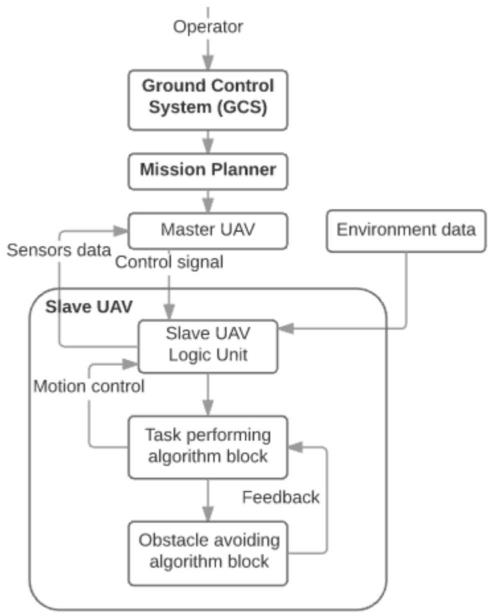

Fig. 4. Separated unit behavior algorithm.

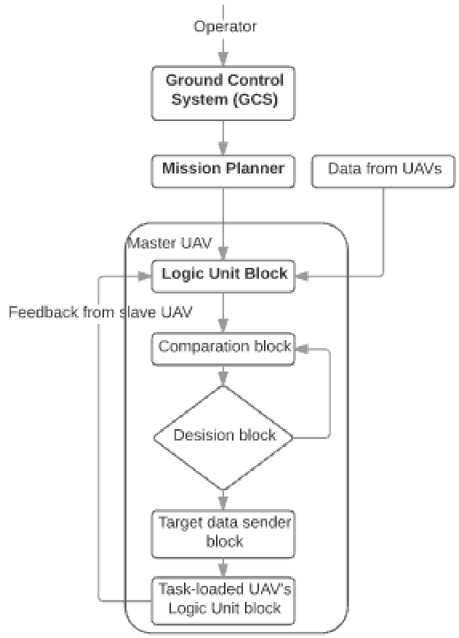

Fig. 5. Master unit task performance algorithm.

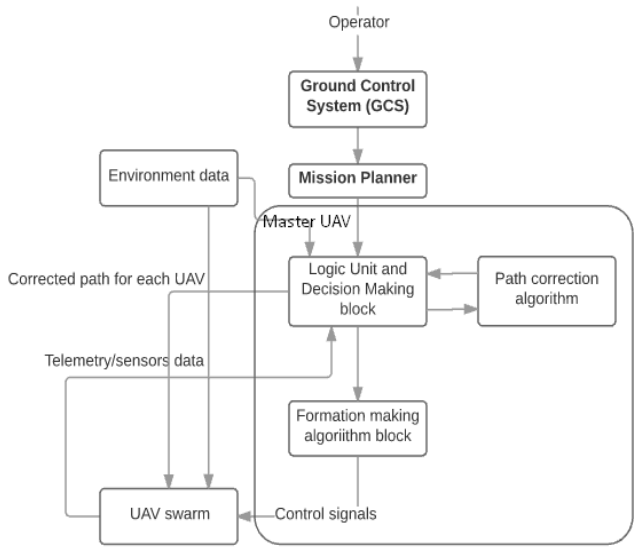

Fig. 6. Formation controlling algorithm for master UAV

VII. CONCLUSIONS

Some novel methods and algorithms for control of the UAV cooperative group were proposed.

It was shown that development of such algorithms, which are usable for controlling groups of UAVs allows to increase the efficiency of task performance, tasks distribution among the agents.

Using these 4 algorithms for UAVs makes the patrolling issues (as remote control of the group, gathering and processing of multi-thread information threads and also the ISTAR battlefield practice (which stands for intelligence, surveillance, target acquisition and reconnaissance) possible and properly performed on such a system.

Future works should concern control system development, based on this set of interconnected algorithms, and also detailed development of the formation choosing, space orientation and changing should be performed.

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