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CONTROL SYSTEM ALGORITHMS FOR GROUPS OF UAVs

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Abstract—*The paper is dedicated to 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 four novel control system algorithms for a group of UAVs.*

Index terms—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 the 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.

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

The task of this paper is the problem of control distribution algorithms development solution, some UAVs supervisory control existing algorithms in a formation analysis and collective behavior approach appliance. Based on the previous research 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.

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].

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

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].

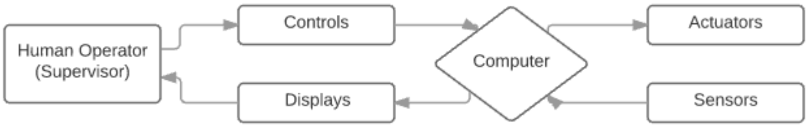

Fig. 1. Supervisory Control of UAVs

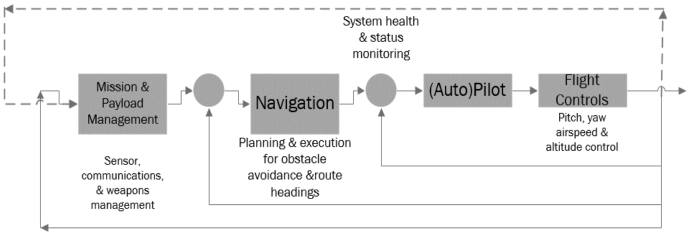

Fig. 2. Hierarchical control loops for a single UAV

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.

IV. 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.

A. Slave unit behavior (Fig. 3)

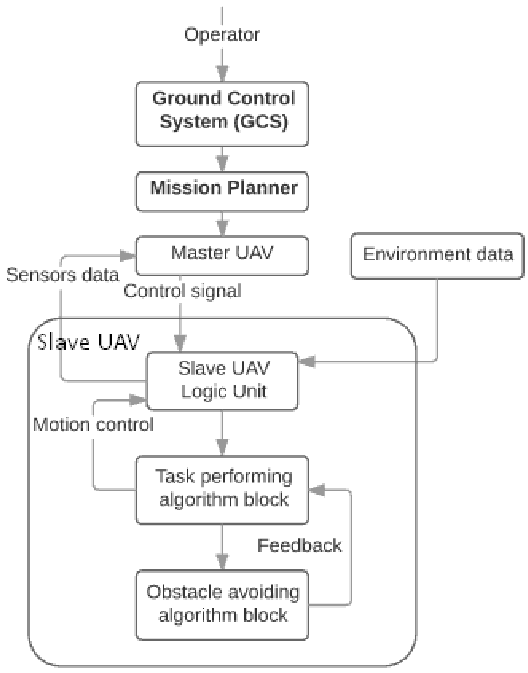

Fig. 3. Slave unit behavior algorithm.

This type of behavior is rather simple, 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.

B. Separated unit behavior (Fig. 4)

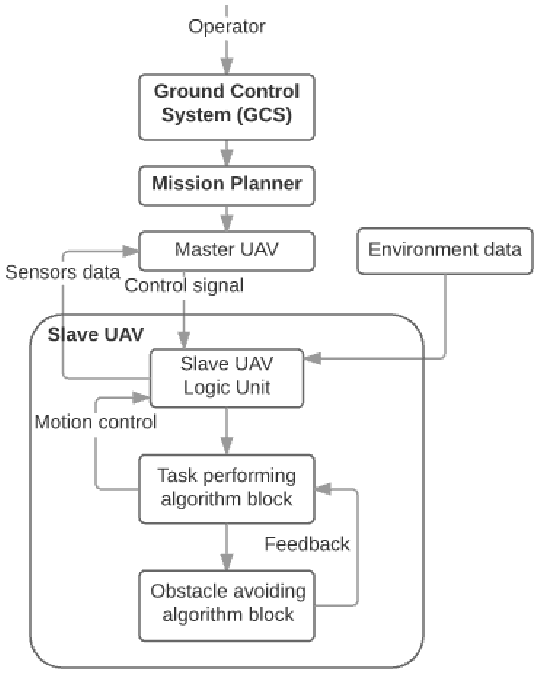

Fig. 4. Separated unit behavior algorithm

The principle of action of such an algorithm 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.

C. Master unit behavior in task performance (Fig. 5)

This type of control 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.

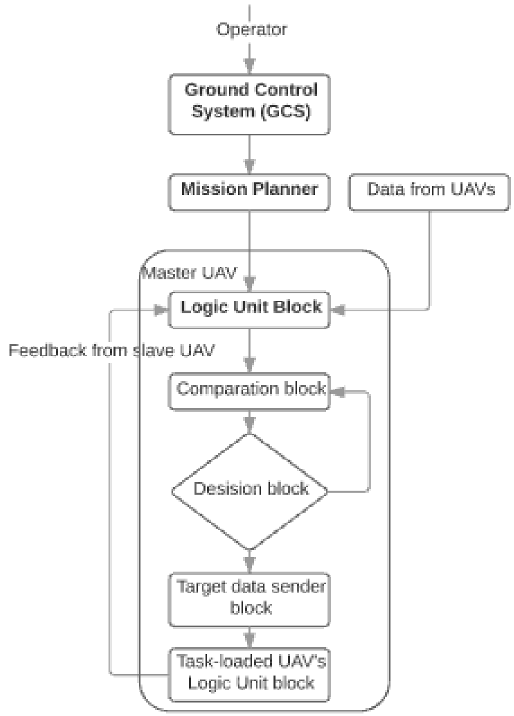

Fig. 5. Master unit task performance algorithm

D. Master unit behavior in formation controlling (Fig. 6)

This type of system 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.

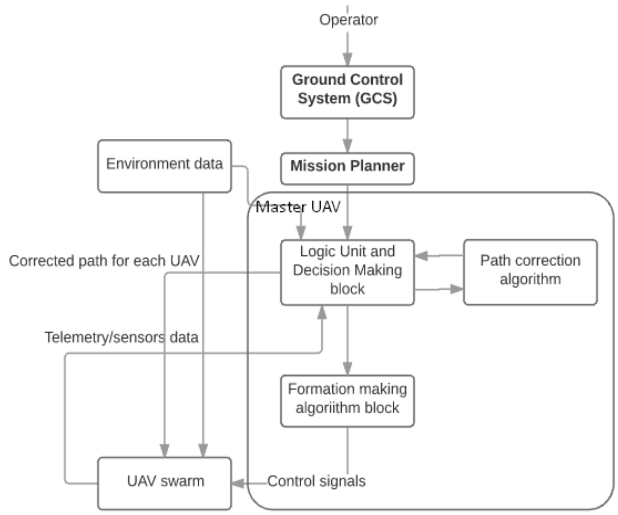

Fig. 6. Formation controlling algorithm for master UAV

V. CONCLUSIONS

In this work some novel behavioral algorithms for control of the UAV cooperative group were proposed.

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.

It was shown that development of such algorithms, which are usable for controlling groups of UAVs allows to control the task performance feedback and variability 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) available 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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С. П. Борсук, І. О. Третяков. Алгоритми для системи керування групами БПЛА

Досліджено алгоритми для систем керування групами безпілотних літальних апаратів. Розглянуто чотири нові алгоритми систем керування для групи безпілотних літальних апаратів. Доведено, що згрупованими безпілотниками, які знаходяться на завданні, набагато зручніше керувати меншою кількістю пілотів, і контролювати їх за ройовим принципом. Використовуючи тип комунікації ad-hoc між агентами, здійснюється

віддалений контроль одного провідного безпілотного літального апарату над групою ведених літальних апаратів, цей тип системи може бути використаний для виконання цілого ряду актуальних завдань.
Ключові слова: безпілотний літальний апарат; мультиагентна система; система SMMS.

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С. П. Борсук, И. А. Третьяков. Алгоритмы для системы управления группами БПЛА

Исследованы алгоритмы для систем управления группами беспилотных летательных аппаратов. Рассмотрены четыре новых алгоритма систем управления для группы беспилотных летательных аппаратов. Доказано, что сгруппированными беспилотниками, которые находятся на задании, гораздо удобнее управлять меньшим количеством пилотов, и контролировать их по роевому принципу. Используя тип коммуникации ad-hoc между агентами, осуществляется удаленный контроль одного ведущего беспилотного летательного аппарата над группой ведомых летательных аппаратов, этот тип системы может быть использован для выполнения целого ряда актуальных задач.
Ключевые слова: беспилотный летательный аппарат; мультиагентная система; система SMMS.

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