Task Allocation Algorithm for the Cooperating Group of Light Autonomous Unmanned Aerial Vehicles ⋆

Konstantin Amelin * **Natalia Amelina** *,** **Oleg Granichin** *
Victor V. Putov ***

* *St. Petersburg State University, Russia (e-mail: konstantinamelin@gmail.com, natalia_amelina@mail.ru, oleg_granichin@mail.ru)*
** *Norwegian University of Science and Technology, Department of Telematics, Trondheim, Norway*
*** *St. Petersburg Electrotechnical University (LETI), Russia, e-mail: vvputov@mail.ru*

Abstract: In this paper a task allocation problem for multi-UAV systems was considered. The possibility of applying a consensus approach to organize a distribution of tasks in an autonomous group of small Unmanned Aerial Vehicles (UAVs) is studied. The use of several small UAVs with autonomous distribution of tasks gives a significant advantage over the use of a single UAV. The well-known consensus protocol — local voting protocol is suggested to solve this problem. To provide the communication in the network multi-agent technologies are used.
Keywords — unmanned aerial vehicle (UAV), UAVs network, consensus, stochastic discrete network, multi-agent systems.

1. INTRODUCTION

Distributed coordination in networks of dynamic agents has attracted an the interest of numerous researchers in recent years. It is mostly due to broad applications of multi-agent systems in many various areas including formation control, distributed sensor networks, cooperative control of UAVs, etc. Armbruster (2005); Olfati-Saber et al. (2007); Ren et al. (2007); Bullo et al. (2009); Granichin et al. (2012).

In recent years, distributed parallel networks have been increasingly used. For such systems the problem of separating tasks among several nodes (devices) is important. Nowadays, numerous articles are devoted to the load balancing problem, indicating the relevance of this topic. Most of these articles are related to the area of computer science and they usually do not consider noise and delays. Within the single computer this assumption could be rather realistic. However, if we consider networked systems, noise, delays and the links "break" may be justified.

Essentially, there are different approaches to organize the control of such systems. A lot of them based on centralized scenario. In this scenario it is assumed that all the nodes are connected and we can choose one node as a load broker that redistributes tasks among agents. All new tasks come to the load broker. The broker collects all the information about the load of agents and sends tasks to agents according to their load. Nevertheless, in the real world it is usually difficult to imagine a network system in which all agents are connected to each other. In this case, it is reasonable to consider the decentralized scenario. Eventually, it is important to design a network system, which would work no worse than a centralized system but without choosing a leader (load broker). It turns out that it is possible with multi-agent technologies.

One of the challenges for Unmanned Aerial Vehicle (UAV) is the problem of area monitoring in order to collect the information about it Sinha et al. (2009); Marthaler and Bertozzi (2003); Chosa et al. (2010). The operation of such UAVs in a group can offer a significant advantages over a single UAV on time, speed and performance guarantee of the global task. One of the main advantages of an autonomous group interaction is a possibility of individual tasks redistribution to maximize a probability of a global task execution Amelin et al. (2012). Typically, when UAVs are used in a group, they can only interact when a danger of a collision appears. In this case, several UAVs can monitor the same area at the same time and not be aware about it Baxter et al. (2008); Kothari et al. (2009); Rodríguez-Seda et al. (2010); Jadbabaie et al. (2003). Such approach increases the amount of information to be processed, the execution time and reduces the performance guarantees of the global task of the group. Under the autonomous and adaptive interaction, UAVs are able to redistribute the tasks among neighboring UAVs according to remaining battery power of UAVs.

Generally, in this paper we consider homogeneous group of UAVs which should monitor the area and take photos of the area. Each photo is assumed to be a single task for UAV. The task allocation problem is justified. In this case, we propose the consensus approach for the redistribution

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of tasks in a decentralized distributed network of UAVs. In addition, we consider the way to form the general task for the group of UAVs and particular tasks for each UAV. The interaction between multi-UAV will be organized with the use of multi-agent technologies. Specifically, we describe the operation of such system in a multi-agent platform JADE.

2. SYSTEM MODEL

Consider the multi-agent system of light UAVs as an autonomous group of UAVs with communication between agents (single UAVs). The network system consists of multiple UAVs, and a set of the same type of tasks, that have to be executed in the system. UAVs can perform incoming tasks in parallel and tasks can be redistributed among UAVs. In this system UAVs fly around some area with the purpose of taking photos of it. Each photo is a unit of a task and a flight route, divided into such tasks, is a queue of tasks.

The control system of a single UAV is consists of three layers. On the upper layer we have a base station — a computer (notebook, netbook or desktop computer) with different communication modules (Wi-Fi, Internet or radio modem). Basic tasks of a base station are:

- indicate the global mission for the group of UAVs (parameters of the monitoring area, objects of the monitoring, flight altitude, etc.);
- define individual tasks for each UAV-agent based on the number of UAVs and specifics of the problem;
- exchange of the information with UAV-agents;
- collect and process the information from the group of UAVs;
- define the new global mission for the group of UAVs based on the new information that was received.

On the middle layer we have a microcomputer (Linux, ARM processor). A microcomputer is the basic device of the UAV-agent control system. Its main purpose is to perform tasks with the minimum amount of time and resources. It implements the following actions:

- generate updates to the autopilot flight program;
- get telemetry data from autopilot;
- process data for navigation equipment and telemetry;
- work with additional equipment;
- communicate with other UAVs microcomputers, if work occurs in a group;
- send data to a base station;
- receive new tasks from a base station.

On the lower layer we have autopilot software. It controls the actuators and processes sensor data.

The goal of this paper is to introduce the distributed protocol for task allocation which will be implemented on the middle layer of each UAVs. It will be used in the software of microcomputer of the middle layer.

3. PROBLEM STATEMENT

Let the network system be composed by n agents (UAVs), and a set of the same type of tasks. UAVs perform incoming tasks in parallel. We suppose, that tasks can be redistributed among UAVs. Note, that the task can not be interrupted after it is assigned to the agent. Let i, $i = 1, \dots, n$ be a number of an agent, and $N = \{1, \dots, n\}$ be a set of agents in network system.

In general, UAVs fly around some area and make its photos with overlapping of 20 % between photos. In this network the task allocation problem could be justified. We assume, that the UAV's flight altitude is 100 meters above the ground, and the viewing angle of photorecorder is 90 degrees. A photo should give us a projection of the land's surface area onto the plane of the UAV's motion with a size of 200 x 200 meters and the center at the location of the UAV at the time of photography. Consequently, photos have to overlap each other in a strip of 40 meters, and a distance from one photo to another should be 360 meters. The average speed of UAV is 12 m/s and a maximum — up to 25 m/s. Therefore, the pictures should be taken with a frequency of no more than 1 photo in 8 seconds.

Denote, a queue of tasks at time t by q_t^i. Here and below, an upper index of agent i is used as a corresponding number of an agent (not as an exponent). Now, we define parameters of tasks. Altitude of UAV is 100 meters above the ground, the matrix resolution 3200x2400 pixels, a lens with a focal length of 2 mm and a viewing angle of 105 degrees. Thus, one photo should give us the projection of area surface on the motion's plane of the UAV of size 270x200 meters with the center at the location of the UAV at the time of photographing. In this case, a large side faces on the direction of the aircraft movement. From these calculations may also be obtained that the pixel will cover the square with dimensions 8.44x8.44 cm. For better pictures' gluing and exclusion of white spots we define the overlap of 20% of the area that covers by one photo. We get the overlap in a rectangular cavity with a width of 200 meters and a length of 54 meters, or 640 pixels. The distance from the center of one photo to the center of the following by the moving direction photo is of 216 meters.

Since we use the UAV which equipped with an electric motor, the unit of energy expended per unit will be 1 mV. In order to calculate the number of tasks that could be performed by a UAV, we need to know the rate of voltage loss $\vartheta_V = \Delta V/t$ and an execution speed of a task $\vartheta_q = (q_t^i - q_{t-1}^i)/t$. Thus, we denote by the productivity of the UAV p_t^i at time t the number of tasks that could be done by spending 1 mV of battery's voltage $p_t^i = \vartheta_q/\vartheta_V$. Note, that we consider a group of UAVs with the same parameters and equal productivities at the initial time. However, parameters and productivities will change over time. The execution time of a task varies from one agent to another and depends on the productivity of an agent.

If we take $x_t^i = q_t^i/p_t^i$ as a state of agent i of a dynamic network at time $t = 0, 1 \dots, T$, then the control goal of achieving consensus in network will correspond to the optimal redistribution of tasks among agents Amelina and Fradkov (2012). At the start time $t = 0$ all UAVs have equal states $x_0^i = x_0^j \; \forall i, j \in N$. During the flight, each UAV has its own number of tasks in a queue, and new tasks could be added to the queue over time. Moreover, productivities changes over time due to environmental influence such as, for example, the wind, which could be compensated by applying filtering techniques Amelin and Granichin (2012); Amelin (2012).

We suppose, that to form the redistribution control strategy each agent $i \in N$ has the following data:

- noisy data about its own state
$$y_t^{i,i} = x_t^i + w_t^{i,i}, \tag{1}$$
- noisy and delayed observations about its neighbors' states, if the set N_t^i is not empty,
$$y_t^{i,j} = x^j_{t-d_t^{i,j}} + w_t^{i,j},\ j \in N_t^i, \tag{2}$$
where $w_t^{i,i}, w_t^{i,j}$ are noises, $0 \leq d_t^{i,j} \leq \bar{d}$ are integer-valued delays, and $\bar{d}$ is a maximum of possible delays.

Note, that voltage measurements are made with noise (increased resistance from battery aging) and delays in the measurements. The execution speed of a task depends on the location of UAV, so delay and noise in determining the coordinates could be justified.

4. TASK REDISTRIBUTION VOTING PROTOCOL

In Amelina and Fradkov (2012) properties of the control algorithm, called local voting protocol, for load balancing problem of a stochastic network were studied. For the redistribution of tasks in a decentralized distributed network of intelligent agents (UAVs) we suggest to use this protocol.

The control value of the local voting protocol for each agent is determined by the weighted sum of differences between the information about the state of the agent and the information about its neighbors' states:
$$u_t^i = \gamma \sum_{j \in N_t^i} b_t^{i,j}(y_t^{i,j} - y_t^{i,i}), \tag{3}$$
where $\gamma > 0$ is a step-size of the control protocol, N_t^i accounts for a neighbors set of agent $i \in N$ at time instant t, $b_t^{i,j} > 0 \quad \forall j \in \bar{N}_t^i$. We set $b_t^{i,j} = 0$ for other pairs (i,j). The matrix of the control protocol is denoted by $B_t = [b_t^{i,j}]$.

It could be shown, that protocol (3) provides an approximate consensus is stochastic network with switched topology, noise and delays. Conditions for achieving an approximate balance of the network load were set in our previous works Amelina and Fradkov (2012); Amelina and Granichin (2013).

5. MULTI-AGENT APPROACH FOR UAV'S INTERACTION

We consider the consensus problem in the network of moving UAVs which should should fly around some area and make photos. The aim of UAV's group is to perform all the tasks (make photos of the entier area) and send them to the base station. We describe an algorithm for splitting a global task into particular tasks:

- Determine the area to explore.
- Select the required number of UAVs to fly around the area, based on the information that the UAV fly a distance of 15 km at a constant altitude of 100 meters with a constant average speed of 12 m/sec. The UAV should fly the entire route (i.e., its initial state x_0 is calculated in such a way that the UAV is able to complete the entire queue of tasks). The beginning and the end of the path should be be at the starting point.
- Divide the whole area into tasks. In the center of each task (part of the area) we put the point with GPS coordinates.
- Draw up a text file with the coordinates of all the tasks.
- For each UAV we form its own set of tasks from a common set in such a way that the UAV's path begins and ends at the starting point and each following task was adjacent to the previous one.

Consider the principle of interaction between mobile agents in multi-agent systems (we take the multi-agent platform JADE as an example):

- Run the JADE platform and create the same number of switches-agents, navigators and planners how many UAVs will be used. These are the "main agents". Switches-agents provide a possibility of interaction between microcomputers. Navigator determines the route, removing it from the tasks recorded in the memory of the microcomputer. Planner is responsible for responding to unforeseen events in real-time, detection and avoidance of collisions.
- Create a backup of the system with all the agents and write a copy to each microcomputer.
- As a result, on each microcomputer we get the system, which consists of two service agents: DF — Directory Facilitator (contains addresses of all agents and knows about their functionality) and AMS — Agent Management System, and of three "main agents", whose tasks include work with flight route text file (record the new data, compare of the accumulated data with the text of a neighbor), work with a folder of files with accumulated data (photos, etc.), work with a productivity data (analysis of current consumption, battery capacity, and execution speed of a task).

Since each microcomputer has a copy of a system, all DF agents have addresses of all other agents. Thus, we do not need the permanent connection between all the agents in the system. Note, that when two UAVs connect to each other by wireless connection, then relevant agents appear and they begin to exchange data.

6. UAV FOR MULTI-AGENT GROUP

In future work we plan to use theoretical results in our practical project: multi-agents group of UAV. For our UAV-agent we use a planner flying wing. It has a length of 0.5 m, wing span — 1.9 m , max take-off weight — 1.5-2 kg, payload — 600 g, velocity — 3-20 m/s and range of 20 km. On the middle layer we have microcomputer with Android. It has a size of 30 mm x 70 mm x 10 mm, ARM Cortex-A9 processor with 1000 Mhz clock frequency, 2 GB RAM and 4 GB NAND Flash. Microcomputer is the main on-board device in the control system of UAV-agent. Communication with the base station carried out due to a separate channel, or via radio modem with a frequency of 433 MHz. It can be easily integrated with a microcomputer, but data packets should be compressed.

Connection between microcomputers of different UAVs carried out due to Xbee modem with a frequency of 2.4 GHz and a communication protocol 802.15.4. Thus, microcomputers in UAVs will be able to simultaneously receive and send information to each other (see, Amelin (2010)).

Due to the small weight of UAVs the take-off is carried out with human hands or with a catapult. Landing is carried out either through the built-parachute, or by manual control.

7. CONCLUSION

In this paper we suggested consensus protocol for autonomous tasks distribution in a group of interacting UAVs. Moreover, we described an example of multi-agent system for the multi-UAV interactions based on JADE platform.

In future, we plan to implement the described consensus approach to the real group of UAVs. We also plan to study the image conversion for the faster data transfer.

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