MULTIAGENT NETWORK CONTROL FOR THE GROUP OF UAVS

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Abstract

In this paper the adaptive network control for multiple unmanned aerial vehicles (UAVs) is considered by two sides as problems of a hardware implementation and an algorithm choice. We develop two levels network for interactions. High level is for communication with group and low level is for the interaction between UAVs. Physical basements of both interactions are radio and Wi-Fi channel or Internet. But for high level communications with ground stations we mainly use Internet or radio channel and Wi-Fi is used for the low level. There are no strong tasks for the single UAV and this principle allows increasing the overall performance for the group which has a general task. To realize this approach we suggest three layers control UAV's system. For example the common group's task of monitoring of wide land is studied in the focus of the maximizing the flight duration through common usage possibilities of thermal updrafts. For the precise detection of the thermal updraft's center the simultaneous perturbation stochastic approximation (SPSA) type algorithm is proposed.

Key words

Unmanned aerial vehicle (UAV), UAV's network, multiagent systems, simultaneous perturbation stochastic approximation.

1 Introduction

New tasks, globalization of problems, exponential increasing of the computer systems complexity move us to change the traditional understanding: "What is the process of computing?". In many practical fields new computing and control schemes arise and often they have no pure separation for three isolated phases: data preparation, calculating and analysis of results (resulting control action). This was promoted by the wide usage of personal computers, smart phones, mobile phones, which radically changed our understanding of the place of computers in everyday life. Computer systems are already integrated into many spheres of human activity. Developers embed diminutive computing devices and specialized programs inside of many processes. The role of computers in real life has been shifted from super calculators to mobility devices which are understood very broadly.

Actually the mobility and the high performance computing are more closely related. Let's look at an example of a traditional IT field as a "information coding /decoding". Half a century development since the pioneering works of Kotelnikov-Nyquist-Shannon managed to convince several generations in the firmness and correctness of the postulates: double number of samples require as a minimum for accurate reconstruction of a signal (function). But the development of technology in the 90 years of the last century allowed to move from one-dimensional signal processing to images, and now on the agenda is the solution of problems of three-dimensional scenes. The real processing of such signals through the traditional tools of encoding and decoding is hard even for supercomputers!

What is happening right before our eyes with the development and change of "encode / decode paradigm"? Instead of classical there is a new paradigm — "Compressive Sensing" (e. g., see [Granichin and Pavlenko, 2010]). What is it? All information about the processes at any time is usually not needed for users in real time. The important is only the changes of principal components. For example, when transferring video from a three-dimensional scene it is enough to pass once the general form and details, select specific characters, and then only to track their changes. It turns out that having intelligent sensors (using the mobility principle of gathering information), it is advisable before encoding and data transmission, instead of determining all the values of the three-dimensional scenes (usually a huge number) make several "roll" of the whole scene with some of randomized matrices, and then encode and transmit to the supercomputer to handle just these few measurements. This means that the mobility and the use of intelligent agents in the collection and preliminary processing of data can significantly reduce the data preparation for supercomputing. If a deeper look at a new paradigm for encoding / decoding, it becomes clear that not only the process of preparing the data changes significantly, but also the process of treatment. So we have been talking about mutual complement and develop of such critical technologies as mobility and supercomputing.

Based on above the calculation model can be summarized as follows: mobile devices, which have different sensors (e. g., video or photo camera, GPS, temperature and pressure sensors, etc.) and are able to "communicate" with each other. They collect the information and then hand over information on the supercomputer which does the finite calculations. Mobile devices, gathering the information at the same time can filter it, i.e., mark features and separate data on different topics (such as separate files with coordinates from photo files).

In this paper such a model is illustrated on real example of the project "Multiagent system for the group of unmanned aerial vehicles (UAVs)" [Amelin, Antal, Vasil'ev and Granichina, 2009], [Amelin, 2010]. The aspects discussed above are manifested in the creation of such a system. Many of the problems (mineral exploration, finding people, finding the causes of technological disasters, regular territory patrolling, etc.) require the supercomputing with huge amount of input data, which should come into a supercomputer in real time. to obtain practical results. If anybody uses traditional UAVs with operators and systems of transmit / receive data then usually automated system failed to work properly on a huge stream of data , which should also save and pass it to the computer for processing. For the reverse of UAVs flow control the results can not be obtained in real time.

The main idea of proposed project is to create network of UAVs. This is a group of UAV-agents, which are able to communicate and exchange data on two level: between each other and with base (ground) stations. Base stations receive data from a group of UAVs, filter it and send to a supercomputer. The group of UAVs solves the current task which can be changed by supercomputer or operator through the network of the base stations. There are no strong tasks for the single UAV and this principle allows increasing the overall performance for the group which has a general task. Three layers of UAV's control system are considered in details to realize this approach. For example the common group's task of monitoring of wide land is studied in the focus of the maximizing the flight duration through common usage possibilities of thermal updrafts. For the precise detection of the thermal updraft's center the simultaneous perturbation stochastic approximation (SPSA) type algorithm is proposed [Spall, 1992] [Granichin, 1989], [Granichin, 1992].

2 Multiagent approach and three layers of UAV's control system

UAV's complex usually consists of a single UAV and the base station is controlled by an operator. The operator sets the program for UAV and starts it. UAV performs the program. The operator monitors the implementation of the program and received data if there is a link with UAV. In this case, the flight program can not be change. When several of these complexes are used each UAV communicates with its own base station and operator. The interaction between the complexes can be realized only between base stations. It's can to represented as two layers of UAV's control system. Upper layer is a base station's software. It creates global mission control for UAV, flight altitude, velocity, route, the location to be data collection, etc. Lower layer is an autopilot software. It controls the actuators and processes sensor data to achieve the goal. Autopilot communicates with the base station too.

Using network of "Intelligent" UAVs for the group allows the group to autonomously change the script of flight. Because each UAV is able to change its flights program to a common starting goal. Typical examples of events that change is: emergence of a new source of information, failure parts of existing resources, change of decision criteria, etc. The highest the uncertainty, the more the process of uncertainty is common character and the more case of unplanned events is frequents the lower the efficiency of the existing rigid systems, who make decisions independently and automatically tuned by changes in the environment can not. In addition, any modification of decision trees in traditional systems is very complex and laborious process and requires highly skilled performers, it make he development and operation of such systems is very expensive.

Multiagent systems are used for solving similar problems. the concept of "intelligent agent" is the basis of these technologies. Agent is able perceive the situation, to decide and communicate with another agents. Characteristic features of the intelligent agent are:

- collegiality, that is the ability of the collective goal-directed behavior for to solving the general problem;
- autonomous, that is the ability to solve the local problems separately;
- activity, that is the ability to be active for to achieve the general goal;
- information and move mobility, that is the ability to move actively to targeted search of information, energy and facilities necessary for cooperative solutions of the general problem and to find it;
- adaptivity, that is the ability the automatically adapt to uncertain conditions in a dynamic environment.

These features is a difference of multiagent systems (MAC) from existing rigid systems for control group of UAVs. In [Baxter, Horn and Leivers 1992] example of multiagent interaction of the host computer (of manned aircraft) and a group of UAVs to perform tasks set by the first is described. The UAV communication per-to-per is the basis of multiagent system in our project.

To develop multiagent system for the UAV group we need a small but powerful microcomputer for control of autonomous jobs for the autopilot and interact with other agents through an organized confident relationship between them for each UAV.

Group of interacting UAVs have a number of useful properties compared a single UAV such that:

• collective circled produces a large picture of the world;

• per-to-per communication helps to optimize the flight route, based on existing data from other UAVs;

• large set of strategy;

• a more effective solution of problems (ecology, meteorology, optimization of flight);

• gain in time (this is the main condition for the problems of finding lost people);

• the ability to simultaneously explore different areas of the territory;

• the possibility to adjust the plan and choose the best route based on available data of neighboring UAVs.

We add middle layer of control to implement the usage of multi-agent system for group of UAVs through the including of additional microcomputer in UAV [Amelin, Antal, Vasil'ev and Granichina, 2009], [Amelin, 2010]. Thus, we get a new three levels of UAV-agents control system (Fig. 1). Upper layer is also software base station. But it creates global tasks for group of UAV. It is goals, initial conditions, adjustment or modification of the initial problems. Also the base station receives and processes data from the group of UAVs. Base station is the computer (server) with different communication modules (modems, radio receivers, etc.) Middle layer is multi-agent software, which works in the embedded microcomputer. It is able to communicate with the another UAV-agents and with the base station. Microcomputer can change the initial problem for a UAV based on the new information to expedite the achievement of global objectives, if necessary. Thus, a group of UAV agents that can adapt to the changes occurring in the external environment is formed. Lower layer is autopilot software too. It controls the actuators and processes sensor data to achieve the goal. But microcomputer generates the program for autopilot rather than the base station.

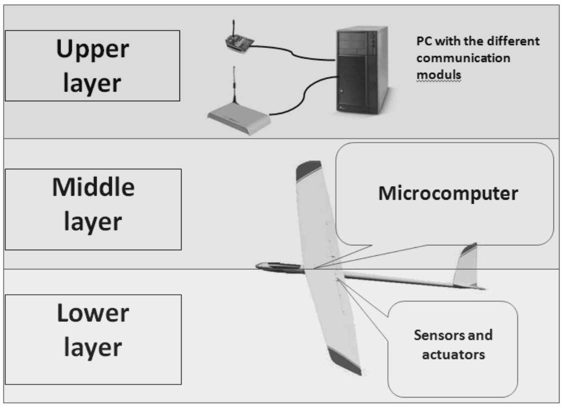

Figure 1. Three levels of UAV's control system.

3 UAV-agent for autonomous group

Autonomous UAV communication between agents is the main difference between the control group, described in s. 2, of UAVs from the traditional complex of UAVs. Hardware equipment is necessary to reconstruct a single UAV and the base station to implement multiagent systems for managing a group of UAVs [Amelin, 2010]. On the upper layer a computer (notebook, netbook or desktop computer) with the different communication modules (Wi-Fi, Internet or radio modem) works. The main tasks of the base station are:

• defining of a global mission for the group of UAV-agents (parameters of the terrain research, kind of research, flight altitude, etc);

• defining of a individual tasks for each UAV-agents in dependence on the number of UAVs and problem;

• exchanging information with UAV-agents;

• collection and processing information from the group of UAVs;

• defining of new a global mission for the group of UAVs in dependence on new information which base station receives.

For our UAV-agent, we use a model of lung glider "PAPRIKA". It is 1.2 m in length, 2 m wing span, 2-2.1 kg max take of weight, 600 g payload., 40–120 km/h velocity and 200 km range. On the middle layer is microcomputer. It is $17mm \times 58mm \times 4.2mm$ sizes, Linux operating system, ARM Cortex-A8 processor with 600 Mhz clock frequency, 256 MB RAM and 256 MB NAND Flash. Microcomputer is the main device in the control system of UAV-agent. Its main purpose to carry out task with the least amount of time and resources. It performers five basic functions:

• generation updates to the flight program for the autopilot;

• data processing of navigation equipment and telemetry;

• work with additional equipment;

• communicate with other UAVs microcomputers , if work occurs in group;

• sending data to a base station and receiving new tasks from her.

Microcomputer receives basic information from the base station (the initial state, the endpoints, the task for the group, etc.). In group flight general task is divided into particular tasks for each UAV. During task execution microcomputer carries out communication with other team members who are in the range of the radio. Interaction in group allows effectively carry out general task, as well as avoid collision.

Based on data obtained from the base station, navigation equipment and other UAVs microcomputer can generate a new program for the autopilot if the old does not support the necessary requirements to perform a common task. While UAV flies in the area of communication with the base station microcomputer sends a new accumulated data and receives new tasks. In this case, the accumulation of data is not only due to its own sensors and detectors, but also in connection with other UAVs. Microcomputer has information about a particular problem of the UAV and a general problem for the group. In communication process microcomputer gathers information about a general task. Data about the performance of its particular problem he gets himself using on-board sensors.

Communication with the base station carried out due to separate channel, or via GPRS over GSM modem. A GSM modem can be easily integrated with a microcomputer, but data packets should be compressed.

Connection between microcomputers of different UAVs carried out due to FM radio with a frequency of 2.4 GHz and the communication protocol 802.11 n (Wi-Fi), which uses technology that connects the two nearest channels into one. Thus microcomputers in the UAVs will be able simultaneously receive and send information to each other. Communication with the base station carried out due to individual channel, or via GPRS over GSM modem [Amelin, 2010].

Due to the small UAVs weight the takeoff is carried out with human hands or with a catapult. Landing is carried out either through the built-parachute, or due to "takeover of control" of the operator to manual control. Middle control layer carries out by autopilot of UAV-agent. Autopilot is a set of devices with a microcontroller with real-time system. The main task of the autopilot is to control the actuators (servos, engine, additional equipment) based on given flight program and data from sensors (inertial, infrared sensors, pressure and velocity sensors, etc.). Thus the hardware implementation of a three level system, which is necessary for creation of multi-agent network of controlling group of UAVs, is possible.

4 Algorithms for the network of UAVs Group

Consider two basic types of algorithms for controlling UAVs flight: the terrain monitoring (for example, studies of the environmental situation) and optimize the flight of UAV (e. g., using thermal updraft to extend the range of flight [Allen, 2005], [Antal, Granichin and Levi, 2010]).

When solving the problem of monitoring the environmental situation in the bay area (for example, the search for oil spills), the system work is organized as follows:

• Selects the type of problem (in the chosen example is searching for oil spills and their source).

• Depending on the area of the study area and the number of UAVs in the group, their characteristics, the area is divided into regions, and formed separate tasks for each team member (for chosen example the selected task will stand thus: the search for anomalies in the intensity of the color of the surface area).

• Record to in each microcomputer of UAVs group the global task (parameters of studied area, *etc*) and the separate task of this aircraft agent.

• Each agent begins to carry out his task.

• When the UAV get in area of Wi-Fi vision of each other, with "communication" between the agents the accumulated information and if necessary, a mutual specification of individual tasks is being transferred.

(Thus, during performance of particular task, all agents accumulate information about the solution of the general problem of the group, as well as make local decisions to adjust their particular problems for more effective implementation of the general. For example, for search of oil spills all UAV explore different squares. After exchange of information between group members it founds out the presence of spots in one of the squares. While task execution the whole team changes the problem, which reduces to finding the source of the oil spill.)

• Basic ground stations, providing a connection with data center (DC), take / send information from the UAVs which are in visibility zone or communicate via the Internet. In the process of communication between UAVs the information about the general problem is accumulated in all of microcomputers, and the data from even those aircraft which rarely makes contact still falls within the DC.

• The information obtained in the DC is processed and visualized for the customer (gives the card with researched characteristics).

• Feedback with mobile agents (UAVs) allows give quickly instructions from DC for adjusting their tasks. Such algorithm of group action is suitable for any problems of visual territory monitoring. The main differences would be in type of the desired signal and the appropriate additional equipment for search for that signal.

One of the important topic for the development of control UAVs programs is an optimization flight algorithms. One way to energy accumulation and increase the flight range is to use thermal updrafts (or updrafts), formed in the lower atmosphere due to disruption of warm air from the surface when it is heated by sunlight.

UAV, which is equipped with sensors of velocity and pressure, measures the speed of its vertical displacement at each point of the path and when it detects zone with a positive buoyancy, it runs centering algorithm in a stream, which allows him to climb, moving along a helical trajectory around the center. After climbing machine goes into planning mode and remains there until its height becomes less than some specified threshold. The increase of flight time by using updrafts can be 4-6 times.

Similar research were conducted in work of Allen [Allen, 2005], where the autonomous UAV long-term soaring project with using energy of thermal updrafts was shown. In the event of a positive vertical velocity the UAV uses a strategy developed by glider H. Reichmann [Reichmann, 1978]. It is as follows for curvature of the UAVs trajectory:

• with an increase in vertical velocity, reduce the radius;

• with a decrease in vertical velocity, increase the radius;

• at a constant vertical velocity, keep a constant radius.

If we have a group of UAVs the additional problem when UAV occurred the updraft is to estimate precisely updraft center coordinates for transmission to other UAVs. In [Edwards, 2008] there was showed how inaccurate and laborious way to determine the coordinates of the center updraft that is described in [Allen, 2005].

We propose to use the modification of SPSA method for determining the center of updraft. Details of SPSA method are described in [Amelin, 2010], [Spall, 1992], [Granichin, 1989], [Granichin and Polyak, 2003]. The purpose of centering is to find the coordinates of the updraft's center.

General scheme of mean-risk optimization problem.

We choose the points at which do the measurements $x_1, x_2, \ldots \in \mathbb{R}^1$ and observations at these points $y_1, y_2, \ldots \in \mathbb{R}^1$ satisfies

$$y_n = F(x_n, w_n) + v_n,$$

where $F(\cdot, \cdot)$ is a density of updraft flow, $w_1, w_2, \ldots$ are uncontrolled unknown random sequence with an unknown distribution in $P(\cdot)$, $v_1, v_2, \ldots$ are unknown but bounded (non-random).

The goal is to find the point x which maximizes

$$f(x) = \int F(x, w) P(dw).$$

SPSA method:

Let $\Delta_1, \Delta_2, \ldots$ are sampling with the Bernoulli distribution, where $\Delta_n = (\pm 1, \pm 1, \ldots, \pm 1)^{\mathrm{T}} \in \mathbb{R}^d$,, α_n, β_n are positive constants, $\widehat{\theta}_0 \in \mathbb{R}^d$ is initial point,

$$x_n^{\pm} = \widehat{\theta}_{n-1} \pm \beta_n^{\pm} \Delta_n,$$

$$\widehat{\theta}_n = \widehat{\theta}_{n-1} + \frac{\alpha_n}{\beta_n^+ + \beta_n^-} (y_n^+ y_n^-)$$

or one measurement form:

$$\widehat{\theta}_n = \widehat{\theta}_{n-1} + \frac{\alpha_n}{\beta_n} y_n.$$

By the SPSA algorithm when the UAV-agent "finds" the updraft and determines the center updraft then it sends data to other UAV-agent. Those in its turn are assessing the distance to the updraft and possible energy savings. Then determine whether it is profitable to fly to this updraft. In [Antal, Granichin and Levi, 2010] presented the advantages of using the system of thermal updrafts by the group of cooperative UAVs compared with a single glider. Authors prove the condition with proof for the optimal distance between the UAV flying in a group:

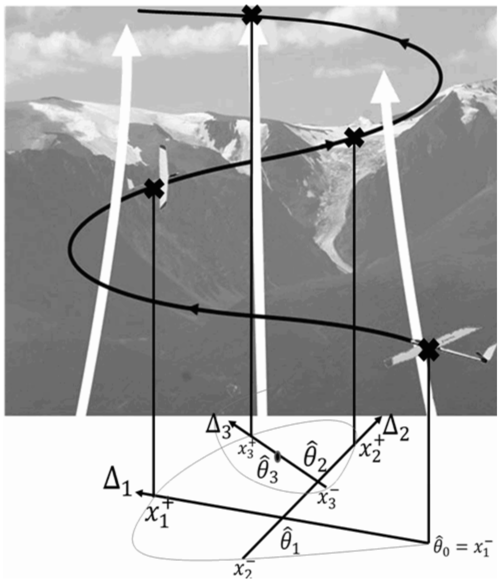

Figure 2. Illustration of the SPSA method.

$$L = \frac{b}{2c(K-1)},$$

where b is the energy benefit obtained from using the thermal updraft, c is designates the energy sink rate for a single UAV flying at the cruise speed, K is a number of UAVs in the group, and, as a consequence, give for the distance r the inequality:

$$b - 2rc > 0$$

under which the average power consumption of the one UAV-agent reduces while using of updrafts founded by another UAV-agent. Example of simulation is shown on Fig. 3.

5 Conclusion

The advantages of using multi-agent network of UAVs instead of group of single UAV systems were shown. Due to the multi-agent cooperation in group, each UAV-agent can autonomously correct its mission when the situation in the environment or global problem changes. To create a network of multi-agent UAVs the new three level system of group control is given. Hardware implementation for such control system is real due to the introduction of the middle layer - the microcomputer. It makes data exchanges with other UAV's microcomputers and the base station, and also corrects the problem on autopilot. The examples of two main types of problems for group of UAVs were considered

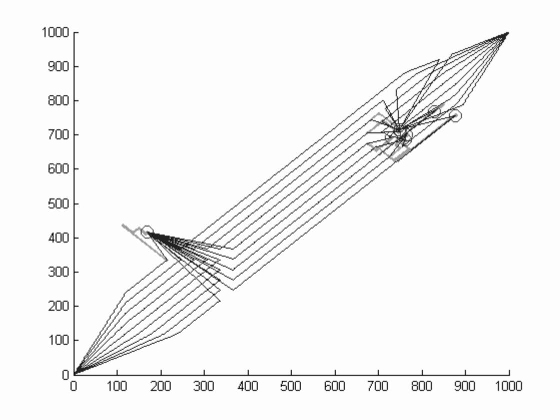

Figure 3. Group of $K = 9$ UAVs soaring.

- the problem of terrain monitoring and the problem of optimizing the UAV's flight. Algorithm for terrain monitoring was shown by the example of research of ecological conditions in the area. It is shown that for any visual territory research by group of UAV's the algorithm will differ only in the type of signal source. In the hardware section of the aircraft the difference will be only in the type of equipment. The problem of optimizing the flight is shown by the example of the using thermal updrafts. It is shown that a group use the updrafts more efficient for the accumulation of high. SPSA-method for determining the center of the thermal updrafts was also considered. Center of updraft is the information that passes from the UAV agent to other agents.

In the future work we plan to study and create algorithms for collision avoidance of UAVs agents during the approach. We also plan to research data transmission protocols and conversion of product pictures for faster data transfer. We're going to use the algorithms in a real group of UAVs.

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