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DEVELOPMENT OF UAV SOS FLIGHT COMBAT RECONNAISSANCE MISSION PROGRAM

System of systems (SoS) conception for dynamic objects group have been become a very important direction in various areas on science and industry, including military. SoS is consisted of components which solve one task and on the whole jointing own properties and possibilities these components creat the complex system with new qualities. SoS is such system which during various operations combines and joints itself a synergetics of comands, control functions, network and feedback information change. In given paper, development of the combat task program of Unmanned Aerial Vehicles System of Systems offered version has been presented. Usually, the land control center manage UAVs by using of radio wireless. But it has shortcomings: 1) a radio wireless can be destroy, and in the best case UAV does not emplement task and self returns base; 2) an enemy taps the radio wireless and carry out UAVs control. The creation of SoS on the basis of UAVs eliminates these flaws. In accordance with written in memory software program, UAVs SoS is self-controlled by infra-red (IR) wireless using "feedback" principle and it implement combat task independently. If some of UAVs loss IR-wireless then it (or they) return land control center independently. If some of UAVs is destroyed under enemy fire then other UAVs continue to implement a combat task. The Hamilton equations of motion of the given system has been obtained. The IR wireless between UAVs, radio wireless between UAVs and land control post, and UAVs flight control conditions have been offered. It is shown that Unmanned Aerial Vehicle System-of-System complex can implement in various military reconnaissance tasks.

K e y w o r d s : UAV, System of Systems; control system; reconnaissance task; infrared wireless.

Introduction

Recently the system of systems (SoS) conception for dynamic objects group have been become a very interesting and important direction in various areas on science and industry, including military. Since 1990s the posibilities and advantages of SoS ideology are very interesting and this ideology finds wide application to dynamic groups control and solution of various tasks [1, 2]. The SoS components are systems too. In technical area the SoS definition can be divided on two groups:

1) SoS is consisted of components which solve one task and on the whole jointing own properties and possibilities these components creat the complex system with new qualities;

2) SoS is such system which during various operations combines and joints itself a synergetics of comands, control functions, network and feedback information change.

In the previous paper development of Unmanned Aerial Vehicle System-of-System (UAVs SoS) complex and the opportunity of military application had been considered. The characteristic of developed 6-rotors Unmanned Aerial Vehicle had been presented [1–3]. It was shown that UAVs SoS complex can implement various military tactic and reconnaissance tasks.

Presented paper is devoted development of the combat task program of UAVs SoS and development of complex control algorithm.

"State of Art"

There are many articles devoted UAVs and SoS [4-6]. Let us observe some of published works concerning UAVs SoS architecture conception. In order to obtain optimized flight vehicle concepts which meet SoS operation requirements, designers have to pay high attention to the impact of SoS at conceptual design stage. Perspectives and progresses of SoS oriented flight vehicle conceptual design are reviewed in paper [7]. Such basic concepts of SoS as definition, characteristics, differences between systems engineering and SoS engineering, as well as SoS design process are introduced in this article. SoS engineering process model for research and development of flight vehicles and SoS design wheel model for conceptual design are proposed.

The use of UAVs in the military environments is predicted to grow significantly. The availability of more robust and capable vehicles that can perform multiple mission types will be needed. Militaries continue to demand more UAV capabilities for diverse operations around the world. Significant research has been performed and continues to progress in the areas of autonomous UAV control, as for example results presented in article [8].

Interesting results concerning interpreting development of unmanned aerial vehicles using systems thinking are presented in [9]. Starting from general systems theory authors formulate classification of UAVs that properly groups diverse produced UAVs, along with their currently unproduced. Authors have structured the context of applications of UAVs using systems thinking. Then they divide UAVs according to their function in environment: transfer of mass, energy and information. At last, they have analyse possible types of UAVs and divide them based on the structure of their lift-creating element, on their regulating programmes, and on the type of their power-plant.

UAVs SoS flight combat task program

In accordance of offered program, on the base of UAVs the development of SMART SoS of dynamic flight objects, making and testing will been carried out.

Usually, the land control center manage UAVs by using of radio wireless. But it has shortcomings: 1) a radio wireless can be destroy, and in the best case UAV does not emplement task and self returns base; 2) an enemy taps the radio wireless and carry out UAVs control. The creation of SoS on the basis of UAVs eliminates these flaws.

The most important distinctive property of UAVs SoS complex in our case is a radio wireless break down intentionally on the line of land control center after UAVs take off. In accordance with written in memory software program, UAVs SoS is self-controlled by infra-red (IR) wireless using "feedback" principle and it implement combat task independently. If some of UAVs loss IR-wireless then it (or they) return land control center independently. If some of UAVs is destroyed under enemy fire then other UAVs continue to implement a combat task.

One UAV can execute next combat tasks: battle, reconnaissance, control, communication facility, for example as booster converter in mountainous conditions. The tactical activities are offence, defence, encounter battle, march, posture of forces. The battle activities are offence, defence, encounter battle.

Let us assume that there are three reconnaissance UAVs in one UAVs SoS complex:

- UAVs flight on the prescribed altitude (H ≥ 300 m, UAVs are painted blue colour, so at this height UAVs aren't seen by unaided eye [10]) and the distance between each other is varied from 50 m to 200 m;

- UAVs are provided of radio wireless in "signal-output" mode for connection with land control center and IR- wireless in "signal-input-output" mode for interconnection between UAVs.

This UAVs SoS complex can execute combat and control tasks.

Combat tasks:

- air support of offence battle;

- terrain monitoring during defence;

- interconnection between troops and units during battle activities, especially in mountans where there are many zones of radio silence;

- reconnaissance tasks implementation during offence or defence activities;

- electronic warfare, radio countermeasures, radio reconnaissance tasks.

Control tasks:

- interconnection between troops and units on the large area, especially in mountans where there are many zones of "radio silence";

- interconnection between troops and units during march especially in mountans where there are many zones of "radio silence";

- interconnection between troops and units during offence especially in mountans where there are many zones of "radio silence".

UAVs SoS management architecture

The general UAVs SoS control (management) architecture has been defined for proposed autonomous complex system and has five primary functions (see Fig. 1): mission control, UAV control, sensors control,

communications control and safety control. These five areas provide the sufficient framework for offered system, regardless of mission and UAV type. The advantage of this UAVs SoS complex is that it provides a modular functionality architecture that can be adjusted for specific UAVs or any numerous vehicle types. The UAVs SoS algorithms will reside within the mission control functionality and will be dependent upon common interfaces and architecture.
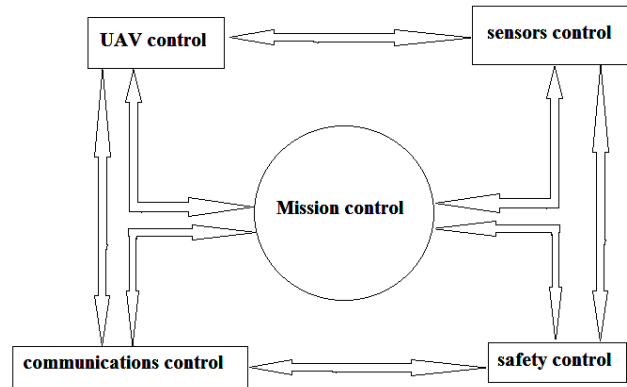

Fig. 1. The general UAVs SoS control (management) architecture

Infra-red radio communication system between UAVs

Infra-red radio communication system (IR-wireless transmission) is an equipment which provides information transfer between UAVs in optic IR range [11, 12]. Infrared band of the electromagnet corresponds to 300 GHz and a wavelength of 980 nm [13]. Usually, during IR-wireless the LEDs (Light Emitting Diodes) are used for IR-waves transmission. As opposed to radio wireless, the IR-wireless isn't sensible to electromagnetic interference, has low power, doesn't demand a communication channels reservation, provides signal hiding and high intercept security of information transfer.

In line of sight conditions the IR channel can provide communication in the distance up to several kilometers. In present, there are information-transferred modules in IR range capable 1 Gbit/sec. rate. The propagation of light waves in this band can be used for a communication system (for transmission and reception) of data. This communication can be between two portable devices or between a portable device and a fixed device.

IR-wireless system includes IR radiator, IR transmitter, IR source and IR receiver (Fig. 2). IR transmitter is a device, which transforms information to electrical signal for IR source modulating. IR source is infra-red source for signals transfer. IR radiator is a device for transformation of input electrical signal to infra-red radiation. IR receiver is a device with infra-red detector and signal processing which transforms or recodes input signal (information) for remote control.

For porpose of providing signal hiding and high intercept security of information transfer and control mission between UAVs the especial IR wireless system is offered in given program (see Fig. 3).
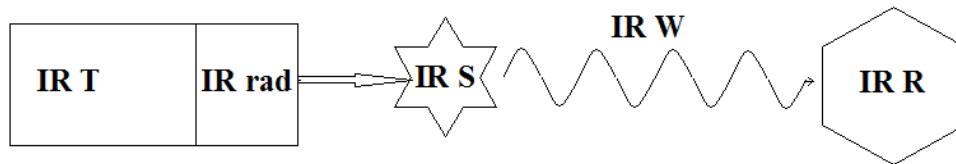
Fig. 2. IR-wireless system: IR T – infra-red transmitter, IR rad – infra-red radiator,
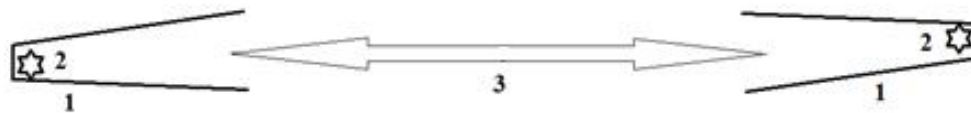IR S – infra-red source, IR W – infra-red wave, IR R – infra-red receiver.

Fig. 3. The chart of IR wireless between UAVs:
1 – IR input-output radiation flux tubes in UAVs with screened waveguide;
2 – the sources of IR emission and lIR light receivers; 3 – IR light

Let us consider IR wireless IR-transmitter and IR-receiver between two UAVs as tubes form.

The tube form with screened waveguide provides a signal hiding and a high intercept security of information transfer. Morever, this form of IR wireless system doesn't allowed to execute a control from the enemy's side. IR-control signal is propagated directly in a line sight between UAVs. Some radio- or infra-red signal from ground cannot impact to this IR wireless system. Also, UAVs have radio wireless for send output-signal to ground control post center (UAVs takeoff point). UAVs have screened electronic blocks and therefore cannot be controlled by ground enemy posts.

UAVs' main characteristics

There are developed UAVs' main technical characteristics descripted below [2, 3]:
- takeoff weight: 10-15 kg;
- load capacity: 5 kg;
- flight range: 20 km;
- cruising speed: 80 km/h;
- flight time: 1 hour.

UAVs SoS mission program

The UAVs SoS mission program includes next stages.

1. 3 UAVs are considered: UAV1, UAV2 and UAV3. These UAVs have a reconnaissance mission.

2. After takeoff all UAVs are controled off-line by themselves, the ground center hasn't possibilities to control UAVs.

3. UAVs are provided by radio (only in output mode) and IR wireless (both input and output mode for information exchange only between UAVs) systems.

4. UAVs are provided by high-precision digital electronic-optical photographic camera systems: Full Frame DSLRLike Camera a7R EMount Compact Camera | Sony US, 36 MP. Obtained by this camera photographies are sent to ground control center. In result of the test on proving ground obtained one image of land, as the example, is shown in the photography 1, the flight height is 200 m.

5. After UAVs takeoff, on a regular basis UAVs are exanged control IR signals, it is necessary for handshaking. If for some reason the handshaking is broken, then information about it is sent to ground center by radio wireless and this UAV comes back to ground center.

6. After takeoff UAVs flight jointly in triangular form (see Fig. 4).

For testing of the IR communication reliable performance, the size of this triangle is changed cyclically: from 50 m to 200 m and then again to 50 m (see Fig. 5):
- in moment t_1, l_1=100 m;
- in moment t_2, l_2=200 m;
- in moment t_3, l_3=100 m.
- in moment t_4, l_4=50 m.
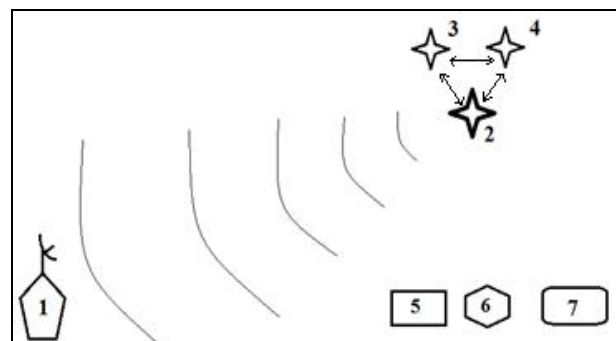

Photography 1

Fig. 4. The chart of UAVs SoS reconnaissance flight.
1 – ground control center; 2, 3 and 4 – UAVs;
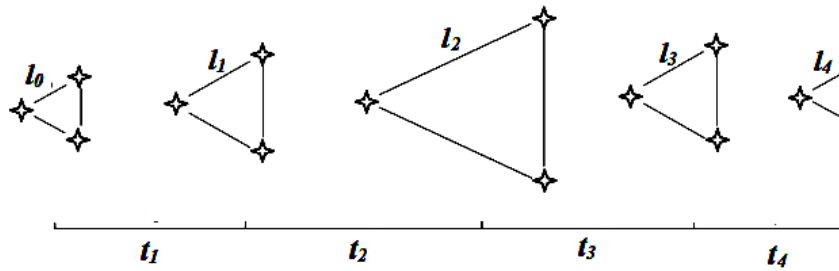5, 6 and 7 – investigated enemy objects

Fig. 5. The chart of UAVs flight conditions: l_0, l_1, l_2, l_3 and l_4 are the distances
between UAVs; t_1, t_2, t_3 and t_4 are the flight time slots

7. After UAVs takeoff in 5 minutes IR-transmitter of UAV1 is cut off; it goes on mission: flight, shoot images of land and sends this information to ground center. It will check the UAV autonomy.

The simplified chart of flight program of UAVs SoS is shown in Fig. 6. Let us take UAV1 as "commander" one. UAV1 gives flight speed (V), flight height (h) and distance (S_1 and S_2) between UAVs (in our case $S_1 = S_2 = S \in [50, 200]$ m). UAV1 sends İR signal f to both UAV2 and UAV3. If there is IR handshaking ($f \neq 0$ - "yes"), then UAVs continue flight. If there isn't IR handshaking ($f = 0$ – "no"), then UAVs come back to ground conrol center.

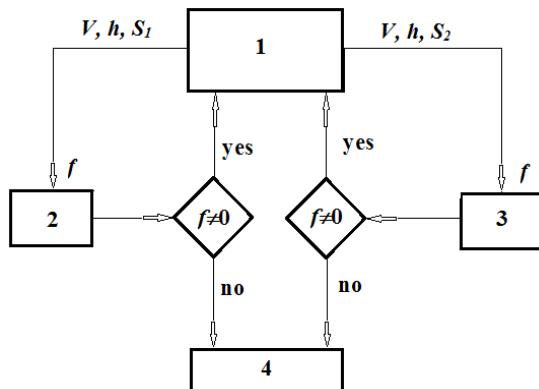It should be noted that this only for UAVs flight testing program.

Fig. 6. The chart of flight program of UAVs SoS:
1 –"commander's" UAV; 2 and 3 – UAVs;
4 – return ground control center.

The SoS UAVs dynamic motion equation

Let us consider UAVs SoS flight as a motion of material points system. Hamilton equations is one of main equations of Newtonian mechanics for the investigated dynamic system, which in overall view describe a temporal change of the points coordinates of system [14]. Let write these canonical equations of motion as:

$$\frac{dp_i}{dt} = -\frac{\partial H}{\partial q_i}; \quad \frac{dq_i}{dt} = \frac{\partial H}{\partial p_i}. \tag{1}$$

It seems, that system is consisted of 2N first-order differential equations ($j = 1, 2, …, N$) for the dynamic system described by N generalized coordinates which are system motion. Here:

$H \equiv H(q_1, q_2, …, q_N, p_1, p_2, …, p_N, t)$ is a Hamilton function (Hamiltonian),

t is time, q_i are generalized coordinates,

p_i are generalized momentums.

These generalized coordinates and momentums determine a state of system in phase space.

Since, a rectilinear flight of UAVs SoS (a material points system) is planar, then for simplicity, we assume that Hamiltonian H can be presented as a sum of kinetic $T(p)$ and potential $V(q)$ energies of UAVs SoS system:

$$T(p) = p^2/2m;$$
$$V(q) = V(x).$$

In our case, $x = h$ – is a flight high of SoS PUAs.
Let all UAVs are of the same mass that is

$$m_1 = m_2 = … m_N = m.$$

Then, Hamilton equation can written as:

$$H = \frac{1}{m} \sum_{i=1}^{N} p_i^2 + N \cdot m \cdot g \cdot h, \tag{2}$$

where: g is the gravitational acceleration, $g = 9{,}8$ m/s^2.

Therefore, by using (1) and (2) equations it is possible to describe of motion of UAVs SoS system. If it is necessary to take into account of rotational motion of UAVs then the equations system described in previously work [2] can used.

Conlusion

So, in paper the development of UAV SoS flight combat reconnaissance mission program has been presented. The general UAVs SoS management (control) architecture has been defined for proposed autonomous smart complex system. IR communication has been considered and offered for information exchange between UAVs. UAVs preliminary flight testing program has been offered. The Hamilton equations of motion of the given system has been obtained.

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Розробка програми бойового розвідувального завдання польоту безпілотних літальних апаратів SoS

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Концепція "System of Systems" (SoS) для динамічних об'єктів стала дуже важливим напрямком в різних областях науки і промисловості, включаючи військову. SoS складається з компонентів, які вирішують одну задачу і в цілому, об'єднуючи власні властивості і можливості створюють комплексну систему з новими якостями. SoS – це така система, яка під час різних дій комбінує і об'єднує в собі синергетику команд, функцій управління, мережу і обмін інформацією зі зворотним зв'язком. У даній статті представлена розроблена програма бойового завдання польоту безпілотних літальних апаратів (БПЛА) SoS. Зазвичай, наземний центр управління БПЛА використовує радіозв'язок. Але це має свої недоліки: 1) радіозв'язок може порушитися, БПЛА не виконає завдання і в кращому випадку повернеться на базу; 2) ворог може порушити радіозв'язок і перехопити управління БПЛА. Створення БПЛА SoS комплексу обмежує ці недоліки. Відповідно до записаної в пам'ять програмного забезпечення, БПЛА SoS, використовуючи інфрачервоний радіозв'язок, є самоврядною системою, котра використовує принцип "feedback" і незалежно виконує бойове завдання. Якщо якийсь БПЛА втратить інфрачервоний радіозв'язок, тоді він (або вони) незалежно повернуться на базу. Якщо якийсь БПЛА буде збитий, інші продовжать свою місію. Отримано рівняння Гамільтона для руху даної системи. Запропоновано ІК зв'язок між БПЛА і радіозв'язок між БПЛА і наземним постом управління, а також умови управління польотом БПЛА. Показано, що комплекс БПЛА SoS може виконувати різні військові розвідувальні завдання.

Ключові слова: безпілотний літальний апарат; "System of Systems"; керуюча програма; розвідувальне завдання; інфрачервоний зв'язок.

Разработка программы боевой разведывательной задачи полета беспилотных летательных аппаратов SoS

А. А. Байрамов, Э. Г. Гашимов

Концепция "System of Systems" (SoS) для динамических объектов стала очень важным направлением в различных областях науки и промышленности, включая военную. SoS состоит из компонентов, которые решают одну задачу и в целом, объединяя собственные свойства и возможности, создают комплексную систему с новыми качествами. SoS – это такая система, которая во время различных действий комбинирует и объединяет в себе синергетику команд, функций управления, сеть и обмен информацией с обратной связью. В данной статье представлена разработанная программа боевой задачи полета беспилотных летательных аппаратов (БПЛА) SoS. Обычно, наземный центр управления БПЛА использует радиосвязь. Но это имеет свои недостатки: 1) радиосвязь может нарушиться, БПЛА не выполнит задания и в лучшем случае вернется на базу; 2) враг может нарушить радиосвязь и перехватить управление БПЛА. Создание БПЛА SoS комплекса ограничивает эти недостатки. В соответствии с записанным в память программным обеспечением, БПЛА SoS, используя инфракрасную радиосвязь, является самоуправляющейся системой, использующей принцип "feedback" и независимо выполняющей боевую задачу. Если какой-то БПЛА потеряет инфракрасную радиосвязь, тогда он (или они) независимо вернутся на базу. Если какой-то БПЛА будет сбит, остальные продолжат свою миссию. Получены уравнения Гамильтона для движения данной системы. Предложены ИК связь между БПЛА и радиосвязь между БПЛА и наземным постом управления, а также условия управления полетом БПЛА. Показано, что комплекс БПЛА SoS может выполнять различные военные разведывательные задачи.

Ключевые слова: беспилотный летательный аппарат; "System of Systems"; управляющая программа; разведывательная задача; инфракрасная связь.