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METHOD FOR DETERMINING THE RATIONAL NUMBER OF UAV FLOTILLA TAKING INTO ACCOUNT THE RELIABILITY OF THE AIRCRAFT

The conducted studies showed that projects of analysis and assessment of emergencies at critical infrastructure facilities have been initiated in Ukraine and abroad. The purpose of such a system is the formation of data for the development of architecture, demonstration analytics and a prototype of decision support capabilities, taking into account the use of currently available data and analytical methodologies. Unmanned aerial vehicles (UAVs), which work with ground and air control points in emergencies, are planned as the basis for the construction of such a system. **The subject of the study** is methods of determining the rational number of UAV flotillas taking into account the assigned tasks and characteristics. Currently, there is no method for determining the rational number of a UAV flotilla, taking into account the reliability of the aircraft. **An urgent scientific and technical task** is the task of creating a rational number of the UAV flotilla, taking into account the reliability of the aircraft and the necessary quality of monitoring the situation in emergencies. **The purpose of the article** is to develop a method for determining the rational number of UAV flotillas taking into account the reliability of the aircraft and the necessary quality of monitoring the situation in emergencies. **Research methods –** provisions of risk theory, probability theory, combinatorics, mathematical apparatus of reliability theory, mathematical methods of optimization. **Research results:** an analysis of factors affecting the structure of the UAV grouping was carried out; the dependence of task performance on the probability of UAV failure under the influence of interfering factors was obtained; it is shown that in conditions with a low impact of interfering factors, the reliability of individual UAVs does not have a significant impact on the performance of assigned tasks. It has been established that with increasing influence of interfering factors, the probability of completing tasks depends on the reliability of the aircraft. **Conclusions:** The proposed method makes it possible to create a rational number of UAV flotillas taking into account the reliability of the aircraft and the necessary quality of monitoring the situation with a rational number of UAVs in emergencies.

Keywords: UAV flotilla control; UAV grouping; rational number; emergencies; reliability of functioning.

Introduction

A number of publications by domestic and foreign scientists have been devoted to ensuring and assessing the reliability, survivability, and safety of technical systems, in particular those intended for monitoring, control, and management in emergencies. In Ukraine and abroad, projects have been initiated to analyze [1, 4], assess the occurrence of emergencies [5, 6], generate data for architecture development [2, 3], and demonstrate analytics and prototype decision support capabilities using currently available data and analytical methodologies to prevent accidents and incidents [3, 5]. Unmanned aerial vehicles (UAVs) working with ground and airborne control centers in emergencies can become the basis for building such a system. The idea of such systems is quite simple. A UAV or a group (fleet) of UAVs operate in the emergency zone. The number of aircraft is determined by the list of tasks assigned to the UAV group. In addition, each of the aircraft is capable of duplicating the assigned tasks to a neighboring UAV.

Analysis of recent research and publications

The construction of an information management system involves structural and numerical redundancy of UAVs. Paper [7] proposes a methodology for assessing the probability of performing a task by a fixed number of flotilla taking into account the reliability characteristics of UAVs. This approach provides for maximum redundancy of the grouping, as well as the use of highly reliable aircraft, and therefore expensive UAVs, and does not allow for rational construction of aircraft groups.

Paper [8] considers risk models in information systems and formulates the tasks of building self-healing systems.

Studies [9, 10] solve the problem of detecting covert attacks using false data in intelligent networks. At the same time, the network structures for detecting attacks are not substantiated and algorithms for building a system in case of network degradation are not considered.

Works [11, 12] predict the load in an intelligent network based on long-term and short-term memory. The results obtained make it possible to solve the problem of predicting the state of the system, but do not

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allow solving the problem of self-healing of the system in the event of failure of its elements.

The following papers [13, 14] consider the impact of cyber-physical attacks on data in real-time smart grids. A mechanism for detecting cyber-physical attacks with false data is proposed to protect the operation of power transmission and distribution systems by automatically determining the main physical relationships using cross-sensory analytics.

The study [15] raises the issue of the ability of the smart grid to self-heal and receive new energy. The results obtained can be applied to power systems that combine different energy sources to maximize the safety of system operation.

Despite the significant number of developed methods and models, a number of important issues remain outside the scope of research, namely

– development of models and methods for ensuring self-healing in information systems for the management and operation of the UAV flotilla;

– organization of a multi-level information system for the management and operation of the UAV flotilla and creation of a method for assessing the characteristics of such systems;

– development of self-healing methods in information systems of UAV fleets with multi-stage degradation and recovery;

– creation of a model for deploying multi-purpose self-healing unmanned systems for monitoring and analyzing emergencies.

In addition, it is necessary to emphasize the lack of information technology to plan the use and ensure the reliable operation of UAV fleets, given the existing capabilities of unmanned aircraft to measure, transmit and analyze information about the state of objects.

Existing approaches to determining the number of UAVs in a flotilla are aimed at some redundancy of aircraft and do not take into account the ability of UAVs to operate under specific destabilizing factors and threats. Currently, there is no method for determining the rational number of UAV flotillas, taking into account the reliability of the aircraft. The rational number of a UAV flotilla will be understood as the minimum number of aircraft capable of performing the assigned tasks with a given probability.

Therefore, the task of creating a rational number of UAV flotilla taking into account the reliability of the aircraft and the required quality of control of the situation in emergencies is relevant.

The purpose of the article is to develop a method for determining the rational size of a UAV flotilla, taking into account the reliability of the aircraft and the required quality of control of the situation in emergencies.

Materials and methods of the study

Advances in probabilistic accident modeling and data analysis make it possible to explain and predict events and incidents with greater accuracy using large amounts of available data and sophisticated analytical tools. Unmanned aerial vehicles (UAVs) that work with ground and airborne control centers in crises can be the basis for building such a system. The idea of the system is quite simple. A UAV or a group (fleet) of UAVs operates in a crisis area (Fig. 1). The number of UAVs is determined by the list of tasks assigned to the UAV group. In addition, each UAV is capable of duplicating the tasks assigned to a neighboring UAV.

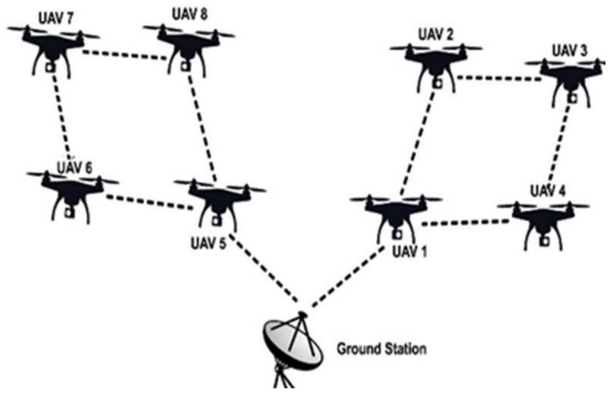

Fig. 1. UAV grouping

An analysis of the tasks assigned to UAV groupings that require decision-making shows that the same typical elements are usually present in these processes (Fig. 2). These elements include the following:

The analysis of Fig. 2 shows that, depending on the required probability of completing tasks, increasing the impact of interference, the quality of the UAV fleet depends on both the reliability of the aircraft and the quality of the control system.

Let F be the functional describing the quality of the UAV grouping control system under threats [9, 10]:

$$F\left\{G(h,R),\ I(R),\ S(L),\ V(e),\ T(t)\right\}, \qquad (1)$$

where $G(h,R)$ is a function characterizing the energy parameters of the control system;

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$I(R)$ is a function characterizing the resistance to external influences;

$S(L)$ is a function characterizing the structural reliability of the control system software;

$V(e)$ is a function that characterizes the speed characteristics of the control system;

$T(t)$ is a function characterizing the time parameters of the control system.

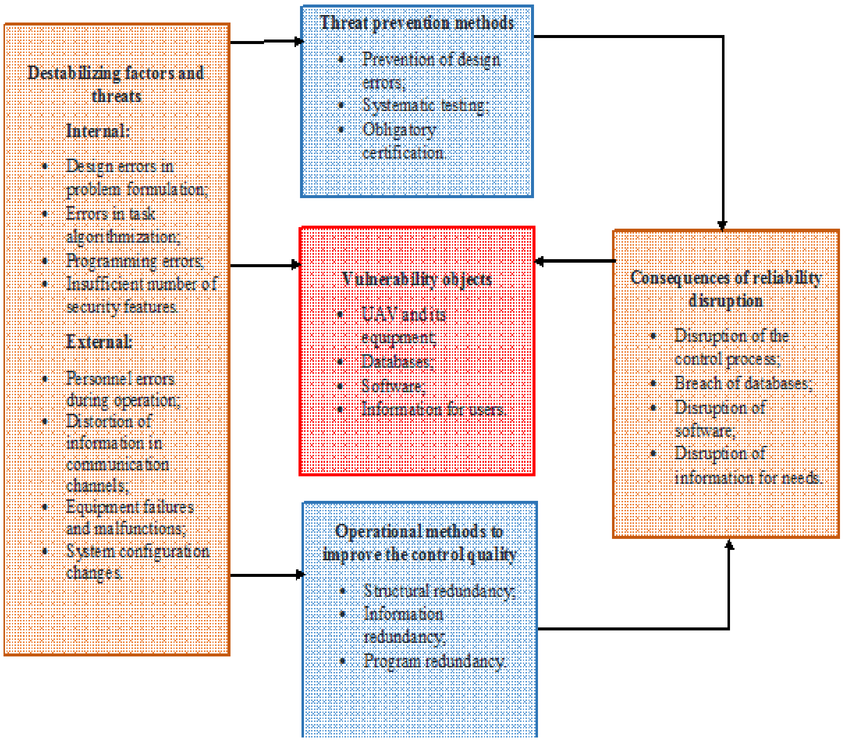

Fig. 2. Typical elements and factors affecting the structure of a UAV grouping

Thus, the task of synthesizing a self-healing system is to develop methods and algorithms that maximize the functional of the form (1). Mathematically, this can be expressed through the objective function $\gamma(x)$, which is written in the form [3]:

$$\gamma(x) = max\{F\{G(h, r), I(R), S(L), V(r), T(t)\}\}, \quad (2)$$

where $x = (h, r, R, L, e, t)$.

In addition, the following restrictions must be met:

$$\begin{aligned} &G(h,R) \ge g_{all}, \\ &I(R) \le I_{all}, \\ &S(L) \ge S_{all}, \\ &V(e) \le V_{all}, \\ &T(t) \le T_{all}, \end{aligned} \quad (3)$$

where g_{all} is the minimum allowable value of the energy parameters of the control system;

I_{all} is the required value of resistance to external influences;

S_{all} is the set value of structural reliability of the control system software;

V_{all} is the minimum allowable value of the speed characteristics of the control system;

T_{all} is the maximum allowable time for executing control commands.

Thus, expression (2), taking into account the constraints (3), describes in a generalized form the main task of research – the synthesis of the control system – and ensures the maximum quality of the system in the complex under the conditions of given probabilistic and temporal characteristics and the influence of interference.

The studies conducted have shown [11] that the synthesis task that ensures conditions (2) in the case of their limitations (3) is an extreme task. The variational nature of the problem of constructing a self-healing system implies the use of ideas and methods as a mathematical apparatus, including theoretical-numerical and combined-multiple methods. Solving the problem of rational allocation of resources of the system of

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aircraft operating in emergencies is associated with the following areas [7]:

1. Creation of a UAV fleet with some redundancy of aircraft that ensures guaranteed mission performance in case of failure or destruction of a part of the UAV;

2. Creation of a UAV grouping, taking into account the possibility of self-healing of the system of both the aircraft itself and the redistribution of management resources of the grouping itself.

The elements considered in (2) and (3) are interdependent. The objective function cannot be formed without identifying those variables and parameters that determine the outcome of the operation. An in-depth analysis of the relationships and correlations between the parameters and variables is also necessary. The choice of an objective function optimization method depends entirely on the specific form of its representation, which reflects the content of the mathematical model.

In the course of the research, a structural scheme for managing a UAV flotilla was developed, taking into account the self-healing of the system in the conditions of degradation of the control system in the event of the influence of destabilizing factors and threats. The structural and functional diagram is shown in Fig. 3.

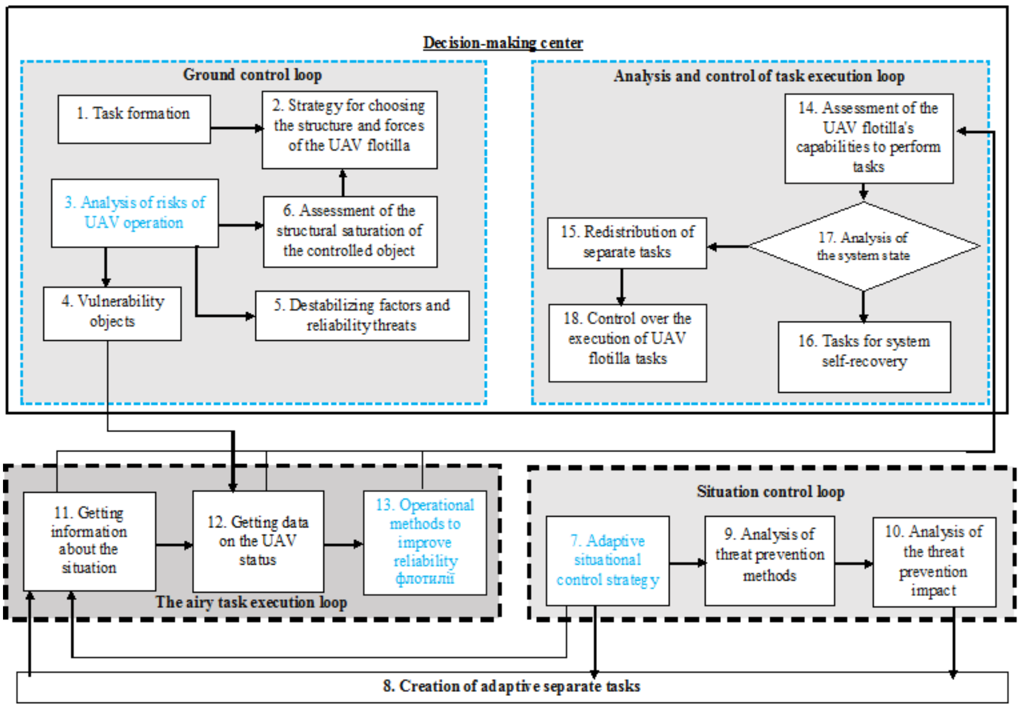

Fig. 3. Block diagram of UAV flotilla control

In the course of research, we analyzed the proposed method.

Let the probability of completing a task by a fleet of UAVs be equal to P_{comp}. Each UAV has its own task. The probability of each UAV completing its task is equal to P_i.

Assuming that a UAV flotilla contains n UAVs whose failures are random and independent events, the probability P_{comp} of the flotilla completing a task can be taken as equal to the product of the probabilities of an individual UAV completing a task [13]:

$$P_{comp} = \prod_{i=1}^{n} P_i .$$

When using a single UAV, taking into account the effects of obstacles, the probability of completing the task is written in the form [6]:

$$P_f = P_{int} P_c + (1 - P_{int}) P_w , \quad (4)$$

where P_{int} is the probability of an interference effect on the UAV at a particular time;

P_c is the probability of UAV failure under the condition of interference;

P_w is the probability of UAV failure without interference.

The probability of UAV failure in case of interference depends on the UAV failure rate and the

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adopted failure model. In known studies, a simple failure model is considered.

In the context of a UAV grouping, let's assume that if one UAV fails, its tasks are instantly assigned to another vehicle. The probability of such an event is equal to [3].

$$P_0 = P_{ci} P_{c\,j/i}\,, \quad (5)$$

where P_{ci} – the probability of failure of the i-th UAV if the UAV is affected by interference;

$P_{c\,j/i}$ – is the conditional probability of failure of the j-th UAV in case of interference, after the failure of the i-th UAV.

UAVs can be in one of two possible states during a task: operable or failed. In [3], it is shown that in this case of a UAV failure after it is turned on in the active mode of operation, the Bernoulli scheme can be applied. As a result, we have:

$$P = \sum_{i=t+1}^{n} C_n^i P_0^i \left(1 - P_0\right)^{n-1}. \quad (6)$$

Using expressions (4)–(6), we analyze the probabilities of performing a UAV task in the face of interference. Fig. 4 shows the dependence of P_f on P_c if P_w has different values.

These dependencies make it possible to justify the number of UAVs and the probability of obtaining information for analyzing the situation in the face of interference. The results obtained are taken into account in the process of emergency response.

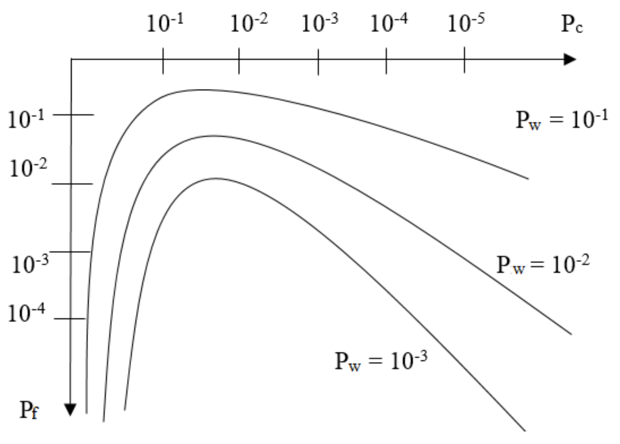

Fig. 4. Dependence of task performance on the probability of UAV failure in case of interference and when using aircraft with different reliability

Fig. 4 shows that in conditions with insignificant interference, the reliability of individual UAVs does not significantly affect the performance of tasks. As the impact of interference increases, the probability of completing tasks depends on the reliability of the aircraft.

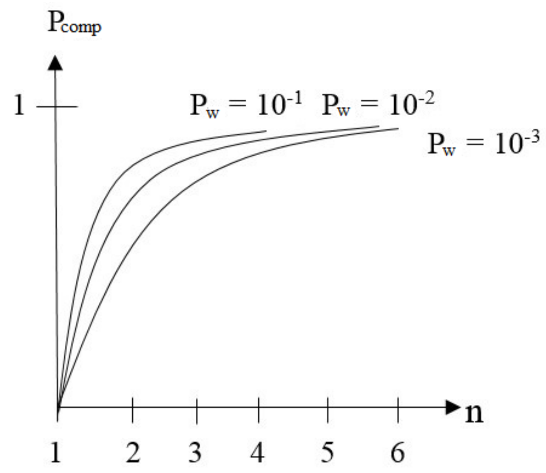

Fig. 5. Dependence of the UAV flotilla's mission performance on the number of aircraft

Implementation of the functions of reallocation of group management resources will allow efficient use of each aircraft.

Fig. 5 shows the probability of completing a task by a UAV flotilla depending on the number of aircraft. The figure demonstrates that, given the required probability of completing a task, the size of the UAV fleet depends on the reliability of the aircraft.

Conclusion

Thus, the proposed method makes it possible to substantiate the rational size of the UAV flotilla, taking into account the reliability of the aircraft and the required quality of control of the situation in emergencies. The obtained results allow us to determine the rational size of the UAV flotilla depending on the required probability of performing tasks, the growing influence of interference and the reliability of aircraft. The basis for building such a system should be unmanned aerial vehicles that work with ground and airborne control centers in emergencies.

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Given the results obtained, the developers of the emergency control system can justify a strategy for choosing a rational number of UAV flotilla and the reliability of the aircraft used. The question is whether to choose a large number of cheap but less reliable UAVs, or to choose aircraft that are more reliable with a smaller number. The results of the study can serve as a basis for economic justification of the size of the UAV flotilla and the quality of the aircraft used.

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МЕТОД ВИЗНАЧЕННЯ РАЦІОНАЛЬНОЇ ЧИСЕЛЬНОСТІ ФЛОТИЛІЇ БПЛА З УРАХУВАННЯМ НАДІЙНОСТІ ЛІТАЛЬНОГО АПАРАТА

Проведені дослідження показали, що в Україні та за кордоном ініційовано проєкти аналізу й оцінювання виникнення надзвичайних ситуацій на об’єктах критичної інфраструктури. Мета інформаційної системи управління – формування даних для розроблення архітектури, демонстраційної аналітики та прототипу можливостей підтримки прийняття рішень з урахуванням використання наявних на сьогодні даних і аналітичних методологій. Основою побудови такої системи можуть бути безпілотні літальні апарати (БПЛА), що працюють із наземними й повітряними пунктами керування в надзвичайних ситуаціях. **Предметом** дослідження є методи визначення раціональної чисельності флотилії БПЛА з урахуванням покладених завдань та характеристик. Нині відсутній метод визначення раціональної чисельності флотилії БПЛА з урахуванням надійності літального апарата. **Актуальним науково-технічним завданням** є створення раціональної чисельності флотилії БПЛА з урахуванням надійності літального апарата та необхідної якості контролю обстановки в умовах надзвичайних ситуацій. **Мета статті** – розробити метод визначення раціональної чисельності флотилії БПЛА з урахуванням надійності літального апарата й необхідної якості контролю обстановки в умовах надзвичайних ситуацій. **Методи** дослідження: положення теорії ризиків, теорії ймовірності, комбінаторики, математичного апарату теорії надійності, математичних методів оптимізації. **Результати досліджень:** проаналізовано чинники, що впливають на структуру угруповання БПЛА; отримано залежності виконання завдання від імовірності виходу з ладу БПЛА під час дії дестабілізаційних факторів; показано, що в умовах з незначною дією перешкод надійність окремих БПЛА істотно не впливає на виконання поставлених завдань; установлено, що зі зростанням впливу перешкод імовірність виконання завдань залежить від надійності літального апарата. **Висновки:** запропонований метод дає змогу створити раціональну чисельність флотилії БПЛА з урахуванням надійності літального апарата й необхідної якості контролю обстановки за умови раціональної кількості БПЛА під час надзвичайних ситуацій.

Ключові слова: управління флотилією БПЛА; угруповання БПЛА; раціональна чисельність; надзвичайні ситуації; надійність функціонування.

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