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THE NUMERICAL ESTIMATION METHOD OF A TASK SUCCESS OF UAV RECONNAISSANCE FLIGHT IN MOUNTAINOUS BATTLE CONDITION

The numerical estimation of performance of battle task in mountainous region by using Unmanned Aerial Vehicles (UAV) reconnaissance flight is very important for theatre-of-war planning of battle operations. In paper, the numerical estimation method of a task support success of UAV reconnaissance flight in mountainous battle condition has been offered and considered. This method is based on the probabilistic approach. The battle support (security) is activities complex realized for the purpose of creation of the favorable conditions for successful battle activities and enemy impact degradation for any conditions. The battle support includes reconnaissance, electronic warfare, tactical camouflage, engineering support, radiation-chemical and biological protection, aiming control and astrogeodetic support, hydro-meteorological support, protection. The minimum of permissible safety height of UAV flight by using geoinformation system (GIS) technology has been determined. Only the UAV tactic reconnaissance flight is considered in paper. For solution of this task, the various input parameters have been took into account: security events set of the troops, security events set of UAV reconnaissance flights, set of the UAV performance characteristics, set of UAV operating conditions, set of mountainous landscape characteristics. The calculations have been carried out for the specific conditions of one of the mountainous broken ground region of the Azerbaijan Republic.

Keywords: Unmanned Aerial Vehicle; reconnaissance flight; probabilistic parameters; Geoinformation System; mountainous region.

Introduction

The numerical estimation of performance of battle task in mountainous region by using Unmanned Aerial Vehicles (UAV) reconnaissance flight is very important for theatre-of-war planning of battle operations. The numerical estimation is mean a level of the battle task performance, which is varied from 0 to 1. For solution of this task it is necessary to know next input parameters:

- security events set of the troops;
- security events set of UAV reconnaissance flights;
- set of the UAV performance characteristics;
- set of UAV operating conditions;
- set of mountainous landscape characteristics.

Below the method of numerical estimation method of a success level of the battle support based on the application of UAV reconnaissance flight in mountainous battle conditions. The battle (strategical) support is activities complex realized for the purpose of creation of the favorable conditions for successful battle activities and enemy impact degradation for any conditions. The battle support (security) includes reconnaissance, electronic warfare, tactical camouflage, engineer support, radiation-chemical and biological protection, aiming control and astrogeodetic support, hydro-meteorologic support, protection [1]. Only UAV tactical reconnaissance will be considered below.

The problem formulation

Taking into an account that the considered process is stochastic, then the numerical estimation of events realization can be carried out by using probabilistic factors: a degree of success of the event of battle support, a guaranteed probability of realization of the event of battle support, a probability of realization of the M events among of all Z events etc. For the purpose of finally solution (choice reasonable option of battle support) it is necessary to use a validity criterion [2].

The investigation task is: by using UAV to find reasonable option of a battle support U^* belong among U set when a mathematical expectation of the number of successfully performed events of battle support will be the largest, that is

$$U^* \in U:\ M_{suc}(t) = \sup M'_{suc}(t), \tag{1}$$

where $M'_{suc}(t)$ is determined by method of the examination of obtained calculated values of the mathematical expectation in sample of its general set.

Calculated values of the mathematical expectation of the number of successfully performed events are calculated by next formula [3, 4]

$$M_{suc}(t) = \sum_{i=1}^{Z} P_{suci}(t), \tag{2}$$

where $P_{suci}(t)$ is a probability of successfully performed i event of UAV battle support; Z is a common number of performing events.

UAV flight above mountainous landscape with terrain following

The providing of accident-free UAV application is the main task during UAV flight in mountainous difficult broken relief. The mathematical model of UAV flight in regime of the terrain following was offered in

[5]. The minimal permissible safety height of flight is the main operation factor determined UAV flight safety in regime of the terrain following. The minimal permissible safety height of UAV flight is determined from the conditions of UAV non-collision with ground. It is depended from UAV mobility and maximum overloads, the rate of overloads forming, the range of permissible flight speed:

$$H_{min}=f\,(n,\,k_{max},\,t,\,\Delta V),$$

where n is a value of the normal component of overload determined by the limiting value of lift force which can be formed at instantaneous values of flight height and speed; k_{max} is the maximum overload (UAV ultimate strength limit) determined by the maximum permissible value of lift force; t is a duration of normal overload formation; ΔV is a range of flight speed.

The duration of normal overload formation t defines possibilities of violent maneuvers making demanded an agility of flight trajectory curvature in UAV plane of symmetry. It is very important during flyby around mountainous difficult broken relief of the terrain.

The duration of normal overload formation t and type of dependence

$$\Delta n = f(t)$$

are depended from UAV moment of inertia relatively transverse axis; damping moment; static steadiness moments, efficiency of elevation rudder, sluggishness of UAV moving control.

Let's determine the minimum of permissible safety height of UAV flight by using geoinformation system (GIS) technology. We use experimental data obtaining in our previous work [8]. The task of determination of the height relief for specific region of the Azerbaijan Republic by using GIS technology had been considered in this work. Let's consider the features of UAV reconnaissance flight between observation point A and point B (see Fig. 1 [6]).

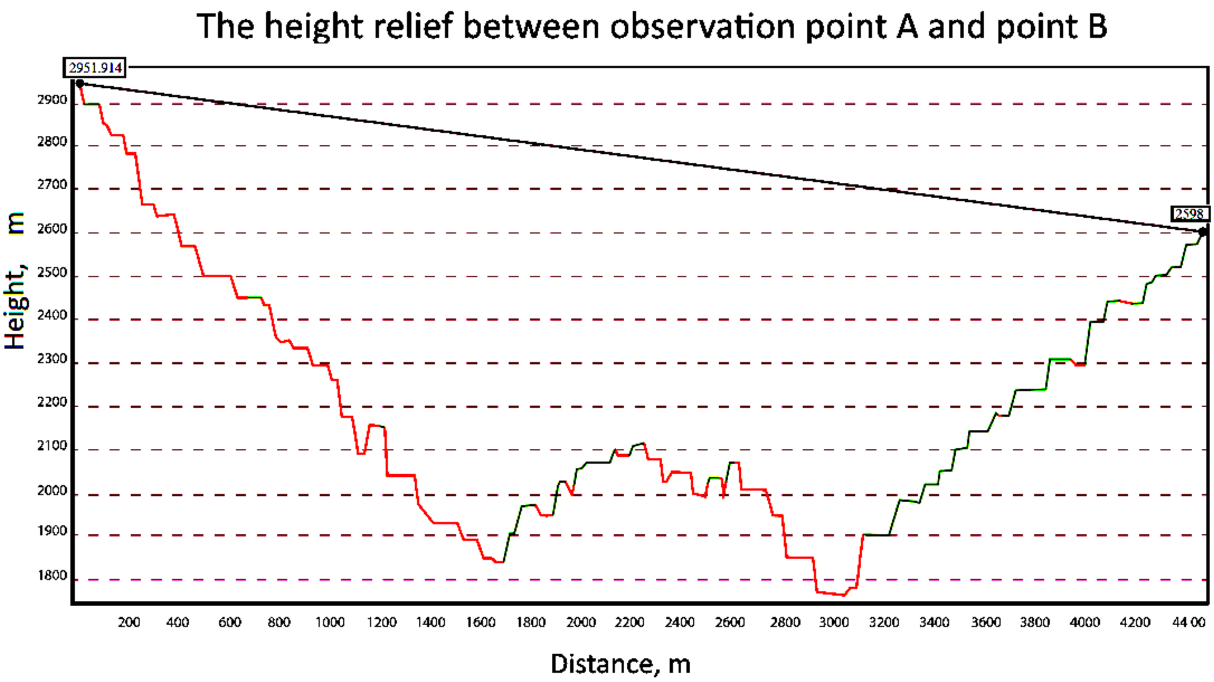

Fig. 1. The height relief between observation point A (2951 m height) and point B (2590 m height) obtained by using GIS technology: red colour lines are invisible areas, green colour lines are visible areas

By analyzing data from fig. 1 we can make next conclusions:

- at UAV flight on 4400 m distance the mountain with 250 m height is the highest obstacle 1600 m away from point A;
- the hill with 50 m height is the highest among hills 1100 m away from point A;
- the cruising speed of used wing-shaped "Trimble UX5 HP" UAV [9] is 24 m/sec;
- the widths of the largest depression in point of 1600-1700 m from away A and in point of 2900-3100 m from away A are from 100 m till 200 m;
- the estimated flight time these depressions are from 5 till 10 sec.

By using these date, we can estimate that the minimum permissible safety height of UAV flight in regime of the terrain following taking into account UAV speed change is ≈ 50 m.

The probability of UAV battle task realization

Now, let's consider and estimate the probability (a success level) of UAV reconnaissance flight realization.

Let's write the expression of an objective function of successful realization of one battle task based on one UAV application [8].

Then, for the battle conditions, we get the next expression:

$$P_{suc}(t) = K_{per}(t)\cdot K_{env}(t)\cdot P_{unf}(t)\times \times P_{im}(t)\cdot P_{hid}(t)\cdot P_{inf}(t)\cdot P_{unaf}(t). \quad (3)$$

We don't take into account correlations between factors in (3). Here:

$K_{per}(t)$ is the factor of personnel combat readiness for the battle tasks realization;

$K_{env}(t)$ is the factor of nature features (mountainous landscape, wind etc.);

$P_{unf}(t)$ is a probability of UAV fault-free operation;

$P_{im}(t)$ is a probability of objects and events identification;

$P_{hid}(t)$ is a probability of hidden UAV operation;

$P_{inf}(t)$ is a probability of information transfer to central post;

$P_{undes}(t)$ is a probability of UAV un-destruction.

For getting the specific expressions in (3) we need to choose the theoretical laws of random values distribution. In considered case we can choose exponential and normal distribution laws [2–4]. At the same time, for determination of the values of coefficients and probabilities in objective function (3) we need to use empirical data obtained, for example, in tactical exercises.

In case of realization of the M events of battle support by using one UAV, the probabilities of successful realization of the indicated events are determined by formula

$$P_{sucM}(t) = \prod_{i=1}^{M} P_{suci}(t),$$

In case of realization of the K events of battle support from Z events we can use Bernoulli's formula [4]:

$$P_{sucKZ}(t) = C_{KZ} \cdot P_{sucK}(t) \cdot [1 - P_{suc}(t)]^{Z-K},$$

where C_{KZ} is the number of combination of executed battle support events

$$C_{KZ} = \frac{Z!}{K!(Z-K)!}.$$

The guaranteed probability $P_G(Z,t)$ of successful realization Z events of UAV battle support in combat task conditions can be determined by using Poisson's formula [4]:

$$PG(Z,t) = \exp(-\lambda \cdot t) \cdot \sum_{k=0}^{Z} \frac{(\lambda \cdot t)^k}{k!},$$

where $\lambda = 1/\mathrm{T}$, T is average time of battle task realization.

Let's carry out specific calculations for practice event with conditions described in [6] (fig. 1).

Let's assume, that personal is ready at all to realize combat task, that is, $K_{per}(t) = 1$.

The reconnaissance event is realized in conditions of mountainous difficult broken relief of the terrain (see fig. 1).

Given region is characterized by leap direction and speed of air flow till 15-20 m height, and by unstable state of atmosphere till 100 m height. The UAV has obstacle's sensors.

The UAV's frame is made on based of very firm and light composite fiber carbon material. This UAV's frame can be stand high overloads and can execute spin round. Based on the expert judgements and height relief (fig. 1) we can assume that $K_{env}(t) = 0{,}90$.

The UAV used by us has high reliability [7], therefore $P_{unf}(t) = 0{,}92$.

UAV has high-precision optics, and it provides a high probability of events and objects identification, that is $P_{im}(t) = 1$.

By using the results of investigations in [9,10,11], we determine a probability of UAV hidden operation $P_{hid}(t) = 0{,}80$.

Taking into account that the distance of information transfer is less 5000 m, then we can assume that the probability of information transfer to central post is $P_{inf}(t) = 1$.

Taking into account that UAV executes flight not above enemy region then the probability non-destruction of UAV is $P_{unaf}(t) = 1$.

Thereby, taking into account above obtained parameters and coefficients in (1) we can determine the probability of successful realization (level realization) of reconnaissance task in conditions of mountainous difficult broken relief of the terrain:

$$P_{suc}(t) = 1 \cdot 0{,}90 \cdot 0{,}92 \cdot 1 \cdot 0{,}80 \cdot 1 \cdot 1 = 0{,}66$$

or

$$\mathrm{Psuc(t)} = 66\%.$$

Mountainous very difficult broken relief of the terrain and atmospheric meteorological conditions causes such not high probability;

When N identical UAVs execute one battle task [8] then we have

$$P_{suc}(t) = 1 - \prod_{i=1}^{N} \left(1 - P_{suci}(t)\right)$$

When $N = 2$ UAVs, then $P_{suc}(t) = 88$ %.

When $N = 3$ UAVs, then $P_{suc}(t) = 96$ %.

Thereby, 3 UAVs are sufficient for successful, with high probability level, execution of combat reconnaissance task.

Conclusion

Thus, the numerical estimation method of a combat task success of UAV reconnaissance flight in mountainous battle condition has been developed.

For specific conditions of the mountainous difficult broken relief of one of the terrain of the Azerbaijan Republic, it is determined that the probability of successful execution of combat reconnaissance task by using one UAV is 66%. 3 UAVs are sufficient for successful, with high probability level (96%), execution of combat reconnaissance task.

The calculations have shown, that the minimum permissible safety height of UAV flight in regime of the terrain following taking into account given parameters is ≈ 50 m.

Obtained results can be useful when determination of the application limits of UAV complexes in the system of execution of the combat support tasks of troops.

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Кількісний метод оцінки виконання розвідувального завдання БПЛА в бойовій обстановці в гірських умовах

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Чисельна оцінка виконання бойового завдання в гірському районі з використанням безпілотного літального апарата (БПЛА), дуже важлива для планування бойових операцій на театрі військових дій. У статті розглянуто та запропоновано метод кількісної оцінки успішності виконання заходів бойового забезпечення військ при застосуванні БПЛА з розвідувальними цілями в бойовій обстановці. Цей метод заснований на імовірнісному підході. Бойове забезпечення – це є комплекс дій, здійснюваних з метою створення сприятливих умов для успішних бойових дій і ослаблення дій ворога в будь-яких умовах. Бойове забезпечення включає розвідку, радіоелектронну боротьбу; тактичну маскування; інженерне забезпечення; радіаційний, хімічний і біологічний захист; контроль прицілювання і астрономо-геодезичне забезпечення; гідрометеорологічне забезпечення; охорону. Визначено мінімально допустиму висоту польоту БПЛА, використовуючи технологію геоінформаційних систем (ГІС). У статті розглянуто лише тактичний розвідувальний політ БПЛА. Для вирішення цього завдання враховані різні вхідні параметри: заходи бойового забезпечення, що виконуються військами; заходів бойового забезпечення, що виконуються БПЛА з розвідувальною метою; тактико-технічні характеристики БПЛА; умови експлуатації БПЛА; характеристики гірського ландшафту. Розрахунки проведені для конкретних умов гірського складного рельєфу місцевості в одній з обраних областей Азербайджанської Республіки.

Ключові слова: безпілотний літальний апарат; розвідувальний політ; імовірнісні показники; географічна інформаційна система; гірський регіон.

Количественный метод оценки выполнения разведывательного задания БПЛА в боевой обстановке в горных условиях

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Численная оценка выполнения боевого задания в горном районе с использованием беспилотного летательного аппарата (БПЛА) очень важна для планирования боевых операций на театре военных действий. В статье рассмотрен и предложен метод количественной оценки успешного выполнения мероприятий боевого обеспечения войск при применении БПЛА с разведывательными целями в боевой обстановке. Этот метод основан на вероятностном подходе. Боевое обеспечение –это комплекс действий, осуществляемых с целью создания благоприятных условий для успешных боевых действий и ослабления действий врага в любых условиях. Боевое обеспечение включает разведку, радиоэлектронную борьбу; тактическую маскировку; инженерное обеспечение; радиационную, химическую и биологическую защиту; контроль прицеливания и астрономо-геодезическое обеспечение; гидрометеорологическое обеспечение; охранение. Определена минимально допустимая высота полета БПЛА используя технологию геоинформационных систем (ГИС). В статье рассмотрен только тактический разведывательный полет БПЛА. Для решения этой задачи учтены различные входные параметры: множество мероприятий боевого обеспечения, выполняемых войсками; множество мероприятий боевого обеспечения, выполняемых БПЛА с разведывательной целью; множество тактико-технических характеристик БЛА; множество условий эксплуатации БПЛА; множество характеристик горного ландшафта. Расчеты проведены для конкретных условий горного сложно-пересеченного рельефа местности в одной из выбранных областей Азербайджанской Республики.

Ключевые слова: беспилотный летательный аппарат; разведывательный полет; вероятностные показатели; географическая информационная система; горный регион.