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A METHOD OF SELECTING AN UNMANNED AERIAL VEHICLE FOR THE TASK COMPLETION BASED ON A PRIOR EVALUATION OF IMAGE QUALITY

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Abstract

The article is devoted to the topic of current interest, namely the selection of unmanned aerial vehicle (UAV) to perform the task of a prior evaluation of image quality. The article analyzes the current condition of UAVs development and the range of tasks that are assigned to them. It is emphasized that the main task of a UAV at the present stage is aerial photography, the result of which is obtained images of the Earth's underlying terrain in a target area. The basic approaches to the aerial photography quality evaluation were considered. Their advantages and disadvantages were highlighted. The main quality performance criteria of photography by means of UAV were introduced, the most relevant ones were picked out for the task accomplishment. The evaluation of the aerial photography quality by using UAVs is presented as a multi-criteria decision-making task. The modern approaches to optimization of multicriteria solutions were reviewed and there was introduced an acceptable optimization model, with the help of which it became possible to automate the selection of UAV type for the assigned task. The main obtained results were analyzed and the steps of future research for solving the given tasks were developed.

Keywords: unmanned aerial vehicle; quality performance criteria for assigned tasks accomplishment; multicriteria; decision theory

1. Introduction

The Class I UAVs are most commonly aimed for aerial surveillance and reconnaissance of areas (distinct sites). The main results of these tasks accomplishment are images. Thus, the result of decoding images obtained by using UAVs is the background for successful completion of the tasks.

Currently, the planning of UAVs use is carried out without considering the required quality of the received images, which can result in obtainment of uninformative images and failure to complete the tasks. Therefore, the objective of selecting UAVs to perform the assigned tasks by the prior evaluationn of the images quality is relevant.

2. Analysis of the research and publications

Many scientific papers of foreign and domestic scientists were devoted to the issues of evaluating the efficiency of using UAVs and the methods and techniques of selecting UAVs for performing various functional tasks.

Thus, the issues of evaluation of the obtained images quality are discussed in detail in reference [1]. It analyzes the main characteristics of the received images and various approaches to improve the quality of these images. Nevertheless, reference [1] considers the approaches approved for space photography, but there is no analysis to specify the process of obtaining images when carrying out photography using UAV. Reference [2] studies the issue of the effect of contrast on image quality, whereas reference [3] is devoted to the problem of determining the viewing area to perform photo shooting. Still these publications did not address the issue of aerial photography using UAVs.

The features of the obtained images decoding are considered in reference [4], but at the same time the possibilities of selecting the UAV which is expedient to be used for the fulfillment of the particular tasks under given photography conditions are not taken into account. Reference [5] is devoted to the process of planning the UAVs application and the analysis of key criteria that affect the quality of task performance using UAVs. Reference [6] discusses in detail the requirements for image quality and appropriate resolution to perform the tasks.

In references [7,8] the general concepts of decision-making system and multi-purpose optimization are investigated. Common approaches to addressing these issues are analyzed. References [9-11] are devoted to multicriteria problems and models of multicriteria optimization. In [12] the main known approaches to minimizing vector performance criteria are discussed in detail. Their disadvantages and advantages are distinguished depending on the value of criteria and their quantity.

Article [13] deals with how to obtain a generalized criterion. This paper also discusses in detail the multiplicative convolution and its advantages and disadvantages compared to other approaches. In [14] the possibilities of applying a nonlinear compromises scheme and its advantages over other known methods are considered in detail.

At the same time, the aforementioned references did not pay sufficient attention to the aerial photo shooting using UAV. The problem of choosing UAVs to improve the quality of the obtained image and the application of multicriteria optimization to select UAVs to fulfill the tasks were not considered. Thus, we can conclude that the issue of UAVs selection for the fulfillment of the assigned objectives by the prior evaluation of the image quality is relevant.

The purpose of the article is to develop a method for selecting UAVs based on the prior evaluation of the obtained images, which will ensure the performance of the flight task and sufficient quality of the obtained images for their further decoding.

3. Problem statement

Suppose we have N types of UAVs that can be used to complete the tasks. Each of these UAVs has the predetermined criteria for flight task performance, where R stands for resolution, P_{rec} – for probability of object recognition in the image, H_{fl} – for altitude, and S_k stands for frame area.

It is necessary to define a generalized criterion for each of Y_i UAVs that will satisfy the following conditions:

$$Y_i(R, P_{rec}, H_{fl}, S_k) \Rightarrow \begin{cases} R \to min, \\ P_{rec} \to max, \\ H_{fl} \to max, \\ S_k \to max. \end{cases} \quad (1)$$

Taking into account expression 1, it is necessary to evaluate the ratio of the required resolution for the task completion (by Johnson criterion) and the resolution of i UAV which is $R_i = R\left(min\, Y_i\left(R, P_{rec}, H_{fl}, S_k\right)\right)$. Based on this, it is necessary to select the UAV implementing the result of the obtained evaluation.

4. Program structure and calculation results

When performing a UAV survey, it is very important to get an image of acceptable quality that will ensure proper decoding. After all, the work of a photo interpreter is significantly dependent on the quality of images and the ability to decode them. The process of decoding images can be represented in the form of the algorithm, which is shown in Fig. 1.

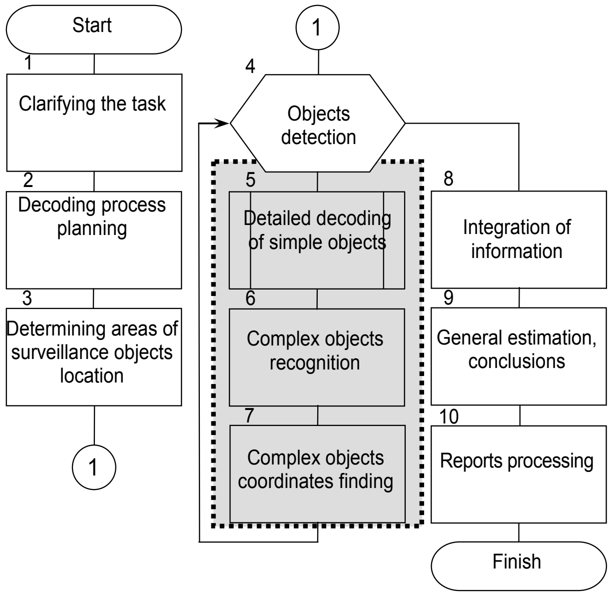

Fig. 1. Image decoding algorithm

As we can see in Fig. 1 the main steps in the process of decoding images obtained by using UAVs are the detection of objects in the image (block 4), their recognition (block 6) and location finding (block 7). Therefore, the quality of the obtained images plays a significant role for decoding them.

To solve the problems with the use of UAVs, let us determine the main criteria that will affect the quality of the images received and the quality of the tasks accomplishment. These criteria are supposed to find: photo shooting height, image resolution, image recognition probability, and coverage area (frame area).

The introduced method for selecting UAVs is based on regarding certain criteria and finding an alternative compromise solution and includes the following 5 steps.

For step 1 we need to calculate resolution of the image R and its contrast K under the given conditions. The resolution depends on photo shooting height H_{fl}, focal length of payload f, linear size of payload matrix l_m, number of pixels along the of payload matrix n, and deflection angle of the optical axis from nadir θ that is calculated by the expression [1]:

$$R = \frac{l_m \cdot H_{fl}}{n \cdot f \cdot cos\theta}. \quad (2)$$

The contrast of the image depends on brightness of the object background M_o and surface brightness M_s that is calculated by the expression [6]:

$$K = \frac{M_o - M_s}{M_o + M_s}. \quad (3)$$

During stage 2 the probability of recognizing the object of the image is calculated. It depends on resolution of UAV payload R, required resolution R_0, and contrast K, that is determined by the expression [6]:

$$P_{rec} = e^{\left[\frac{ln\alpha}{log\left(\frac{1+K}{1-K}\right)}\cdot\left(\frac{R}{R_0}\right)^2\right]}. \quad (4)$$

After that, using expressions (2-4), the altitude of the flight is determined considering contrast K, recognition probability P_{rec}, image resolution R, and required resolution R_0:

$$H_{fl} = \sqrt{\frac{log\left(\frac{1+K}{1-K}\right)}{ln\alpha}\cdot ln(P_{rec})}\cdot\left(\frac{f \cdot R_0 \cdot cos\theta \cdot n}{l_m}\right). \quad (5)$$

Then we should calculate the frame area, which depends on height of photo shooting $H_{пол}$, viewing angle of photo equipment γ, and deflection angle of optical axis from nadir θ during photo shooting using UAV [3]:

$$S_k = \left(\frac{2 \cdot H_{fl} \cdot tg\left(\gamma/2\right)}{cos\theta}\right)^2. \quad (6)$$

Step 3 of the introduced method is the choice of optimization scheme. Therefore, after calculating the suggested partial criteria, it is necessary to determine a generalized criterion that will reflect the compromise decision regarding the task of the flight. To proceed with the work, we will use decision theory.

The selection of the optimality principle is a decisive step in solving multicriteria decision-making problems. Taking into account the studies described in [1,12], the choice of a compromise scheme includes the following steps: determining the area of compromise, selecting the scheme of compromises, and normalizing the partial criteria with regard to their priorities.

Determining the area of compromise. In vector optimization problems, contradictions between the defined criteria can occur. Though, the area of permissible solutions is divided into two parts: the area of agreement and the area of compromises (Pareto area). In the area of compromises, there are contradictions between the criteria: in order to improve the quality of the solution by some criteria, it is necessary to calculate the quality loss by the other ones (at least by one). The optimal solution can only belong to the area of compromise.

Selecting the scheme of compromises. The selection of one or another principle of optimality transforms the vector problem of decision making to the scalar (scalarization of the problem) one. Multicriteria optimization methods allow us to effectively solve problems of a quite wide class [12].

Normalizing the partial criteria with regard to their priorities. As a rule, partial optimization criteria have different physical nature, and therefore different physical dimensions. In addition, one part of them can be maximized and the other one can be minimized. Thus, along with normalization, the problem of bringing them to the only way of extremization often arises. Also, partial criteria are usually of different value. This should be taken into account when choosing the optimal solution, giving preference to more important criteria.

According to the results of analysis and consideration of the specificity of the assigned tasks, a nonlinear scheme of compromises was chosen for further work [11,12]. It is a scalar criterion of a special kind in which the partial criteria are reduced. Unlike other approaches, a nonlinear compromise scheme allows us to find a solution that cannot be improved (i.e. it is optimal by Pareto area) but it is a unimodal (i.e. single) solution.

The following step is a normalizing of the criteria to bring their value to the same form using the normalizing on the basis of stimulants (criteria that are maximized) and destimulants (criteria that are minimized):

$$\mu_R = \frac{R^{min}}{R}, \quad \mu_{P_{rec}} = \frac{P_{rec}}{P_{rec}^{max}}, \quad \mu_{H_{fl}} = \frac{H_{fl}}{H_{fl}^{max}}, \quad \mu_{S_k} = \frac{S_k}{S_k^{max}}. \quad (7)$$

There was performed the modeling how the normalized criteria depend on height in the MathCAD software environment (Fig. 2) for the given conditions:

1) The selected type of UAV - PD-1;
2) payload - Sony Alpha 7R camera;
3) contrast $K = 0{,}75$;
4) photo shooting is carried out in nadir $\theta = 0$;
5) the height varies from 0 to 2300 meters.

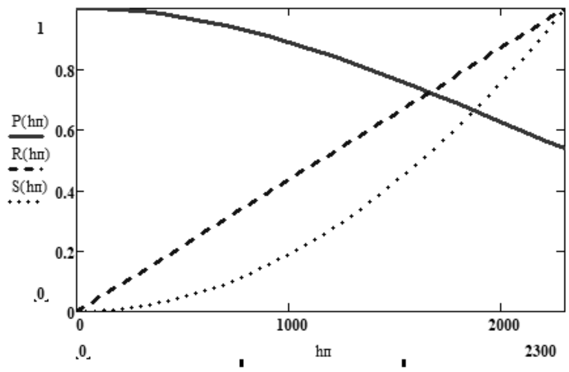

Fig. 2. The results of normalized criteria modeling

The modeling results reflect the existing intersection area, which is the optimal solution for the task.

Step 4 is the calculation of the generalized criterion for the selected nonlinear scheme of compromises in terms of equality of weighting factors:

$$\lambda_R = \lambda_{P_{rec}} = \lambda_{H_{fl}} = \lambda_{S_k} = 0{,}25 \ , \qquad (9)$$

$$Y_i(\lambda_i, \mu_i) = \lambda_R \cdot (1 - \mu_R)^{-1} + \lambda_{P_{rec}} \cdot \left(1 - \mu_{P_{pos}}\right)^{-1} + $$
$$+ \lambda_{H_{fl}} \cdot \left(1 - \mu_{H_{nom}}\right)^{-1} + \lambda_{S_k} \cdot \left(1 - \mu_{S_k}\right)^{-1}.$$

The result of modeling the behavior of a certain generalized criterion with the increasing height in the MathCAD software environment is presented in Fig. 3.

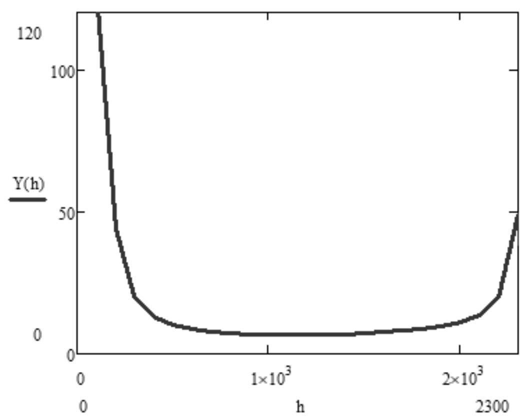

Fig. 3. The results of generalized criterion modeling

Step 5 is to evaluate the results. To do this, we will define the minimum value of the generalized criterion and the resolution value corresponding to the given generalized criterion:

$$\widetilde{Y}_i(\lambda_i, \mu_i) = \min Y_i(\lambda_i, \mu_i), \quad i = \overline{1, n} \ , \qquad (10)$$

$$R_i = R\left(\widetilde{Y}_i(\lambda_i, \mu_i)\right) \ . \qquad (11)$$

To evaluate the results obtained, it is necessary to compare the obtained resolution with the required resolution (in accordance with the tasks assigned to a photo interpreter). To determine the required resolution, it is preferable to select the Johnson criterion [13]. This criterion determines the resolution requirements based on the specifics of the task (object detection, recognition, or identification) and the geometric dimensions of the aerial object. Table lists the resolution criteria for each of the requirements and provides the required probability of completing the task.

Table

The Resolution Requirements for Targeted Intelligence Equipment by *Johnson* Criterion

Object type	Critical object size, m	Resolution requirements R0, m/pixel			
		Detection	Identification		
			Type	Description	Technical analysis
Human	0,6	0,13	0,11	0,04	0,02
Motor veficle	1,5	0,32	0,21	0,1	0,06
Truck transport	2,5	0,4	0,31	0,16	0,09
House	3,5	0,7	0,55	0,19	0,1
Warehouses	4	0,8	0,62	0,22	0,12
Large building	4	0,8	0,62	0,22	0,12
Aircraft	4,5	0,9	0,68	0,28	0,15
Bridge	6	1,2	0,98	0,34	0,21
Airport facility	6	1,2	0,98	0,34	0,21

Thus, it is necessary to determine the ratio of the required resolution to perform the task (according to Table) and the calculated resolution according to the value of the generalized criterion:

$$\xi_i = {R_0}\Big/{R_i\left(\widetilde{Y}_i(\lambda_i, \mu_i)\right)} \Rightarrow \begin{cases} if \ \ \xi \geq 1, & result \ \ positive, \\ if \ \ \xi < 1, & result \ \ negative. \end{cases} \qquad (12)$$

Expression (12) enables us to make conclusions as for the possibilities of the tasks accomplishment by means of one or another type of the available UAVs.

For example, the calculation was made for the following conditions:

a) three types of UAVs are available - "Leleka-100", "Furia-A1C", "PD-1";

b) the task is to identify the object "person" by type;

c) photo shooting conditions – day time, clear weather.

The calculations having been made and the modeling of the obtained results in the MathCAD software environment showed the following values of the generalized criteria, which are presented in Fig. 4:

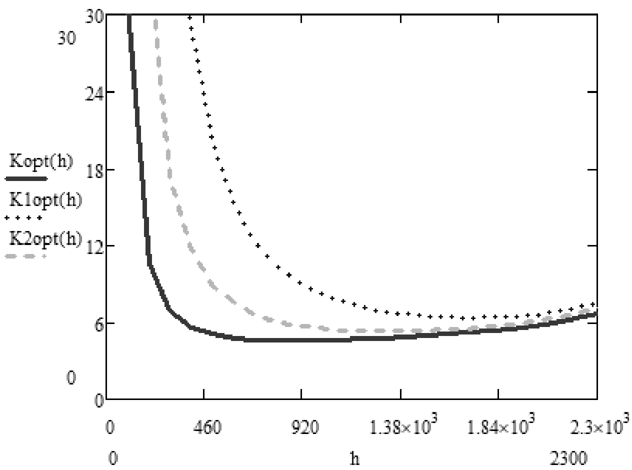

Fig. 4. The results of generalized criterion modeling for different UAVs

After processing the values of the generalized criterion, the following results were obtained:

$$\xi_1 = R_0 \Big/ R_1\left(\tilde{Y}_1(\lambda_1, \mu_1)\right) = 0{,}72,$$
$$\xi_2 = R_0 \Big/ R_2\left(\tilde{Y}_{2i}(\lambda_2, \mu_2)\right) = 1{,}07, \qquad (13)$$
$$\xi_3 = R_0 \Big/ R_3\left(\tilde{Y}_3(\lambda_3, \mu_{3i})\right) = 1{,}19.$$

Thereby, it can be concluded that it is advisable to use only type 2 and type 3 of UAVs (“Furia-A1C” and “PD-1”), since type 1 will not provide the required quality of photography. Therefore, the UAV operator (a unit commander) will be able to choose the necessary UAV, which will ensure the maximum probability and accuracy of the assigned task completion, regarding objective factors (technical status of the available UAVs, readiness of personnel, uniformity of use of UAV technical resources, etc.).

6. Conclusions

The article introduces a method of selecting UAVs based on a prior image evaluation. The criteria to have been chosen for calculations are identified. The use of a nonlinear compromise scheme for further studies is justified. The results obtained will significantly reduce the impact of the “human factor” on the choice of UAVs to accomplish the assigned task. With the help of the developed method, a unit commander will be able to quickly and accurately determine the capabilities of the UAV available in the unit and make conclusions as for the expediency of their use under the given conditions. Thus, it is expected to reduce the decision making time to select the type of UAV and increase the probability of successful completion of the task.

The prospects of future research are:

1). Considering the qualification of the operator-interpreter and the influence of time and number of images on the successful decoding;

2). Regarding the state of the environment (cloudiness, air fog, etc.).

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Спосіб вибору безпілотного літального апарата для виконання цільового завдання за апріорною оцінкою якості знімків

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Мета: розробка способу вибору безпілотного літального апарату за апріорною оцінкою отриманих знімків, який забезпечить виконання польотного завдання та достатню якість отриманих знімків для їх подальшого дешифрування. **Методи:** розглянуто метод багатокритеріальної оптимізації процесу вибору безпілотного літального апарату. **Результати:** запропоновано спосіб вибору безпілотного літального апарату за апріорною оцінкою знімка. **Обговорення:** за допомогою розробленого способу можна швидко та точно визначити можливості наявних в підрозділі безпілотних літальних апаратів і зробити висновки щодо доцільності їх використання за заданих умовах. Обґрунтовано використання нелінійної схеми компромісів для подальших досліджень.

Ключові слова: безпілотний літальний апарат, показники якості виконання поставлених завдань, багатокритеріальність, теорія прийняття рішень

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Способ выбора беспилотного летательного аппарата для выполнения целевого задания по априорной оценке качества снимков

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Цель: разработка способа выбора беспилотного летательного аппарата за априорной оценкой полученных снимков, который обеспечит выполнение полетного задания и достаточное качество полученных снимков для их дальнейшего дешифрования. **Методы:** рассмотрено метод многокритериальной оптимизации процесса выбора беспилотного авиационного летального аппарата. **Результаты:** предложенный способ выбора беспилотного летального аппарата за априорной оценкой снимка. **Обсуждение:** с помощью разработанного метода можно быстро и точно определить возможности имеющихся в наличии в подразделениях беспилотных летальных аппаратов и сделать выводы о целесообразности их использования в заданных условиях. Обосновано использование нелинейных схем компромиссов для дальнейших исследований.

Ключевые слова: беспилотный летательный аппарат, показатели качества выполнения поставленных задач, многокритериальность, теория принятия решений

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