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SEGMENTATION OF IMAGE FROM A FIRST-PERSON-VIEW UNMANNED AERIAL VEHICLE BASED ON A SIMPLE ANT ALGORITHM

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The object of this study is the process of image segmentation from the First Person View (FPV) of an unmanned aerial vehicle (UAV). The main hypothesis of the study assumes that the use of a simple ant algorithm could ensure the necessary quality of the segmented image.

The segmentation method, unlike the known ones, takes into account the number of ants in the image, weight, initial amount and evaporation rate of the pheromone, the "greediness" of the algorithm and provides:

– preliminary selection of individual channels of the Red-Green-Blue (RGB) color space;

– preliminary placement of ants according to the uniform law;

– determining the routes of ants;

– taking into account the attractiveness of the route for each ant;

– change (adjustment) in the concentration of ant pheromones;

– calculation of the probability of movement (transition) of the ant on the movement route;

– determination of the objective function at the j-th iteration and its minimization;

– determining the coordinates of the route of movement (movement) of ants;

– verification of the fulfillment of the stop condition;

– determination of the best routes found by ants;

– calculation of the brightness of the pixels of the segmented image in each channel of the RGB color space;

– further combining the results of channel segmentation.

An experimental study of image segmentation from UAV FPV based on a simple ant algorithm was conducted. The specified object of interest on the segmented image has a certain structure, unevenness of the contours, and can be further used for decoding, categorization, etc. Unlike the object of interest, the background ("garbage" objects) in the segmented image do not have a stable structure and can be further filtered out.

It has been established that the segmented image by the known method based on the gradient module has a low contrast value, there are gaps in the segmented pixels of the object of interest. A segmented image using a method based on a simple ant algorithm is free from that drawback

Keywords: UAV FPV, segmentation, ant movement, pheromone, route attractiveness, objective function

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1. Introduction

The current stage of development of unmanned aerial vehicles is characterized by the massive use of UAV FPVs [1, 2]. UAV FPVs are used to solve various tasks, for example [1, 3]:

– military domain (intelligence, strike missions, etc.);
– demining;
– environmental monitoring;
– protection of the state border;
– oceanography and marine research;
– shipping control;
– cinematography and entertainment, etc.

Unlike conventional unmanned aerial vehicles, UAV FPVs are more maneuverable, have lower cost (purchase and maintenance). At the same time, unlike conventional UAVs, the on-board UAV FPV camera is simpler and does not have such a high resolution. This is especially true of impact UAV FPVs [4]. The specified features of UAV FPVs certainly affect the quality of image processing in general and the quality of an important stage of processing – image segmentation, in particular.

On the other hand, the requirements for completeness and accuracy of information from UAV FPVs remain as strict as for conventional unmanned aerial vehicles. Known methods of image segmentation from airborne surveillance systems are developed mainly for segmentation of images from space optical-electronic surveillance systems (for example, [5]). Such methods do not take into account the peculiarities of image formation in UAV FPV systems. Therefore, research on image segmentation from UAV FPVs is relevant.

2. Literature review and problem statement

In [6], the results of research on the method of segmentation of images from an unmanned aerial vehicle are reported. It is shown that the method involves a combination of textural features of objects using connected components. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the focus of the method on the segmentation of images of agricultural fields. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [7], the results of research on the segmentation method for extracting local homogeneity and texture, taking into account the color in the image, are given. It is shown that the method involves the representation of homogeneities and textures by Gaussian mixture models. The advantage of [7] is the ability of the method to automatically select a model by removing redundant segments. This slows down the requirements for predetermining the exact number of segments in an image. But the quality of image segmentation remains unresolved. The reason for this may be the orientation of the method to represent homogeneities and textures only by mixtures using only Gaussian models.

In [8], the results of research on the method of video stream segmentation of images from an unmanned aerial vehicle using an RGB camera are reported. It is shown that the method [8] provides automation of segmentation and a high degree of segmentation quality. But the questions regarding the quality of image segmentation at medium and long distances remained unresolved. The reason for this may be the application of the method only when solving the task of landing an unmanned aerial vehicle at short distances.

In [9], the results of research on the segmentation method, which is based on the region expansion algorithm, are given. It is shown that the method [9] involves combining objects of interest on images or combining pixels on images. The advantage of [9] is relatively fast performance but the parameters of the method must be configured in advance. The questions regarding the quality of segmentation of images of small objects remained unresolved. The reason for this may be the focus of the method on the segmentation of multispectral images obtained from UAVs for solving tasks in the field of forestry. This leads to the need to pre-set the segmentation parameters, which makes it impossible to fully automate the segmentation process.

In [10], the results of research on the categorization of images obtained from unmanned aerial vehicles are reported. It is shown that the method [10] involves the use of machine learning algorithms. Namely, one of the most popular for solving the categorization problem – the method of ensemble decision trees, using an object-oriented approach. The advantages of segmenting images from unmanned aerial vehicles using [10] are the simplicity of the method and high speed. But questions regarding the application of the method to a wide class of objects of interest remained unresolved. Thus, paper [10] provides image categorization with a limited list of objects of interest for categorization, namely: asphalt, road, roof, and vineyard.

In [11], the results of research on a method for observing coral reefs using unmanned aerial vehicles, which are integrated with digital hyperspectral light sensors, are given. It is shown that the method [11] involves the use of machine learning algorithms. The advantage of [11] is the speed and continuity of geospatial image processing. The segmentation results allow categorization not only by type of coral but also determining the signs of their discoloration. But questions remained unsolved regarding the quality of the combination of different data sets: hyperspectral images and images in the RGB color space with data taken in air and in water.

In [12], the results of research on the use of the method of support vectors in the segmentation and categorization of images obtained during aerial photography of the earth's surface by unmanned aerial vehicles are proposed. It is shown that the method [12] consists in combining a machine learning model with a Support Vector Machine (SVM) (support vector trainer) and images of the specified type. The categorization of objects of interest is performed using the support vector method based on the results of the segmentation performed using the edge segmentation method and the full lambda algorithm. The main advantage of [12] is high accuracy of categorization, but under the condition of segmentation of input images of high resolution. However, the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the multi-stage nature of the proposed approach, in which the boundary selection method is used in the first stage. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [13], the results of research on the Random Forest method for categorization of grass, trees, gravel, sand, and water surface in images from unmanned aerial vehicles are reported. It is shown that the advantage of [13] is the rather high accuracy of the categorization of the specified objects of interest. But the questions regarding the quality of image segmentation for a wide class of objects of interest remained unsolved. The reason for this may be a limited list of data objects of interest, and, as a result, limitations in the processing of images of the earth's surface. That is, paper [13] is relevant only for images of the annual landscape. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [14], the results of research on the online decision-making tree method for increasing the gradient are given. It is shown that the Gradient Boosted Regression Trees (GBDT) method is proposed for images of any earth's surface. The advantage of [14] is the possibility of segmenting images with the presence of different types of objects and the possibility of processing objects of interest with different deformations. But the questions regarding the determination of input parameters for segmentation remained unresolved.

In [15], the results of research on the segmentation of images of the Earth's surface obtained from unmanned aerial vehicles are given. It is shown that it is expedient to use the combination of super pixels with multifunctional distance measurement. The advantage of [15] is the requirements for choosing a super pixel, the criteria of which are both the shape and features of the plane, as well as textural and spectral features. But the issues regarding the fulfillment of the requirement to indicate the number of regions and the subsequent relationship between the achievement of the selected number of regions and the merger remained unresolved. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [16], the results of research on the segmentation of images acquired during the filming of mango ecosystems with the help of unmanned aerial vehicles are reported. It is shown that it is necessary to use the Simple Linear Iterative

Clustering (SLIC) method. The advantage of [16] is the high accuracy of categorization when fulfilling the requirement for demarcating regions of the input image with similar information about texture and color in the specified area of the image. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the inflexibility of categorization results and the limit of the volume of the data set. An option to overcome the relevant difficulties is to develop a segmentation method using other algorithms.

In [17], the results of research on the segmentation of images from unmanned aerial vehicles are given. It is shown that a method based on the textural features of the local binary pattern and the improved mean shift is used. The essence of [17] is the use of texture features and borders on images. The advantages of [17] are the absence of the need to determine the number of clusters and segmentation of both panchromatic and hyperspectral input images at the beginning of the method. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this can be high computational costs when searching for the average shift vector and sensitivity to “outliers”, that is, small areas on the image that do not carry useful information about the semantic structure of the image but require their processing. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [18], the results of research on the segmentation of images from unmanned aerial vehicles are given. It is shown that it is expedient to apply the method of merging areas with the use of several unification criteria. The advantage of [18] is the use of a large number of unification criteria, which were developed to increase the accuracy of segmentation. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the possibility of errors in the segmentation of images, which is the result of the presence of shortcomings in various merging criteria.

In [19], the results of research on image processing from unmanned aerial vehicles for solving problems in the interests of agriculture are reported. It is shown that it is reasonable to use an improved segmentation method using a deep segmentation network based on the United Network (U-Net) neural network. The essence of [19] is to replace the subpixel convolutional layer of the transposed convolutional layer in the U-Net upsampling unit to prevent the loss of information about the boundary structure. The advantage of [19] is improved pixel accuracy and, as a result, smoothness of all boundaries. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the time and resources required to pre-process images from the entire available set obtained from an unmanned aerial vehicle to train the network.

In [20], the results of research on the mapping of various groups of vegetation on the earth’s surface are presented. It is shown that it is advisable to use deep learning methods for segmentation of images from unmanned aerial vehicles. In [20], the use of the architecture of a convolutional neural network within the framework of transfer learning was proposed, and the conducted experiments showed that the combination of the Residual Neural Network 50 (ResNet 50) and Segmentation Network (SegNet) architectures is the best. The main advantage of [20] is the high accuracy of segmentation results. But questions about the quality of image segmentation remained unresolved. The reason for this may be the orientation of the method on the need to increase the set of training data, equipment requirements, and calculation time compared to machine learning classifiers.

In [21], the results of research on the analysis of semi-controlled models that solve the problem of segmentation on aerial photographs obtained with the help of unmanned aerial vehicles are reported. Graph-based label propagation architectures, pseudo-labeling architectures, and U-Net-Autoencoder architectures with deep learning are considered. The advantage of [21] is a significant improvement in the performance of each of them when increasing the specified data for training. But questions about the quality of image segmentation remained unresolved. The reason for this may be the requirement for continuous training in order to obtain high rates of segmentation results.

In [22], the results of research on the selection of camouflaged military equipment on images obtained from space surveillance systems are presented. It is shown that the method [22] consists in the use of a genetic algorithm in order to solve the problem of segmentation on the materials of space shooting. The advantage of [22] is the selection of both masked and unmasked objects of interest in the resulting image. But questions about the quality of segmentation of images from unmanned aerial vehicles remained unresolved. The reason for this may be limitations in image processing of only the RGB color space.

In [23], the results of research on the segmentation of space shooting materials are reported. It is shown that it is necessary to use one of the most known methods of swarm intelligence, namely the particle swarm algorithm. The advantage of [23] is taking into account the complex structure of input images, which is inherent in images from space surveillance systems. But questions about the quality of segmentation of images from unmanned aerial vehicles remained unresolved. The reason for this may be that the segmentation operation is performed only for images from space-based footage and the peculiarities of images from unmanned aerial vehicles are not taken into account.

In [24], the results of research on the improved method of segmentation of complex color images are presented. It is shown that the essence of [24] is the use of the ant colony optimization algorithm for the selection of contours of objects of interest on the materials of space photography. The advantage of [24] is an increase in segmentation accuracy compared to segmentation by known methods. But questions about the quality of segmentation of images from unmanned aerial vehicles remained unresolved. The reason for this may be the appearance of a large number of small contours in the resulting image, that is, re-segmentation.

In [25], the results of research on the segmentation of images acquired from unmanned aerial vehicles are reported. It is shown that the use of a two-stage method of selecting urban infrastructure objects is useful. The essence of [25] is the segmentation of the input image at the first stage by the improved method of the border detector and processing at the second stage by the method of searching for analytically specified primitives. The advantage of [25] is the high accuracy of selection of all elements of objects of interest. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the selection of only those elements that have geometric primitives of the straight line type and high computational and time costs.

In [26], the results of research on the segmentation of images of remote sensing of the earth are given. It is shown that it is expedient to use the well-known *k*-means clustering method. The essence of [26] is to refine the segments and analyze textural features in the image. The advantage of [26] is a significant reduction in segmentation time, but under the condition of correct selection of the initial clusters. But the questions regarding the quality of segmentation of low spatial resolution images remained unresolved. The reason for this may be the significant dependence of segmentation results on the choice of initial clusters.

In [27], the results of research on the C-means clustering method for segmentation of images obtained from remote earth sensing systems are reported. The essence of [27] is that fuzzy entropy and minimum Euclidean distance were used for pixel categorization. The advantages of [27] are the absence of distortions during segmentation and color change. But questions about the quality of segmentation of images from unmanned aerial vehicles remained unresolved. The reason for this may be the dependence of the results on the appearance of noise of various nature.

In [28], the results of research on the segmentation of images obtained from remote sensing systems of the earth are given. It is shown that it is expedient to use the improved method using fuzzy C-means clustering. The advantage of [28] is the stability of the textural component in the image. But questions about the quality of segmentation of images from unmanned aerial vehicles remained unresolved. The reason for this may be the dependence of the segmentation results on the appearance of heterogeneous noises in the input image.

In [29], the results of research on the method of structural categorization based on the values of the distance matrix for the components of the multidimensional description are reported. At the same time, characteristics are formulated in the form of one-dimensional distributions. It is shown that the method significantly reduces computational costs and effective categorization on the training data set. But questions about the quality of image segmentation from UAV FPVs remained unresolved, specifically low spatial resolution. The reason for this may be the difficulty of applying the proposed methods for segmenting images from unmanned aerial vehicles. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [30], the results of research on the comparative analysis of methods for detecting spectral anomalies in images from on-board systems of remote sensing of the Earth are presented. It is shown that the conducted analysis made it possible to choose a rational (one that is used under certain conditions) method of detecting spectral anomalies. But the questions about the quality of segmentation of images from an unmanned aerial vehicle remained unresolved. The reason for this may be the difficulty of applying certain methods for segmenting images from an unmanned aerial vehicle. An option to overcome the relevant difficulties is to develop a segmentation method using other algorithms.

In [31], the results of research on the image segmentation method based on the firefly algorithm are reported. It is shown that the method provides a certain quality of segmentation, but for images from space surveillance systems. But questions about the quality of segmentation of images from unmanned aerial vehicles remained unresolved. The reason for this may be that the application of the method based on the firefly algorithm to the segmentation of UAV FPV images requires additional research. An option to overcome the relevant difficulties is to devise a segmentation method using other algorithms.

In [32], the results of research on image clustering are given. It is shown that the method involves the use of an ant colony. In [32], it is claimed that the algorithm minimizes deterministic imperfections, in which clustering is considered an optimization problem. But questions about finding the global minimum or maximum of the objective function remained unresolved. An option to overcome the relevant difficulties is to develop a segmentation method using other algorithms.

Thus, our review of known methods for the segmentation of images from unmanned aerial vehicles demonstrated that the methods are mainly used for high-quality images. At the same time, the objects of interest for segmentation are planar objects, objects whose class is already known, etc. The direct application of known methods for the segmentation of images from UAV FPVs will not provide the required quality of the segmented image.

Therefore, subsequently, we shall conduct research on UAV FPV image segmentation based on a simple ant algorithm.

3. The aim and objectives of the study

The aim of our study is to segment the image from UAV FPV based on a simple ant algorithm. This will make it possible to ensure the UAV FPV image segmentation process with the necessary quality indicators.

To achieve the goal, it is necessary to solve the following tasks:

– to state the main stages of the method for segmenting an image from an UAV FPV based on a simple ant algorithm;

– to conduct an experimental study on UAV FPV image segmentation based on a simple ant algorithm.

4. The study materials and methods

The object of research is the process of UAV FPV image segmentation.

The main hypothesis of the study assumed that the use of a simple ant algorithm when segmenting an image from UAV FPV could ensure the required image quality.

The following limitations and assumptions were adopted during the research:

– the output image is an optical-electronic image from UAV FPV in the RGB color space;

– only one output image from UAV FPV is considered (not a sample of images);

– the procedure for processing the input image is classic and includes converting the image into digital form, geometric correction of the image, pre-processing of the image, etc.;

– the image is taken not in the direction of the earth's surface but in the direction of the air space;

– it is considered that the image from UAV FPV was acquired by a digital camera;

– the object of interest in the original image is an aerial object;

– there is only one object of interest in the original image;

– the image contains all service information received by the UAV FPV operator;

– the size of the objects of interest is smaller than the size of the background objects;

– it is assumed that the original image is undistorted;

– when comparing the devised method of UAV FPV image segmentation based on a simple ant algorithm to a known method, only visual quality assessment is used, quantitative quality indicators are not used in this study. This is the subject of further research;

– when comparing the devised UAV FPV image segmentation method based on a simple ant algorithm, the well-known method based on the gradient module was chosen as a known method;

– the following hardware was used for experimental research: laptop ASUSTeK COMPUTER INC model X550CC, 3rd Gen processor DRAM Controller – 0154, NVIDIA GeForce GT 720M;

– the following software was used to conduct experimental studies: high-level programming language and interactive environment for programming, numerical calculations, and visualization of results MATLAB R2017b;

– as ground equipment, equipment was chosen that allowed for high-quality signal reception, UAV control and real-time flight monitoring: FPV glasses, remote control, repeater, battery, and charging station [33];

– the bandwidth of the data transmission channel is chosen to be 27 MHz, which enables the transmission of a visual image with a size of (1500–750) pixels, which on average corresponds to the size of an image from UAV FPV.

The following general methods were used during the research:

– theories of probability and mathematical statistics;
– mathematical apparatus of matrix theory;
– methods of digital image processing;
– swarm methods;
– iterative methods;
– system analysis;
– differential calculus;
– integral geometry;
– methods of mathematical modeling;
– analytical and empirical methods of comparative research.

Skyzone SKY04X V2 with Organic Light-Emitting Diode (OLED) displays were used as FPV glasses [34]. Tactical and technical characteristics of Skyzone SKY04X V2 FPV glasses [34]:

– dimensions: 185×75×67 mm;
– weight: 267 grams;
– screen: OLED;
– resolution: 1280×960;
– viewing angle (diagonally): 46°;
– power: 720 mA at 12V;
– receiver: RapidMix SteadyView with a frequency of 5.8 GHz, 48 channels;
– video recorder: H264, 60 frames per second, MOV6Mbps.

FPV RC remote control (HP167-0067) [34] with characteristics:

– weight: 565 grams;
– display: 3.5 inches (128×64);
– number of channels: up to 12;
– radius of action: up to 25 km;
– refresh rate: 250 Hz.

As a repeater, the BattleBorn repeater was chosen with the following tactical and technical characteristics [35]:

– Helix 5.8 GHz video antenna (range 5.3–6.0 GHz, gain 14 dB, half-power beam width 30°): provides reception of a video signal from the UAV camera and video transmitter to the station;

– 915 MHz control antenna (gain 13 dBi, half-power beam width 45°) provides UAV control signal transmission at a distance of more than 20 kilometers, taking into account the characteristics of the terrain (line of sight);

– Foxeer video receiver at a frequency of 5.8 GHz: provides reception of a video signal through the antennas from the UAV camera;

– the Express Link Radio Source (ELRS) transmitter (2 W with built-in battery power): provides the transmission of the UAV control signal from the station to the UAV;

– Molicel 2s3p battery (7.4 v; 10500 mAh) in a shock-proof, moisture-proof case.

The selected battery for UAV FPV is 6S3P Samsung 40T3 with the following tactical and technical characteristics [35]:

– capacity: 12000 mAh;
– constant discharge current: 105 A;
– maximum charge current: 5 A;
– voltage: 22.2 V (nominal);
– size 21×70 mm.

The chosen protocol for information exchange is Digital Shot (DShot) developed by Betaflight (China, United States of America, Great Britain) [36]. The DShot protocol provides digital communication, eliminating the need for analog signals such as pulse-width modulation. This leads to an increase in signal accuracy, a decrease in noise interference, and an increase in reliability [36].

5. Results of research on UAV FPV image segmentation

5. 1. The main stages in the UAV FPV image segmentation method based on the ant algorithm

Taking into account the well-known classical formalization of the segmentation task, this formalization was used to segment the image from UAV FPV (expression (1) [22, 23]):

$$f(x,y) \rightarrow fs(x,y), \tag{1}$$

where $f(x, y)$ is the output image from UAV FPV; $fs(x, y)$ is the image after segmentation (segmented image).

The image $f(x, y)$ was assumed to be received and transmitted by a digital Video Transmitter (VTX). At the same time, the operating frequency for VTX is 5.8 MHz [37]. As a rule, in impact UAV FPVs, the video signal transmission does not provide high-definition video. Such drones do not have high density (HD) systems such as DJI Digital FPV and Caddx Vista [37]. Note that the DShot digital transmission protocol was used [37].

Segmentation of $f(x, y)$ from UAV FPV involves dividing the source image (expression (1)) into segments B_i (expression (2) [22, 23]):

$$\begin{cases} \bigcup_{i=1}^{K} B_i = B; \\ B_i \cap B_j = \varnothing, \text{ for } i \neq j; \ \forall i, j = \overline{1,K}; \\ LP(B_i) = 1; \ \forall i = \overline{1,K}; \\ LP(B_i \cap B_j) = 0, \text{ for } i \neq j; \ \forall i, j = \overline{1,K}, \end{cases} \tag{2}$$

where B: $B=\{B_1, B_2,..., B_K\}$ are segments on $fs(x, y)$; K is the number of segments on $fs(x, y)$, LP is the predicate, (i=1, 2,..., K).

The LP predicate was defined by analogy with [22, 23] in expression (3):

$$LP(B_i)=\begin{cases}1, & \text{if } f(x_1,y_1)=\ldots=f(x_M,y_M);\\ 0, & \text{others,}\end{cases} \quad (3)$$

where $(x_m,y_m)\in B_i$; $m=1, 2,..., M$; M is the value that determines the number of pixels of the segment B_i.

The result of $f(x, y)$ segmentation from UAV FPV is its separation $f(x, y)$ into one object of interest and background. As stated above in the assumptions and constraints adopted in the study, the object of interest in the source image is an aerial object and there is only one.

When determining the main stages of UAV FPV image segmentation method based on the ant algorithm, the material from [24] was used, taking into account the features of UAV FPV. So, the main stages of the UAV FPV image segmentation method based on a simple ant algorithm are shown in Fig. 1.

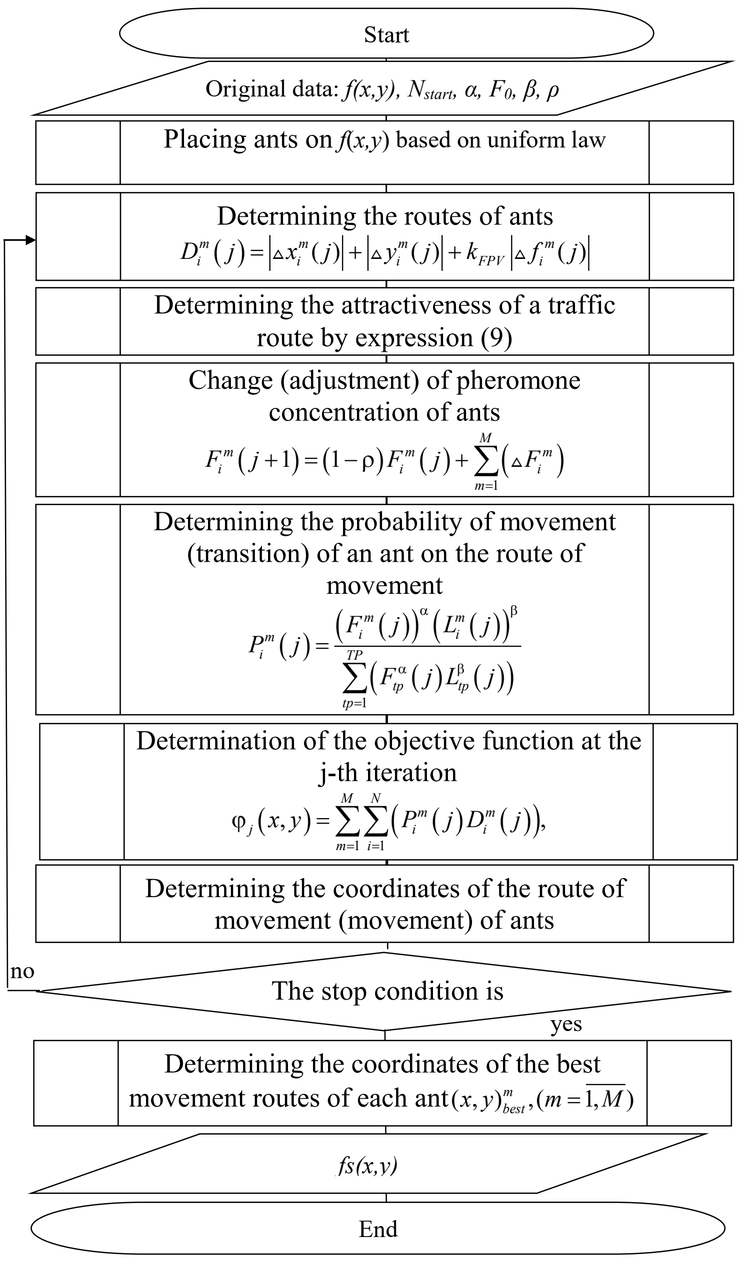

Fig. 1. Main stages in the UAV FPV image segmentation method based on a simple ant algorithm

The main stages of the image segmentation method:

1. Input data: $f(x, y)$ (input image); N_{start} (the number of ants in the image); α (pheromone weight); F_0 (initial amount of pheromone); ρ (the evaporation rate of the pheromone); β (the "greed" of the ant algorithm).

2. Placement of ants according to the uniform law on $f(x, y)$ (expression (4)):

$$(x,y)_{i1}=rand(f(x,y)), \quad (4)$$

where (x_{i1},y_{i1}) is the position of the ants at the first iteration.

It should be noted that if the number of ants N_{start} is equal to the size of the image $f(x, y)$, then at the first iteration each ant has the coordinates of each pixel of the image $f(x, y)$. We also note that expression (4) is used only on the first iteration.

3. Determination of ant routes (expression (5)):

$$D_i^m(j)=\left|\Delta x_i^m(j)\right|+\left|\Delta y_i^m(j)\right|+k_{FPV}\left|\Delta f_i^m(j)\right|, \quad (5)$$

where m is the number of the ant; j is the number of the current iteration; i – pixel number $f(x,y)$; $\left|\Delta x_i^m(j)\right|$, $\left|\Delta y_i^m(j)\right|$ – movement of the ant along the x and y axes, respectively; k_{FPV} – UAV FPV coefficient. The FPV coefficient of UAV takes into account the peculiarities of image acquisition. So, unlike images from space surveillance systems, from images from unmanned aerial vehicles for reconnaissance and surveillance, images from UAV FPVs are obtained through the operator. So, for example, unlike reconnaissance unmanned aerial vehicles, UAV FPVs are not equipped with advanced Global Position System (GPS) sensors and do not have a stabilized camera system. UAV FPVs have no automated features, so they rely solely on the pilot-operator's ability to fly. This, in turn, provides incredible agility and acrobatic maneuvers, creating the opportunity for shots that would be impossible with any other type of drone [33]. Therefore, the FPV factor k_{FPV} is selected empirically, taking into account the type of UAV FPV, weather conditions, etc. Also, k_{FPV} is chosen taking into account the scale of the image, brightness $f(x, y)$, etc.

The brightness difference between neighboring pixels in $\left|\Delta f_i^m(j)\right|$ is calculated from expression (6):

$$\left|\Delta f_i^m(j)\right|=\left|f\left(x_{i+1}^m(j),y_{i+1}^m(j)\right)-\right|f\left(x_i^m(j),y_i^m(j)\right). \quad (6)$$

4. The attractiveness of the route for each ant $L_i^m(j)$ can be calculated in three ways (expressions (7) to (9) [24]):

$$L_i^m(j)=\frac{1}{D_i^m(j)}, \quad (7)$$

$$L_i^m(j)=\frac{1}{1+\frac{D_i^m(j)}{D_0}}, \quad (8)$$

$$L_i^m(j)=\frac{1}{1+\exp\left(\frac{D_i^m(j)}{D_0}\right)}, \quad (9)$$

where D_0 is the coefficient related to the FPV coefficient k_{FPV} that takes into account the maneuverability of UAV FPV and the features of image formation.

The analysis of expressions (7) to (9) reveals that the attractiveness of the route for each ant $L_i^m(j)$ is inversely proportional to the value $D_i^m(j)$ (expression (5)). The analysis of expression (5) allows us to state that the value $D_i^m(j)$ has a physical meaning of the variance of brightness of neighboring pixels of the image $f(x, y)$. So, as the value $D_i^m(j)$ decreases, the attractiveness of the ant's route increases, which is quite fair and understandable.

For further calculations, taking into account the features of UAV FPV and the FPV coefficient k_{FPV}, expression (9) was used to calculate the attractiveness of the route for each ant $L_i^m(j)$. It is more complex, but better than expression (7) and expression (8) takes into account the peculiarities of obtaining an image from UAV FPV.

5. The change (adjustment) of the concentration of ant pheromones is carried out according to expression (10):

$$F_i^m(j+1)=(1-\rho)F_i^m(j)+\sum_{m=1}^{M}\left(\Delta F_i^m\right), \qquad (10)$$

where the pheromone evaporation rate ρ takes the value from 0 to 1 (ρ∈[0;1]); ΔF_i^m is the concentration of the pheromone that remains on the ant's route after its passage.

Note that the initial amount of pheromone F_0 is the input value of the method and is the same for all pixels in the image $f(x, y)$. After updating the pheromone concentration according to expression (10), the pheromone either increases or evaporates.

6. The probability of movement (transition) of an ant on the movement route is calculated according to expression (11):

$$P_i^m(j)=\frac{\left(F_i^m(j)\right)^{\alpha}\left(L_i^m(j)\right)^{\beta}}{\sum_{tp=1}^{TP}\left(F_{tp}^{\alpha}(j)L_{tp}^{\beta}(j)\right)}, \qquad (11)$$

where tp is the current turning point on the ant's route; TP is the total number of turning points on the ant's route; $F_i^m(j)$ is the concentration of the pheromone of the m-th ant in the i-th pixel on the image $f(x, y)$ at the j-th iteration of the iterative process (calculated from expression (10)).

7. The objective function at the j-th iteration, which determines the order of movement of agents, is calculated according to expression (12)):

$$\varphi_j(x,y)=\sum_{m=1}^{M}\sum_{i=1}^{N}\left(P_i^m(j)D_i^m(j)\right), \qquad (12)$$

where N is the size of the input image $f(x, y)$.

8. Determination of coordinates (x, y) of the route of movement (movement) of ants. Each ant starts the route from the starting point where it was initially placed according to the uniform law (expression (4)). Then, the ant during its movement passes the turning points of the route, which are determined from expression (11) taking into account the attractiveness of the route (expression (9)). The completion of each ant's route takes place at a certain "own" end point. When moving ants, the value of the objective function (expression (12)) is calculated, and its minimum is selected.

Taking into account the peculiarities of UAV FPV flight, the formation of the image $f(x, y)$ adopts a four-link structure of the possible movement (movement) of ants (by analogy with [24]), which is defined by expression (13):

$$\left|x_{i+1}^m(j)\right|+\left|y_{i+1}^m(j)\right|=1. \qquad (13)$$

Therefore, taking into account the four-link model of the ant's movement, expression (12) for the objective function $\varphi_i(x, y)$ is transformed into expression (14):

$$\varphi_j(x,y)= =\sum_{m=1}^{M}\sum_{i=1}^{N}\left(P_i^m(j)\left(1+k_{FPV}\left|\begin{matrix}f\left(x_{i+1}^m(j),y_{i+1}^m(j)\right)-\\-f\left(x_i^m(j),y_i^m(j)\right)\end{matrix}\right|\right)\right), \qquad (14)$$

and the route of the ant's movement is determined at the j-th iteration by the minimum of the objective function (expression (14)), which is determined from expression (15)):

$$\varphi_j(x,y)== \sum_{m=1}^{M}\sum_{i=1}^{N}\left(P_i^m(j)\left(1+k_{FPV}\left|\begin{matrix}f\left(x_{i+1}^m(j),y_{i+1}^m(j)\right)-\\-f\left(x_i^m(j),y_i^m(j)\right)\end{matrix}\right|\right)\right)\rightarrow \min. \qquad (15)$$

From the analysis of expression (15), it can be concluded that the routes of ants with the highest concentration of pheromone are more attractive. Routes of ants on which the pheromone "evaporates" become unattractive and gradually disappear.

9. Checking the fulfillment of the stop condition. If the condition is met, the transition to the next stage. In case of non-fulfilment, proceed to step 3.

10. Determining the coordinates of the m-th ant's movement route $(x,y)_{best}^m$. The coordinates of the best found routes of the ants are determined from expression (16):

$$(x,y)_{best}^m,\left(m=\overline{1,M}\right). \qquad (16)$$

11. Calculation of pixel brightnesses of the segmented image $fs(x, y)$.

It should be noted that for the image from UAV FPV, which is represented in the RGB color space, the stages of the method (Fig. 1) are carried out separately for each channel (Red, Green, Blue) with the subsequent combination of the results of channel segmentation.

Thus, the UAV FPV image segmentation method based on a simple ant algorithm, unlike the known ones, takes into account the number of ants in the image, the weight of the pheromone, the initial amount of the pheromone, the rate of evaporation of the pheromone, the "greediness" of the algorithm, and enables the following:

– preliminary distinguishing of individual channels of the RGB color space;

– preliminary placement of ants according to the uniform law;

– determining the routes of ants taking into account the peculiarities of obtaining an image from UAV FPV;

– taking into account the attractiveness of the route for each ant;

– change (adjustment) of the concentration of ant pheromones;

– calculation of the probability of movement (transition) of the ant on the movement route;

– determination of the objective function at the j-th iteration and its minimization;

– determining the coordinates of the route of movement (movement) of ants;

– verification of the fulfillment of the stop condition;

– determination of the best routes found by ants;

– calculation of the brightness of the pixels of the segmented image in each channel of the RGB color space;

– further combining the results of channel segmentation.

5. 2. Experimental study of UAV FPV image segmentation based on a simple ant algorithm

Fig. 2 shows the original optical-electronic image from UAV FPV in the RGB color space [38]. The object of interest for UAV FPV is an aerial object, so the shooting from the UAV FPV is carried out in the direction of the air space. The size of the initial optical-electronic image from UAV FPV (Fig. 2) is (1280×720) pixels.

Fig. 2. Initial optical-electronic image from UAV FPV in RGB color space [38]

The object of interest in Fig. 2 is an impact barrage munition of the Lancet type (manufactured by the Russian Federation). Only one object of interest (Lancet) is present in the source image. The image contains all the service information received by the UAV FPV operator. The size of the objects of interest (Lancet) is smaller than the size of the background objects. The background objects are the earth's surface and part of the air space (sky). The original image is assumed to be undistorted, that is, the image is not affected by heterogeneous artifacts (noise, rotation, scaling, etc.).

During the experimental study of UAV FPV image segmentation (Fig. 2) based on a simple ant algorithm, the parameters of the ant algorithm were determined, which are given in Table 1.

Table 1

Parameters of a simple ant algorithm, which were defined for conducting an experimental study of UAV FPV image segmentation (Fig. 2)

Algorithm parameter	Number of ants in the image N_{start}, pcs.	Pheromone weight α	«Greed» of the algorithm β	The rate of evaporation of the pheromone ρ	Initial amount of pheromone F_0	Number of iterations
Quantitative value of the algorithm parameter	921600	3	1	10^{-2}	10^{-3}	100

The parameters of the simple ant algorithm, which are defined for conducting an experimental study of UAV FPV image segmentation, are determined taking into account the results of [24] and conducting empirical studies.

Fig. 3 shows a segmented image $fs(x, y)$ using a method based on a simple ant algorithm.

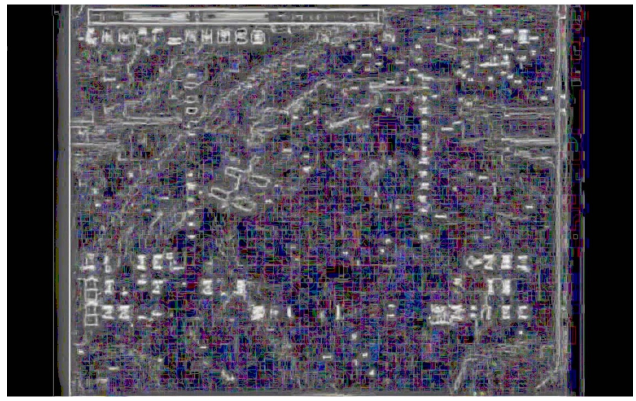

Fig. 3. Segmented image $fs(x, y)$ by a method based on a simple ant algorithm

The main advantages of using a simple ant algorithm for image segmentation from UAV FPV:

– independence from an unsuccessful choice of method parameters (the ant algorithm adapts in the process of segmentation to the features of the image);

– the possibility of parallelizing the segmentation process (each ant chooses its personal route in parallel with other ants);

– relatively high speed, which is important in the case of UAV FPVs;

– the possibility of optimizing the current management of the segmentation process.

At the same time, the main disadvantage of the UAV FPV image segmentation method is the presence of a significant number of "garbage" objects. But such "junk" objects can be further filtered out owing to the use of certain additional features.

So, for example, Fig. 4 shows the object of interest (the Lancet barrage munition), the contours of which were determined as a result of segmentation using a method based on a simple ant algorithm.

The indicated object of interest (Lancet barrage munition) has a certain structure, continuity of contours, and can be used in the future for deciphering, categorization, etc. Unlike the object of interest, background ("garbage" objects) do not have a stable structure and can be further filtered out. But this is the subject of further research.

We shall compare the UAV FPV image segmentation method based on a simple ant algorithm to known methods. At the same time, we shall take one of the "simple" methods as a known one. Fig. 5 shows the result of UAV FPV image segmentation using the gradient module algorithm [15, 21, 26].

Fig. 6 shows the object of interest (the Lancet barrage munition), the contours of which were determined as a result of segmentation using the method based on the gradient module.

Analysis of Fig. 5, 6 in comparison with Fig. 3, 4, respectively, reveals the low contrast value of Fig. 5, 6. Also in Fig. 6, there are omissions of segmented pixels of the object of interest, which affects the quality of its contour selection and subsequent decoding and categorization of the object.

Fig. 4. Object of interest (Lancet barrage munition), the contours of which are determined as a result of segmentation using a method based on a simple ant algorithm

Fig. 5. Segmented image $fs(x, y)$ by the method based on the gradient module algorithm

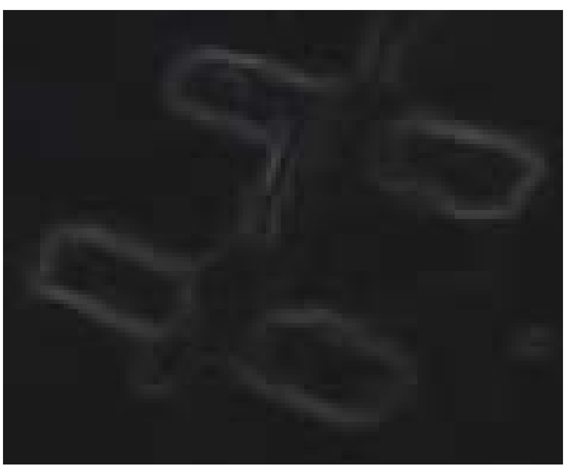

Fig. 6. The object of interest (the Lancet barrage munition), the contours of which were determined as a result of segmentation using the method based on the gradient module

Thus, the comparative visual analysis shows the better visual quality of the UAV FPV image segmented by the method based on a simple ant algorithm. Quantification of segmentation quality is the subject of further research.

6. Discussion of results of investigating the UAV FPV image segmentation based on a simple ant algorithm

The main stages in the UAV FPV image segmentation method based on a simple ant algorithm have been defined (Fig. 1). The choice of the ant algorithm is due to its advantages, in contrast to other algorithms (for example, [22, 23, 26, 27]). The main advantages of using a simple ant algorithm for UAV FPV image segmentation:

– independence from an unsuccessful choice of method parameters (the ant algorithm adapts in the process of segmentation to the features of the image);

– the possibility of parallelizing the segmentation process (each ant chooses its personal route in parallel with other ants);

– relatively high speed, which is important in the case of UAV FPVs;

– the possibility of optimizing the current management of the segmentation process.

The UAV FPV image segmentation method based on a simple ant algorithm, unlike the known ones (for example, [24, 25, 27]), takes into account the number of ants in the image, the weight of the pheromone, the initial amount of pheromone, the rate of evaporation of the pheromone, the "greediness" of the algorithm and provides for the following:

– preliminary highlighting of individual channels in the RGB color space;

– preliminary placement of ants according to the uniform law (expression (4));

– determining the routes of ants taking into account the features of obtaining an image from UAV FPV (expression (5));

– taking into account the attractiveness of the route for each ant (expression (9));

– change (adjustment) of the concentration of ant pheromones (expression (10));

– calculation of the probability of movement (transition) of the ant along the movement route (expression (11));

– determination of the objective function at the j-th iteration and its minimization (expressions (12) to (15));

– determining the coordinates of the route of movement (movement) of ants;

– verification of the fulfillment of the stop condition;

– determination of the best routes found by ants (expression (16));

– calculation of the brightness of the pixels of the segmented image in each channel of the RGB color space;

– further combining the results of channel segmentation.

An experimental study of UAV FPV image segmentation based on a simple ant algorithm was conducted. An optical-electronic image from UAV FPV in the RGB color space was chosen as the input (Fig. 2). We have defined parameters of the simple ant algorithm, which are given in Table 1, and determined them empirically.

A segmented image was obtained using a method based on a simple ant algorithm (Fig. 3). From the analysis of Fig. 3, it was established that the main drawback of the UAV FPV image segmentation method is the presence of a significant number of "garbage" objects. The indicated object of interest (Lancet barrage munition) (Fig. 4) has a certain structure, irregularity of contours, and can be further used for deciphering, categorization, etc. Unlike the object of interest, background ("garbage" objects) do not have a stable structure and can be further filtered out. But this is the subject of further research.

A comparison of the UAV FPV image segmentation method based on a simple ant algorithm with known methods (for example, [15, 21, 26]) was performed. At the same time, one of the "simple" methods was chosen as the known one. Fig. 5 shows the result of UAV FPV image segmentation using the gradient module algorithm. Fig. 6 shows the object of interest (the Lancet barrage munition), the contours of which were determined as a result of segmentation using the method based on the gradient module. Analysis of Fig. 5, 6 in comparison with Fig. 3, 4, respectively, reveals the low contrast value of Fig. 5, 6. Also in Fig. 6, there are gaps in the pixels of the contour of the object of interest, which affects the quality of its contour selection and subsequent decoding and categorization of the object.

Thus, the comparative visual analysis demonstrates the better visual quality of the UAV FPV image segmented by the method based on a simple ant algorithm. This became possible owing to the use of a simple ant algorithm in the segmentation of the image from UAV FPV. Quantification of segmentation quality is the subject of further research.

When applying in practice, as well as in further theoretical studies, the method of segmenting an image from UAV FPV based on a simple ant algorithm, it is necessary to take into account the following main limitations:

– the input image is an optical-electronic image from UAV FPV in the RGB color space;

– the UAV FPV camera must be digital;

– there is only one object of interest in the original image;

– the input image is undistorted.

The disadvantage of the segmentation method based on a simple ant algorithm is the presence of a significant number of “garbage” objects, as well as limitations on its application in the case of the influence of heterogeneous distortions.

Adequacy and reliability of our results have been confirmed:

– by using theoretically grounded and proven in practice methods of probability theory and mathematical statistics, mathematical apparatus of matrix theory, methods of digital image processing, swarm methods, iterative methods, methods of system analysis, differential calculus, integral geometry, mathematical modeling, analytical and empirical methods of comparative research;

– by a good match between theoretical calculations (Fig. 1) and the results of processing the original image (Fig. 3);

– by comparative species analysis of the segmented image using the developed method (Fig. 3, 4) and the known method (Fig. 5, 6);

– based on the results of the comparative analysis and taking into account the limitations and assumptions adopted during the research, the confidence probability is ~0.9;

– by non-contradiction of the obtained results to the basic laws and phenomena of nature, their clear physical interpretation.

Further research should investigate methods to reduce a significant number of “garbage” objects and to conduct a quantitative assessment of the quality of UAV FPV image segmentation methods.

7. Conclusions

1. The UAV FPV image segmentation method based on a simple ant algorithm, unlike the known ones, takes into account the number of ants in the image, the weight of the pheromone, the initial amount of the pheromone, the rate of evaporation of the pheromone, the “greediness” of the algorithm and enables the following:

– preliminary highlighting of individual channels in the RGB color space;

– preliminary placement of ants according to the uniform law;

– determining the routes of ants taking into account the peculiarities of obtaining an image from UAV FPV;

– taking into account the attractiveness of the route for each ant;

– change (adjustment) of the concentration of ant pheromones;

– calculation of the probability of movement (transition) of the ant on the movement route;

– determination of the objective function at the *j*-th iteration and its minimization;

– determining the coordinates of the route of movement (movement) of ants;

– verification of the fulfillment of the stop condition;

– determination of the best routes found by ants;

– calculation of the brightness of the pixels of the segmented image in each channel of the RGB color space;

– further combining the results of channel segmentation.

2. An experimental study of UAV FPV image segmentation based on a simple ant algorithm has been carried out. A segmented image was obtained using a method based on a simple ant algorithm. It has been established that the method of segmentation of an UAV FPV image based on a simple ant algorithm has the main drawback, which is the presence of a significant number of “garbage” objects. The indicated object of interest (Lancet barrage munition) has a certain structure, irregularity of contours, and can be further used for decryption, categorization, etc. Unlike the object of interest, background (“garbage”) objects do not have a stable structure and can be further filtered out.

A comparison of the UAV FPV image segmentation method based on a simple ant algorithm with known methods was performed. It was established that the segmented image using the method based on the gradient module has a low contrast value, there are gaps in the segmented pixels of the object of interest, which affects the quality of its contour selection and subsequent decoding and categorization of the object. A segmented image using a method based on a simple ant algorithm is devoid of the mentioned drawback.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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