UDC 004.932
DOI: 10.15587/1729-4061.2023.277427

IMPROVING A METHOD FOR SEGMENTING OPTICAL-ELECTRONIC IMAGES ACQUIRED FROM SPACE OBSERVATION SYSTEMS BASED ON THE FIREFLY ALGORITHM

Hennadii Khudov
Corresponding author
Doctor of Technical Sciences, Professor, Head of Department*
E-mail: 2345kh_hg@ukr.net

Oleksandr Makoveichuk
Doctor of Technical Sciences, Associate Professor
Department of Computer Sciences and Software Engineering
Academician Yuriy Bugay International Scientific and Technical University
Mahnitohorskyi lane, 3, Kyiv, Ukraine, 02094

Vladyslav Khudov
PhD, Junior Researcher
Department of Information Technology Security
Kharkiv National University of Radio Electronics
Nauky ave., 14, Kharkiv, Ukraine, 61166

Irina Khizhnyak
PhD*

Yurii Dobryshkin
PhD, Head of Department
Depaptment of Laboratory Tests of Scientific and Technical Complex of Measurements
State Scientific Research Institute of Armament and Military Equipment Testing and Certification
Striletska str., 1, Chernihiv, Ukraine, 14033

Oleksandr Kondratov
PhD, Head of Department**

Vitalii Andronov
PhD, Head of Department**

Ivan Balyk
PhD
Department of the First Management**

Tetiana Uvarova
PhD, Senior Researcher
Center for Military and Strategic Studies
The National Defence University of Ukraine named after Ivan Cherniakhovskyi
Povitroflotskiy ave., 28, Kyiv, Ukraine, 03049

Maksym Kalenyk
PhD, Senior Researcher, Deputy Head of Department
Department of Engineering Equipment
Hetman Petro Sahaidachnyi National Army Academy
Heroiv Maidanu str., 32, Lviv, Ukraine, 79026

*Department of Radar Troops Tactic
Ivan Kozhedub Kharkiv National Air Force University
Sumska str., 77/79, Kharkiv, Ukraine, 61023

**Scientific-Research Institute of Military Intelligence
Yuriia Illienka str., 81, Kyiv, Ukraine, 04050

The object of research is the process of segmentation of optoelectronic images acquired from space observation systems. The method of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm, unlike known ones, involves the following:

– the pre-selection of brightness channels of the Red-Green-Blue color space in the original image;

– calculation of the level of luminosity for each firefly;

– assigning each firefly with the neighboring firefly, within a certain radius, whose level of luminosity is higher than the natural level of luminosity of the firefly;

– determination of the coordinate of the updated position of the firefly in each brightness channel.

An experimental study into the segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm was carried out. It is established that the improved segmentation method based on the firefly algorithm allows for the segmentation of optoelectronic images acquired from space observation systems.

The quality of segmentation of optoelectronic images by the method based on the firefly algorithm was evaluated in comparison with methods based on the particle swarm algorithm and the Sine-Cosine algorithm. It was found that the improved method based on the firefly algorithm reduces the segmentation error of the first kind by an average of 11 % and the segmentation error of the second kind by an average of 9 %. This becomes possible by using the firefly algorithm.

Methods of image segmentation can be implemented in software and hardware systems for processing optoelectronic images acquired from space surveillance systems.

Further studies may focus on comparing the quality of segmentation method based on the firefly algorithm with segmentation methods based on genetic algorithms

Keywords: image segmentation, space observation system, firefly algorithm, position, firefly luminosity

Received date 02.02.2023
Accepted date 04.04.2023
Published date 28.04.2023

***How to Cite:** Khudov, H., Makoveichuk, O., Khudov, V., Khizhnyak, I., Dobryshkin, Y., Kondratov, O., Andronov, V., Balyk, I., Uvarova, T., Kalenyk, M. (2023). Improving a method for segmenting optical-electronic images acquired from space observation systems based on the firefly algorithm. Eastern-European Journal of Enterprise Technologies, 2 (9 (122)), 6–15. doi: https://doi.org/10.15587/1729-4061.2023.277427*

1. Introduction

Modern space systems of optoelectronic surveillance make it possible to acquire information about a situation over large areas from a single image and almost without distance restrictions [1]. The relevance of using information from space systems of optoelectronic surveillance is due to the receipt of information in real time, the availability in obtaining (acquiring) satellite imagery materials, the objectivity of obtaining data, etc. This is especially true for solving military-related tasks [2, 3].

The quality of processing and segmentation of optoelectronic images acquired from space observation systems is subject to appropriate requirements for reliability, accuracy, and completeness [4, 5]. Given the need to explore large areas on space images, the workload of decoder operators, and the limited time for processing space imagery materials, their qualitative and timely segmentation in a non-automated way becomes almost impossible [6].

Regarding the automated processing of space imagery materials, which are raster digital images, their processing in specialized graphic editors or in computer-aided design systems is almost impossible due to the large volumes of the image.

Existing methods of segmentation of optoelectronic images acquired from space surveillance systems do not meet the above quality requirements and have certain disadvantages. The main disadvantage of known segmentation methods is the high level of errors of the first and second kind. Given the size of the image, this can lead to corresponding errors in the decryption of the optoelectronic image.

Therefore, the development of methods for segmenting optoelectronic images acquired from space observation systems is an urgent task.

2. Literature review and problem statement

In [7], existing software and hardware systems for processing information from space systems of optoelectronic surveillance and geospatial data management are considered. The disadvantage of software and hardware systems is that they only collect incoming information and lack automated processing.

In [8], the possibility of supplementing software and hardware systems [7] with special software for working with geospatial data is considered. But in [8] the stage of segmentation of optoelectronic images acquired from space surveillance systems is not considered.

In [9], existing specialized software for processing remote sensing data for solving the problem of selecting objects of interest on satellite imagery materials is considered. Specialized software [9] use known methods of segmentation. The disadvantage of [9] is the use of an individual format that is not supported by graphics editors and other remote sensing data processing packages and is not exported to generally accepted and common raster image storage formats.

To solve the problem of semantic segmentation, an improved architecture of the encoder-decoder is proposed in [10]. The advantage of [10] is to solve the problem of precise segmentation of optoelectronic images by combining local contextual details about neighboring pixels in the image with an encoder network. The main disadvantage is the possibility of capturing inherent characteristics in a local and global context only for images acquired from unmanned aerial vehicles.

In [11], for segmentation of images of remote sensing of the Earth, the detection of objects of interest using short connections with a known data set with subsequent division into one of the options (simple or complex case) was proposed. The advantage of [11] is the high quality of segmentation when processing real images with a complex background. The disadvantage of [11] is the good segmentation results only for high-resolution input images and the detection of one type of object of interest, namely the aircraft.

In [12], an approach to semantic segmentation of images acquired from aerial and space observation systems is proposed. The essence of this approach is to isolate the boundaries of natural objects, in the subsequent recognition of textures using digital wavelet transformation and local binary patterns. The advantage of [12] is to obtain systematic information for solving problems in a particular area. The disadvantage of [12] is the identification of only a certain type of objects of interest and the use of a limited texture dictionary.

To detect and identify objects of interest of different sizes on satellite images of any resolution and quality, an improved method of segmentation of satellite images is proposed in [13]. The essence of the method is to combine two significantly different convolutional neural networks, namely the method of segmentation based on the modified architecture U-net, and the detection method based on the architecture RetinaNet. The advantage of [13] is a significant reduction in the frequency of false negative results of detection and identification of objects of interest on satellite images of different resolutions. The disadvantage of [13] is the detection of only one type of object of interest, namely the aircraft.

In [14], a method for segmenting satellite images using the TL-ResUNet residual architecture model is proposed. The advantage of [14] is the combination of the advantages of transfer learning, the residual network, and the UNet architecture. The disadvantage of [14] is its use only for monitoring and analysis of agricultural land.

To process satellite images of an urbanized area, a method of semantic segmentation based on deep learning is proposed in [15]. The advantage is the good results of segmenting only images of a high-resolution urbanized area. The main disadvantage of [15] is under-segmentation when either new objects appear in images of an urbanized area, or when partially capturing another type of terrain when shooting.

The main disadvantages and limitations in the use of deep learning networks to solve the problem of segmentation of remote sensing data are given in [16]. The main disadvantage is the complexity in creating a sufficient amount of labeled data. Therefore, it was proposed to carry out post-processing to refine the results of segmentation or use classical methods of image segmentation.

In [17], limitations and assumptions are set for applying a group of segmentation methods with a global threshold and a group of methods with an adaptive local segmentation threshold. Recommendations for segmenting images by these groups of threshold methods are also provided. The advantage of [17] is the simplicity of implementation of the algorithm of the methods and good results of segmentation on simple images with high computational efficiency. The disadvantage of [17] is the possibility of selecting only one or two values of segmentation thresholds and the difficulty in selecting them automatically, which directly affects the quality of the segmented image.

To avoid this drawback, the threshold method of image segmentation has been improved in [18]. The essence is to use, to highlight the boundaries of the object of interest, the maximum value of interclass variance and the bimodal segmentation threshold. The advantage of [18] is the segmentation of the image into more than two segments. The main disadvantage is the poor result of segmentation of high-contrast images.

In [19], a method of image segmentation based on random walks using interactive marking is proposed. The advantage is the use of all approaches of graph theory to segment the image, which is proposed to be represented as a full-connected graph.

The disadvantage of [19] is the semi-automatic approach of image segmentation.

In [20, 21], to improve the quality of segmentation, it is proposed to preliminarily carry out gradational correction of the image. In [20], this operation is proposed for low-contrast images. In [21], this operation is proposed for high-contrast images. The advantage of [20, 21] is to improve the quality of image preprocessing. The disadvantage is the use of known methods of image segmentation, which have inherent disadvantages of image resegmentation.

In [22], a method for processing images of floods from unmanned aerial vehicles is proposed. The method is two-stage. At the first stage, the k-means segmentation method is used; at the second stage, the method of increasing regions is used to highlight flooded and unflooded areas in the image. The advantage of [22] is the segmentation of unflooded and flooded terrain. The disadvantage is the possibility of using it only for segmentation of flood images.

In [23], a segmentation method based on coherent anisotropic diffuse filtration is proposed. Additionally, the authors of [23] use the minimal skeleton tree algorithm. The advantage of is segmentation taking into account the shape of each segment. The disadvantage is the significant time costs.

Considering the input image in the form of a graph is proposed in [24, 25]. The essence of the approach is to solve the problem of segmentation on images acquired from aerial reconnaissance and surveillance systems based on an ant algorithm based on simulating the natural process of searching for a colony of ants for a food source. The advantage of the methods reported in [24, 25] is the high speed of image segmentation due to parallelization of the algorithm and the high quality of segmentation results due to independence from unsuccessful initial actions of the algorithm. The disadvantage of [24] is the segmentation of tone-only images acquired from aerial reconnaissance and surveillance systems. In [25], segmentation of color images is also proposed, but images acquired from space observing systems have not been considered in any of these papers.

Work [26] took into account the shortcomings of previous work and proposed an improved method for segmenting color images acquired from space observation systems for an urbanized area. The essence of the complex method [26] is the sequential application of two algorithms, namely the ant colony algorithm and the Hough transform algorithm. The advantage is the high quality of image segmentation results of the urbanized area. The disadvantage is a slightly higher time and computing costs and limitations to the list of industries for applying the results of segmentation.

In [27], image segmentation from space observation systems was proposed by using the Sine-Cosine algorithm. The main essence of this approach is to determine the positions of agents in a space image using trigonometric functions of sine and cosine. The disadvantage is the deterioration in the quality of image segmentation when exposed to heterogeneous distortion factors of the input image. The advantage is to highlight all objects of interest in the images, even those that are undefined or have texture.

In [28], in order to isolate camouflaged military equipment in images acquired from space reconnaissance and surveillance systems, a method based on a genetic algorithm was proposed. The advantage is the combination of functions of contour selection methods, swarm methods and texture methods. The main disadvantage is the poor results of image segmentation from aerial reconnaissance and surveillance systems, which imposes limitations in solving military intelligence tasks.

In [29], to solve the problem of image segmentation from air and space reconnaissance and surveillance systems, another method of swarm intelligence was proposed, namely the algorithm of a swarm of particles. The advantages of [29] are optimizing the control of parallel image segmentation processes and taking into account the peculiarities of image formation from air and space reconnaissance and surveillance systems. The main disadvantage is the difficulty in choosing the initial parameters of the method, for example, acceleration coefficients, inertia, and others.

In [30], the problem of segmentation separately for images acquired from aerial and space reconnaissance and surveillance systems by the k-means method and the method based on the genetic algorithm was solved. The relevance and quality of segmentation for both images acquired from unmanned aerial vehicles and images obtained from spacecraft by the proposed segmentation methods were established. Recommendations for image processing of remote sensing of the earth are given, limitations and assumptions are listed when applying the k-means method and the method based on the genetic algorithm, their main disadvantages and advantages.

Thus, our review of known methods for segmenting optoelectronic images acquired from space observation systems highlighted certain shortcomings of these methods.

To further study the segmentation of optoelectronic images acquired from space observation systems, a segmentation method based on the firefly algorithm can be chosen. The main advantages of the firefly algorithm are simple implementation, high scalability, and convergence [31, 32].

Therefore, devising a method for segmenting optoelectronic images acquired from space observation systems based on the firefly algorithm could solve the problem associated with the limitations of known methods for segmenting optoelectronic images acquired from space observation systems.

3. The aim and objectives of the study

The aim of this study is to improve a segmentation method of optoelectronic images acquired from space observation systems through the use of the firefly algorithm. This will reduce the value of segmentation errors of the first and second kind.

To accomplish the aim, the following tasks have been set:

– to determine the main stages of the method of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm;

– to segment the optoelectronic image from the space observation system by the method based on the firefly algorithm;

– to conduct a comparative assessment of the quality of segmentation of the optoelectronic image from the space observation system by known and developed method based on the firefly algorithm.

4. The study materials and methods

The object of research in our work is the process of segmentation of optoelectronic images acquired from space observation systems.

It is assumed that the use of the firefly algorithm in improving the segmentation method could reduce errors of the first and second kind.

The main research methods are:

– metahuristic;

– swarm;

– digital image processing;

– system analysis;

– mathematical apparatus of matrix theory;

– probability theory and mathematical statistics;

– iterative;

– mathematical modeling, etc.

Benchmarking methods have been used in validating new results.

The assumptions and limitations adopted in the study are as follows:

– an optoelectronic image from space observation system is considered;

– a color space of representation of the original optoelectronic image – Red-Green-Blue (RGB);

– heterogeneity of representation of objects of interest;

– the size of objects of interest is much smaller than the size of background objects on an optoelectronic image;

– when segmenting an optoelectronic image, the influence of distorting factors is not taken into account;

– when assessing the quality, errors of the first and second kinds are calculated.

5. Results of the study on image segmentation by the method based on the firefly algorithm

5. 1. The main stages of the image segmentation method based on the firefly algorithm

We shall use [27–29] for formalized recording of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm (expression (1)):

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

where $f(x, y)$ – original image; $fs(x, y)$ – segmented image.

Segments in quantity K (denote them B: $B=\{B_1, B_2,..., B_K\}$), formed as a result of segmentation of the original optoelectronic image $f(x, y)$, are determined from expression (2) [29–31]:

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

where i=1, 2,..., K, LP – predicate (expression (3)) [29–31]:

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

where M is the number of points in the i-th segment; $(x_m,y_m)\epsilon B_i$, m=1, 2,..., M.

The segmented image $fs(x, y)$ represents the result of splitting the original image $f(x, y)$ into two groups of objects: background and interest.

To partition the original image $f(x, y)$ into the specified groups of objects, we shall use the firefly algorithm.

The main stages of the method of segmentation of the optoelectronic image from space observation systems based on the firefly algorithm are shown in Fig. 1.

The method of segmentation of the optoelectronic image from the space observation system based on the firefly algorithm involves:

1. Enter source data:

– original image $f(\boldsymbol{X})$, where $\boldsymbol{X}(x, y)$ – coordinates of the pixel on the optoelectronic image $f(\boldsymbol{X})$ from the space observation system;

– N – number of fireflies used in the algorithm;

– K – number of segments;

– $I_{\max}$ – maximum number of iterations of the firefly algorithm;

– r_i – initial values of search radii for each firefly;

– ρ – coefficient determining the level of luminosity (0<ρ<1);

– γ – coefficient that determines the attractiveness of a firefly;

– l_0 – initial level of luminosity of the firefly (the same level of luminosity for all N fireflies is assumed).

2. The distribution of fireflies at their initial positions on the original optoelectronic image $f(\boldsymbol{X})$ randomly.

3. Determination of the search radius for each firefly r_i.

4. Calculating the level of luminosity for each firefly. In the beginning, all fireflies have the same level of luminosity.

The calculation of the luminosity level is based on expression (4):

$$l_j(t+1)=(1-\rho)l_j(t)+\gamma J_j(t+1), \tag{4}$$

where ρ is the coefficient that determines the level of luminosity (0<ρ<1), γ is the coefficient that determines the attractiveness of the firefly, J_j is the value of the objective function.

The objective function will be chosen in the following form (5):

$$J_j(t)=\frac{1}{1+e^{\frac{D_i^m(t)}{D_0}}}, \tag{5}$$

where

$$D_i^m(t)=\left|\Delta x_i^m(t)\right|+\left|\Delta y_i^m(t)\right|+k\left|\Delta f_i^m(t)\right|, \tag{6}$$

j – image pixel number, $\left|\Delta x_i^m(t)\right|$, $\left|\Delta y_i^m(t)\right|$, $\left|\Delta y_i^m(j)\right|$ – moving the firefly along the x and y axes, respectively, in another pixel of the image; k – coefficient that takes into account the difference in brightness of pixels, scales, units of measurement, etc., D_0 – coefficient taking into account the scale of the image.

5. Determination by each firefly of that neighboring firefly within a defined radius r_i whose luminosity level is higher than the firefly's natural luminosity level. To do this, we calculate the probabilities of choice (movement) (expression (7), it is assumed that the movement goes from the i-th firefly to the j-th firefly):

$$p_{ij}(t+1)=\frac{l_j(t)-l_i(t)}{\sum_{k\in N_i(t)}(l_k(t))-l_i(t)}(1-\rho)+\gamma J_j(t+1), \tag{7}$$

where $j\epsilon N_i(t)$, $N_i(t)$ can be defined as (expression (8)):

$$N_i(t)=\left(j: d_{ij}(t)<r_d^i(t)\right), \tag{8}$$

$d_{ij}(t)$ – Euclidean distance between fireflies i and j at time t, $l_j(t)$ – value of the luminosity of the firefly j at time t, $r_d^i(t)$ – search radius of the firefly i at time t.

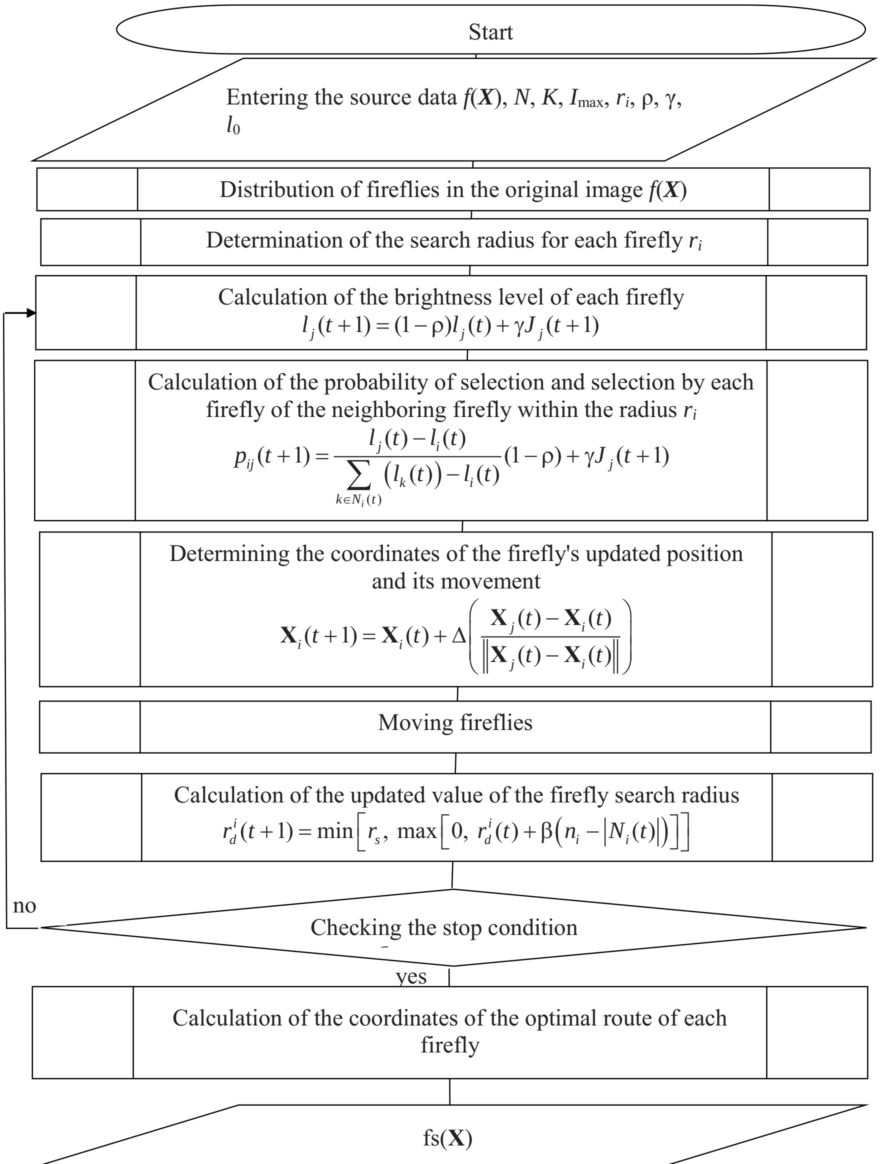

Fig. 1. The main stages of the segmentation method based on the firefly algorithm

6. Determining the coordinate of the updated position of the firefly i if this firefly moves in the direction of the neighboring firefly j (expression (9)):

$$\mathbf{X}_i(t+1)=\mathbf{X}_i(t)+\Delta\left(\frac{\mathbf{X}_j(t)-\mathbf{X}_i(t)}{\left\|\mathbf{X}_j(t)-\mathbf{X}_i(t)\right\|}\right), \qquad (9)$$

where Δ is the size of the move step (number of pixels).

7. Calculation of the updated value of the firefly search radius i by expression (10):

$$r_d^i(t+1)=\min\left[r_s,\ \max\left[0,\ r_d^i(t)+\beta\left(n_i-\left|N_i(t)\right|\right)\right]\right], \qquad (10)$$

where β is a constant coefficient, n_i is the coefficient affecting the number of neighboring fireflies for firefly i.

8. Checking the condition for achieving a given number of iterations (stopping the firefly algorithm).

9. Determining the segmented image $fs(\boldsymbol{X})$.

Given the representation of the original RGB image in the color space, it is first advisable to select the brightness channels. After that, the main steps of the method must be applied to each brightness channel (Fig. 1). Next, you need to combine these brightness channels and determine the segmentation result ($fs(\boldsymbol{X})$).

Thus, the improved method of segmentation, based on the firefly algorithm, unlike known ones, involves:

– preliminary selection of brightness channels in the original image;

– calculation of the level of luminosity for each firefly;

– assigning each firefly with the neighboring firefly, within a certain radius, whose level of luminosity is higher than the natural level of luminosity of the firefly;

– determination of the coordinate of the updated position of the firefly in each brightness channel.

5. 2. Segmentation of images using the method based on the firefly algorithm

For the experimental study, the initial optoelectronic image was selected from the space observation system WorldView-2 (USA) [33]. This original image is shown in Fig. 2 [33]. The size of the original image is (1868×1348) pixels. Objects of interest in Fig. 2 [33] are the objects related to military activities (military equipment, auxiliary facilities, etc.).

Fig. 2. Original color optoelectronic image [33]

To carry out segmentation by the method based on the firefly algorithm, we define the following parameters of the firefly algorithm (Table 1).

Table 1

Parameters of the firefly algorithm

Parameter name	N, pieces	K, pieces	I_{max}, pieces	r_i, pixel	ρ	γ	I_0
Parameter value	50	5	20	200	0.1	0.2	0.01

Experimental studies were conducted using the following software and hardware. The chosen MATLAB R2017b software employed the high-level programming language and interactive environment for programming, numerical calculations, and visualization of results. Hardware: ASUSTeK COMPUTER INC model X550CC, 3rd Gen processor DRAM Controller – 0154, NVIDIA GeForce GT 720M.

Fig. 3 shows a segmented optoelectronic image by an improved method based on the firefly algorithm with parameters according to Table 1. At the same time, for clarity, in Fig. 3 all five segments are shown in pseudo-colors (five pseudo-colors are used).

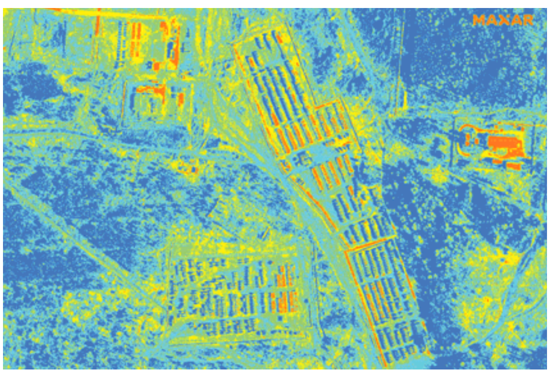

Fig. 3. Segmented optoelectronic image by an improved method based on the firefly algorithm with parameters according to Table 1

It can be seen (Fig. 3) that the improved method of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm does make it possible to segment images.

5. 3. Estimating the quality of image segmentation using the method based on the firefly algorithm

To assess the quality of image segmentation by the method based on the firefly algorithm, as mentioned above, we shall determine segmentation errors of the first and second kind [34–36].

In general, the selected quality indicators are determined by the criterion of maximum likelihood [37–39]. The criterion is directly related to the generalized criterion of minimum medium risk [37–39].

We shall calculate segmentation errors [35, 38] for known segmentation methods and the improved method based on the firefly algorithm. We use known expressions (11), (12) [35, 38]:

$$\alpha_1 = \frac{S_1\left(fs(\mathbf{X})\right)}{S_2\left(f(\mathbf{X})\right)}, \tag{11}$$

$$\beta_2 = 1 - \frac{S_3\left(fs(\mathbf{X})\right)}{S_4\left(f(\mathbf{X})\right)}, \tag{12}$$

where $S_1(fs(\boldsymbol{X}))$ is the defined background plane. This plane is mistakenly attributed to objects of interest on $fs(\boldsymbol{X})$; $S_2(f(\boldsymbol{X}))$ is a defined background plane on $f(\boldsymbol{X})$; $S_3(fs(\boldsymbol{X}))$ is a definite plane of properly segmented objects of interest on $fs(\boldsymbol{X})$; $S_4(f(\boldsymbol{X}))$ is a definite plane of objects of interest on $f(\boldsymbol{X})$.

As known segmentation methods, we define segmentation methods based on the particle swarm algorithm [40] and the Sine-Cosine algorithm [27].

Fig. 4 shows an image segmented by the method based on the Sine-Cosine algorithm [27]. Fig. 5 shows an image segmented by the method based on the particle swarm algorithm [40].

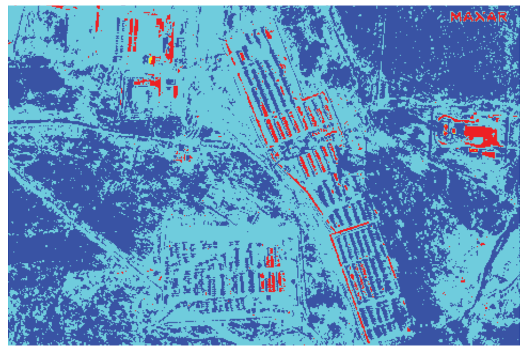

Fig. 4. Segmented image based on Sine-Cosine algorithm [27]

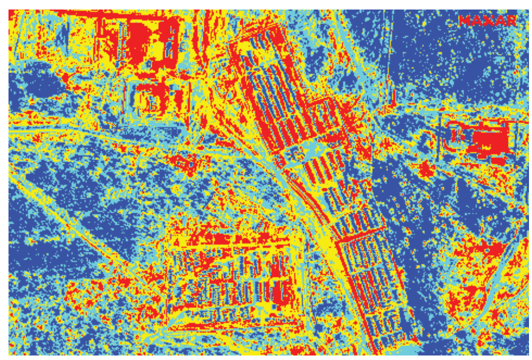

Fig. 5. Segmented image based on particle swarm algorithm [40]

Tables 2, 3 give the determined values of segmentation errors of the first (α_1) and second (β_2) kinds, respectively. The segmentation error values for methods based on particle swarm and Sine-Cosine algorithms are obtained from [40] and [27], respectively.

Table 2

Segmentation errors of the first kind (α_1)

Name of segmentation method	Image segmentation process number									
	1	2	3	4	5	6	7	8	9	10
Method based on particle swarm algorithm	24.9	27.3	24.7	25.4	26.1	25.5	27.1	24.6	25.4	26.1
Method based on the Sine-Cosine algorithm	19.3	20.8	20.2	19.1	19.8	20.6	21.1	19.8	19.5	20.1
Advanced method based on firefly algorithm	18.7	18.9	18.3	18.0	17.9	18.1	18.7	18.0	17.8	18.6

Table 3

Segmentation errors of the second kind (β_2)

Name of segmentation method	Image segmentation process number									
	1	2	3	4	5	6	7	8	9	10
Method based on particle swarm algorithm	22.9	23.1	22.2	23.6	24.1	22.2	23.6	22.6	22.9	23.2
Method based on the Sine-Cosine algorithm	18.9	19.2	19.4	18.2	18.3	19.0	19.4	18.2	18.6	18.3
Advanced method based on firefly algorithm	17.3	17.8	17.9	17.2	17.0	17.3	17.9	17.2	17.2	16.9

Fig. 6, 7 show the dependence of segmentation errors of the first (α_1) and second (β_2) kinds for different implementations (from 1 to 10).

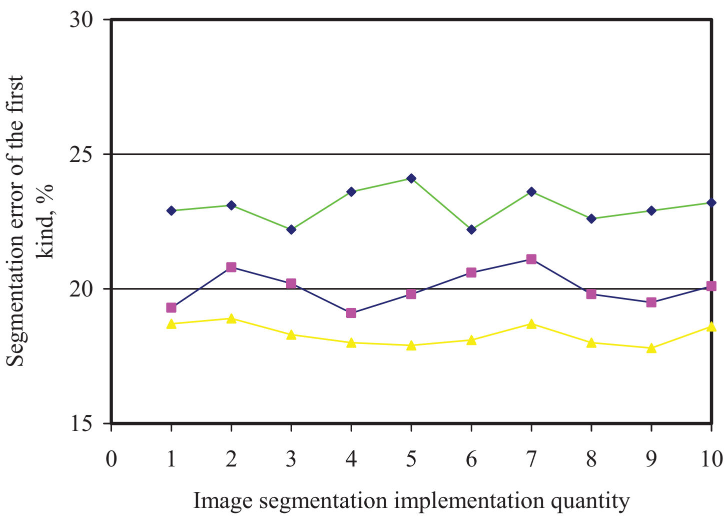

Fig. 6. The value of segmentation errors of the first kind

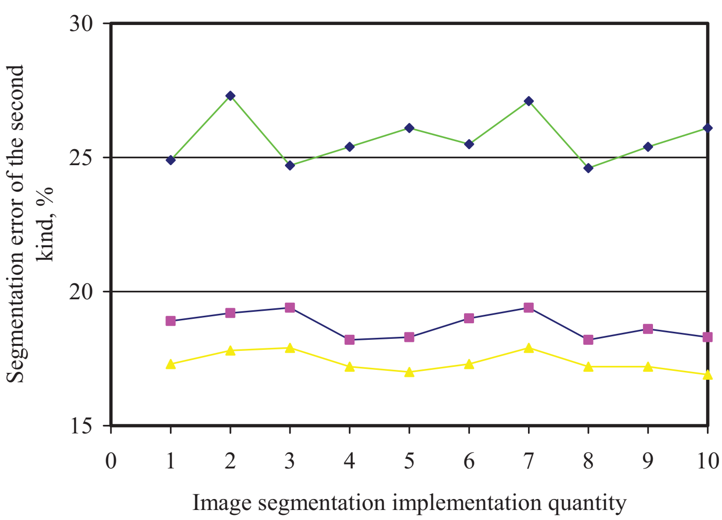

Fig. 7. The value of segmentation errors of the second kind

Fig. 6, 7 show by the green curve the segmentation errors for a method based on the particle swarm algorithm. The blue curve indicates segmentation errors for a method based on the Sine-Cosine algorithm. The yellow curve indicates segmentation errors for the improved method based on the firefly algorithm.

From Tables 2, 3, Fig. 6, 7, it was found that the improved method based on the firefly algorithm reduces the error of the first kind by approximately 11 % and the error of the second kind by approximately 9 %. The use of the firefly algorithm has provided such a reduction in segmentation errors.

6. Discussion of results of the study on improving the segmentation method based on the firefly algorithm

The method of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm, unlike known ones, involves the following:

– the pre-selection of brightness channels of the Red-Green-Blue color space in the original image;

– calculation of the level of luminosity for each firefly;

– assigning each firefly with the neighboring firefly, within a certain radius, whose level of luminosity is higher than the natural level of luminosity of the firefly;

– determination of the coordinate of the updated position of the firefly in each brightness channel.

An experimental study into the segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm was carried out (Fig. 3). The analysis of Fig. 3 shows that the improved method of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm does make it possible to segment images.

The quality of image segmentation by the method based on the firefly algorithm was evaluated. From the analysis of Tables 2, 3, Fig. 6, 7, it was found that the improved segmentation method based on the firefly algorithm reduces the segmentation error of the first kind by an average of 11 % and the segmentation error of the second kind by an average of 9 %. This becomes possible through the use of the firefly algorithm.

The uniqueness of our study is the application of the firefly algorithm to segment optoelectronic images acquired from space observation systems. This, in turn, led to a reduction in segmentation errors of the first and second kinds.

The assumptions and limitations adopted in the study are as follows:

– an optoelectronic image from a space observation system is considered;

– the color space of representation of the original optoelectronic image – Red-Green-Blue (RGB);

– heterogeneity of representation of objects of interest;

– the size of objects of interest is much smaller than the size of background objects on an optoelectronic image;

– when segmenting an optoelectronic image, the influence of distorting factors is not taken into account;

– when assessing the quality, errors of the first and second kinds are calculated.

The method of segmentation based on the firefly algorithm can be implemented in the software and hardware complex of image processing from space observation systems.

The disadvantage of the method is the increase in errors of the first and second kinds when exposed to distorting factors.

Further studies may focus on comparing the quality of segmentation by the method based on the firefly algorithm with methods based on the genetic algorithm.

7. Conclusions

1. The method of segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm, unlike known ones, involves the following:

– the pre-selection of brightness channels of the Red-Green-Blue color space in the original image;

– calculation of the level of luminosity for each firefly;

– assigning each firefly with the neighboring firefly, within a certain radius, whose level of luminosity is higher than the natural level of luminosity of the firefly;

– determination of the coordinate of the updated position of the firefly in each brightness channel.

2. An experimental study into the segmentation of optoelectronic images acquired from space observation systems based on the firefly algorithm was carried out. It is established that the improved method based on the firefly algorithm does make it possible to segment images.

3. The quality of image segmentation by the method based on the firefly algorithm was evaluated. It was found that the improved method based on the firefly algorithm reduces the segmentation error of the first kind by an average of 11 % and the segmentation error of the second kind by an average of 9 %. This becomes possible by using the firefly algorithm.

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 and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available in the main text of the manuscript.

References

1. Sharad, W. (2021). The development of the earth remote sensing from satellite. Mechanics of Gyroscopic Systems, 40, 46–54. doi: https://doi.org/10.20535/0203-3771402020248768
2. Amble, J. (2019). Mwi Podcast: Intelligence And The Future Battlefield, With Lt. Gen. Scott Berrier. Modern War Institute. Available at: https://mwi.usma.edu/mwi-podcast-intelligence-future-battlefield-lt-gen-scott-berrier/
3. Intelligence, Surveillance, and Reconnaissance Design for Great Power Competition (2020). Congressional Research Service. Available at: https://crsreports.congress.gov/product/pdf/R/R46389
4. Air & Space Operations Review. A Journal of Strategic Airpower & Spacepower. Available at: https://www.airuniversity.af.edu/ASOR/
5. Space, the unseen frontier in the war in Ukraine (2022). BBC News. Available at: https://www.bbc.com/news/technology-63109532
6. Khudov, H., Makoveichuk, O., Khizhnyak, I., Shamrai, B., Glukhov, S., Lunov, O. et al. (2022). The Method for Determining Informative Zones on Images from On-Board Surveillance Systems. International Journal of Emerging Technology and Advanced Engineering, 12 (8), 61–69. doi: https://doi.org/10.46338/ijetae0822_08
7. A developer's guide to working with geospatial data (2021). NGIS. Available at: https://ngis.com.au/Newsroom/A-developer's-guide-to-working-with-geospatial-dat
8. A Guide to Geospatial Data Analysis, Visualisation & Mapping. Spyrosoft. Available at: https://spyro-soft.com/a-guide-to-geospatial-data-analysis-visualisation-mapping
9. Gomes, V., Queiroz, G., Ferreira, K. (2020). An Overview of Platforms for Big Earth Observation Data Management and Analysis. Remote Sensing, 12 (8), 1253. doi: https://doi.org/10.3390/rs12081253
10. Kumar, S., Kumar, A., Lee, D.-G. (2022). Semantic Segmentation of UAV Images Based on Transformer Framework with Context Information. Mathematics, 10 (24), 4735. doi: https://doi.org/10.3390/math10244735
11. Meeboonmak, N., Cooharojananone, N. (2020). Aircraft Segmentation from Remote Sensing Images using Modified Deeply Supervised Salient Object Detection with Short Connections. 2020 International Conference on Mathematics and Computers in Science and Engineering (MACISE). doi: https://doi.org/10.1109/macise49704.2020.00040
12. Favorskaya, M. N., Zotin, A. G. (2021). Semantic segmentation of multispectral satellite images for land use analysis based on embedded information. Procedia Computer Science, 192, 1504–1513. doi: https://doi.org/10.1016/j.procs.2021.08.154
13. Grosgeorge, D., Arbelot, M., Goupilleau, A., Ceillier, T., Allioux, R. (2020). Concurrent Segmentation and Object Detection CNNs for Aircraft Detection and Identification in Satellite Images. IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium. doi: https://doi.org/10.1109/igarss39084.2020.9323338

14. Safarov, F., Temurbek, K., Jamoljon, D., Temur, O., Chedjou, J. C., Abdusalomov, A. B., Cho, Y.-I. (2022). Improved Agricultural Field Segmentation in Satellite Imagery Using TL-ResUNet Architecture. Sensors, 22 (24), 9784. doi: https://doi.org/10.3390/s22249784
15. Neupane, B., Horanont, T., Aryal, J. (2021). Deep Learning-Based Semantic Segmentation of Urban Features in Satellite Images: A Review and Meta-Analysis. Remote Sensing, 13 (4), 808. doi: https://doi.org/10.3390/rs13040808
16. Zhang, Q., Hughes, N. (2023). Towards a manual-free labelling approach for deep learning-based ice floe instance segmentation in airborne and high-resolution optical satellite images. doi: https://doi.org/10.5194/egusphere-2023-295
17. Niu, Z., Li, H. (2019). Research and analysis of threshold segmentation algorithms in image processing. Journal of Physics: Conference Series, 1237 (2), 022122. doi: https://doi.org/10.1088/1742-6596/1237/2/022122
18. Li, D., Wang, Y. (2018). Application of an improved threshold segmentation method in SEM material analysis. IOP Conference Series: Materials Science and Engineering, 322, 022057. doi: https://doi.org/10.1088/1757-899x/322/2/022057
19. Jha, S. K., Bannerjee, P., Banik, S. (2013). Random Walks based Image Segmentation Using Color Space Graphs. Procedia Technology, 10, 271–278. doi: https://doi.org/10.1016/j.protcy.2013.12.361
20. Smelyakov, K., Chupryna, A., Hvozdiev, M., Sandrkin, D. (2019). Gradational Correction Models Efficiency Analysis of Low-Light Digital Image. 2019 Open Conference of Electrical, Electronic and Information Sciences (EStream). doi: https://doi.org/10.1109/estream.2019.8732174
21. Smelyakov, K., Hvozdiev, M., Chupryna, A., Sandrkin, D., Martovytskyi, V. (2019). Comparative Efficiency Analysis of Gradational Correction Models of Highly Lighted Image. 2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T). doi: https://doi.org/10.1109/picst47496.2019.9061356
22. Ibrahim, N. S., Sharun, S. M., Osman, M. K., Mohamed, S. B., S. Abdullah, S. H. Y. (2021). The application of UAV images in flood detection using image segmentation techniques. Indonesian Journal of Electrical Engineering and Computer Science, 23 (2), 1219. doi: https://doi.org/10.11591/ijeecs.v23.i2.pp1219-1226
23. Li, H., Tang, Y., Liu, Q., Ding, H., Jing, L., Lin, Q. (2014). A novel multi-resolution segmentation algorithm for highresolution remote sensing imagery based on minimum spanning tree and minimum heterogeneity criterion. 2014 IEEE Geoscience and Remote Sensing Symposium. doi: https://doi.org/10.1109/igarss.2014.6947070
24. Ruban, I., Khudov, H., Makoveichuk, O., Chomik, M., Khudov, V., Khizhnyak, I. et al. (2019). Construction of methods for determining the contours of objects on tonal aerospace images based on the ant algorithms. Eastern-European Journal of Enterprise Technologies, 5 (9 (101)), 25–34. doi: https://doi.org/10.15587/1729-4061.2019.177817
25. Khudov, H., Ruban, I., Makoveichuk, O., Pevtsov, H., Khudov, V., Khizhnyak, I. et al. (2020). Development of methods for determining the contours of objects for a complex structured color image based on the ant colony optimization algorithm. EUREKA: Physics and Engineering, 1, 34–47. doi: https://doi.org/10.21303/2461-4262.2020.001108
26. Khudov, H., Makoveichuk, O., Khudov, V., Khizhnyak, I., Khudov, R., Maliuha, V. et al. (2023). Development of a two-stage method for segmenting the color images of urban terrain acquired from space optic-electronic observation systems based on the ant algorithm and the hough algorithm. Eastern-European Journal of Enterprise Technologies, 1 (9 (121)), 49–61. doi: https://doi.org/10.15587/1729-4061.2023.274360
27. Khudov, H., Makoveichuk, O., Khudov, V., Maliuha, V., Andriienko, A., Tertyshnik, Y. et al. (2022). Devising a method for segmenting images acquired from space optical and electronic observation systems based on the Sine-Cosine algorithm. Eastern-European Journal of Enterprise Technologies, 5 (9 (119)), 17–24. doi: https://doi.org/10.15587/1729-4061.2022.265775
28. Khudov, H., Makoveichuk, O., Butko, I., Gyrenko, I., Stryhun, V., Bilous, O. et al. (2022). Devising a method for segmenting camouflaged military equipment on images from space surveillance systems using a genetic algorithm. Eastern-European Journal of Enterprise Technologies, 3 (9 (117)), 6–14. doi: https://doi.org/10.15587/1729-4061.2022.259759
29. Ruban, I., Khudov, H., Makoveichuk, O., Butko, I., Glukhov, S., Khizhnyak, I. et al. (2022). Application of the Particle Swarm Algorithm to the Task of Image Segmentation for Remote Sensing of the Earth. Lecture Notes in Networks and Systems, 573–585. doi: https://doi.org/10.1007/978-981-19-5845-8_40
30. Ruban, I., Khudov, H., Makoveichuk, O., Khudov, V., Kalimulin, T., Glukhov, S. et al. (2022). Methods of UAVs images segmentation based on k-means and a genetic algorithm. Eastern-European Journal of Enterprise Technologies, 4 (9 (118)), 30–40. doi: https://doi.org/10.15587/1729-4061.2022.263387
31. Chen, K., Zhou, Y., Zhang, Z., Dai, M., Chao, Y., Shi, J. (2016). Multilevel Image Segmentation Based on an Improved Firefly Algorithm. Mathematical Problems in Engineering, 2016, 1–12. doi: https://doi.org/10.1155/2016/1578056
32. Hema, C., Sankar, S. et al. (2017). Performance comparison of dragonfly and firefly algorithm in the RFID network to improve the data transmission. Journal of Theoretical and Applied Information Technology, 95 (1), 59–67.
33. Satellite Imagery. Available at: https://www.maxar.com/products/satellite-imagery
34. Müller, D., Soto-Rey, I., Kramer, F. (2022). Towards a guideline for evaluation metrics in medical image segmentation. BMC Research Notes, 15 (1). doi: https://doi.org/10.1186/s13104-022-06096-y

35. Khudov, H., Makoveichuk, O., Khizhnyak, I., Glukhov, S., Shamrai, N., Rudnichenko, S. et al. (2022). The Choice of Quality Indicator for the Image Segmentation Evaluation. International Journal of Emerging Technology and Advanced Engineering, 12 (10), 95–103. doi: https://doi.org/10.46338/ijetae1022_11
36. Smelyakov, K., Shupyliuk, M., Martovytskyi, V., Tovchyrechko, D., Ponomarenko, O. (2019). Efficiency of image convolution. 2019 IEEE 8th International Conference on Advanced Optoelectronics and Lasers (CAOL). doi: https://doi.org/10.1109/caol46282.2019.9019450
37. Hudov, G. V. (2003). Specific Features of Optimization of Two-Alternative Decisions in Joint Search and Detection of Objects. Journal of Automation and Information Sciences, 35 (9), 40–46. doi: https://doi.org/10.1615/jautomatinfscien.v35.i9.50
38. Khudov, H., Makoveichuk, O., Misiuk, D., Pievtsov, H., Khizhnyak, I., Solomonenko, Y. (2022). Devising a method for processing the image of a vehicle's license plate when shooting with a smartphone camera. Eastern-European Journal of Enterprise Technologies, 1 (2 (115)), 6–21. doi: https://doi.org/10.15587/1729-4061.2022.252310
39. Smelyakov, K., Datsenko, A., Skrypka, V., Akhundov, A. (2019). The Efficiency of Images Reduction Algorithms with Small-Sized and Linear Details. 2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T). doi: https://doi.org/10.1109/picst47496.2019.9061250
40. Khudov, H., Makoveichuk, O., Khizhnyak, I., Oleksenko, O., Khazhanets, Y., Solomonenko, Y. et al. (2022). Devising a method for segmenting complex structured images acquired from space observation systems based on the particle swarm algorithm. Eastern-European Journal of Enterprise Technologies, 2 (9 (116)), 6–13. doi: https://doi.org/10.15587/1729-4061.2022.255203