Problems of identification in information systems

UDC 004.932 **doi:** https://doi.org/10.20998/2522-9052.2024.1.01

Hennadii Khudov[1], Irina Khizhnyak[1], Sergey Glukhov[2], Nazar Shamrai[2], Vladislav Pavlii[1]

[1] Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine
[2] Military Institute of Taras Shevchenko National University, Kyiv, Ukraine

THE METHOD FOR OBJECTS DETECTION ON SATELLITE IMAGERY BASED ON THE FIREFLY ALGORITHM

Abstract. The **subject matter** of the article is the method for detecting of objects on satellite imagery based on the firefly algorithm. The **goal** is to develop a method for detecting of objects on satellite imagery based on the firefly algorithm. The **tasks** are: analysis of existing methods for detecting of objects of interest on satellite imagery, development of a method for detecting of objects on satellite imagery, practical verification of the method for detecting of objects on satellite imagery based on the firefly algorithm, and quantitative assessment of the quality of the proposed method. The **methods** used are: methods of digital image processing, methods of data clustering, mathematical apparatus of matrix theory, methods of swarm intelligence, methods of mathematical modeling, methods of optimization theory, analytical and empirical methods of image comparison. The following **results** are obtained. The advantages and disadvantages of the main methods and approaches to the processing of satellite imagery for the purpose of detecting objects of interest on them are determined. The general principle of operation of the firefly algorithm is considered. It presents a flowchart of the method for detecting of objects on satellite imagery based on the firefly algorithm in one color channel. The values of the input data and parameters for the operation of the algorithm were selected experimentally. Experimental studies were conducted on the operation of the method for detecting of objects on a real satellite imagery based on the firefly algorithm. The values of the errors of the first and second kind for the processed image using the proposed method and the method based on the particle swarm algorithm were calculated. **Conclusions.** Analysis of the calculated values showed that the proposed method for detecting of objects on satellite imagery compared to the method based on the particle swarm algorithm: reduces the error of the first kind by about 11% and the error of the second kind by about 9%. The directions of further research are the study of the problem of selecting input parameters and data for the operation of the method based on the firefly algorithm.

Keywords: satellite imagery; object; segmentation; swarm intelligence algorithm; Firefly Algorithm.

Introduction

Formulation of the problem. Today, situational awareness is especially important for planning different actions, obtaining operational, reliable and detailed information. Therefore, the development of special platforms that provide situational awareness and are located "in the cloud" has been relevant [1, 2].

According to the plan, specialists are appointed who act according to the approved protocol. Their main task is to collect all possible primary information from various sources about the situation that aroused interest. Such sources of information are data from drones, from all radars, from satellites, from sta-tionary cameras, from sensors, from allies, from in-formants and scouts, from automated sources (for example, information systems, chatbots, etc.).

Before loading useful information into the situational awareness system (for example, displaying it on a digital map), all information received from various sources must be analyzed, brought to a standardized form and processed. Processing is the most important stage for obtaining useful information for consumers.

In this article, the main attention is paid to the processing of information received from the satellites. This is due to the fact that data from satellites in the centers of situational awareness is in great demand due to [3]:

– the receiving data in real time;
– the objectivity and reliability of the received data;
– the availability in receiving and/or purchasing data through signed agreements with partner countries that own the satellites;
– the possibility of obtaining information from the territories of a large area;
– the absence of any restrictions on receiving data. This advantage is relevant when receiving information from enemy territory and/or temporarily occupied territory.

The optical-electronic images are the input information from the satellites. Such input data is immediately "passed" through automatic processing with the subsequent issuance of the results of such processing. Image processing algorithms do not always cope well with such a task. Therefore, it is often necessary to involve decryptors. But the automatic processing of satellite images significantly increases the speed of processing incoming information and, as a result, affects the pace of hostilities. After all, the faster useful information is provided to the situational awareness system, the faster the commanders will make a decision [1].

Analysis of recent research and publications. Well-known software tools for processing data of remote sensing of the Earth to detect objects of interest on satellite imagery use well-known processing methods. Specialized software tools must use a limited list of image processing methods and have the main disadvantage of using an individual data storage format [4].

In paper [5] proposed a method for detecting objects of interest based on simple linear iterative clustering. The advantage of the method [5] is the high speed of image processing and the reduction of the number of initial values for the operation of the method. The main disadvantage of [5] is the low quality of processing for complexly structured images and large-sized images.

In paper [6] proposed an improved segmentation method based on the ESEG spectral-texture approach. The advantage of the method [6] is the use of a single metric for both textural features and spectral features in a heterogeneous space. The disadvantage of [14] is good processing results only for multispectral images with ultra-high spatial resolution.

The paper [7] proposed a method of morphological segmentation of satellite imagery. This method based on a graph approach. The advantage of [7] is the elimination of the effect of impulse noise, which affects the quality of the image processing result. The disadvantage [7] is the need for careful selection of markers, because the quality of the segmentation result depends on the correct selection.

The paper [8] proposed the processing of satellite imagery using the convolutional neural network U-HardNet with the additional function of Hard-Swish activation. The disadvantages [8] are significant time costs for obtaining a training sample and working with transformed images to reduce binary cross-entropy losses. The main advantage of method [8] is the detection of different data sets.

In paper [9] proposed a method for detecting urban buildings on satellite imagery using deep learning. The advantage of [9] is the high accuracy of detection of urban objects. The disadvantage [9] is the impossibility of detecting other objects in the image, except for urban buildings.

In paper [10] proposed a method of processing aerial photographs using a fully convolutional artificial neural network. The advantage of [10] is the convenience of obtaining high-quality image processing results. The main disadvantage [10] is the need to involve a graphics accelerator due to large volumes of computing operations.

In paper [11] proposed a method of automatic processing of ultra-high resolution images on new lines. Lines are applied with the highest entropy value to obtain initial values and edges. The advantages of [11] are the automatic processing of all types of images of remote sensing of the earth without the involvement of a specialist decipherer. The main disadvantage of [11] is the low accuracy of detection on the imagery of small objects of interest.

In paper [12] proposed a method of image segmentation by watershed based on gradient values. The advantage of [12] is the segmentation of remote sensing images of the earth with high resolution of different color spaces. The disadvantage [12] is the mandatory intervention of a specialist to adjust the input parameters of the method.

The paper [13] proposed a method for processing satellite imagery using the TL-ResUNet residual architecture model. The advantage of the method [13] is the combination of the advantages of residual network, U-Net architecture and transfer learning. The disadvantage of [13] is the processing and analysis of satellite imagery of agricultural land.

The paper [14] proposed the detection of objects using short connections with a known data set with a division into a simple or complex case. The advantage of [14] is the high quality of processing complexly structured images with a complex background. The disadvantage of [14] is the detection of only one type of object of interest on the images - an aircraft.

Thus, the **goal** of the article is to improve a method for detecting of objects on satellite imagery.

Main results

In these latter days swarm intelligence algorithms have shown good results in solving both continuous and discrete optimization problems. Swarm intelligence algorithms are successfully used to solve problems with the following features, namely, with a high dimension of the search space and computational complexity, with a complex topology of the region of acceptable values and the absence of an analytical expression [15]. As well as non-linear, multi-extremal and non-differentiable problems [16]. The problem of image segmentation has precisely these features.

Swarm intelligence algorithms describe the collective behavior of an artificial or natural decentralized self-organizing system. Swarm intelligence is a set of agents (particles) that simultaneously interact with each other in the swarm and with the environment. One of the representatives of swarm intelligence algorithms is the Firefly Algorithm [15].

This algorithm is based on simulating the natural behavior of fireflies and the process of bioluminescence. The process of bioluminescence is responsible for the emission of the light and is the mechanism of communication between fireflies in a swarm. Each firefly has the ability to emit light. The light intensity for each firefly depends on the amount of special pigment [17]. So, the Firefly Algorithm is based on three basic rules, namely [18]:

1. All fireflies have the property of one-to-one attraction. The firefly will move to something more bright. The higher the level of the light of a firefly, the more other fireflies it will attract.

2. The brightness of a firefly, which is visible to other fireflies, decreases as the distance between them increases. This is due to the fact that air absorbs light. That is, a firefly with a lower level of the light will move towards a firefly with a higher level of the light. It will move chaotically if there is no firefly with a higher level of the light than its own.

3. The intensity of the light emitted by the firefly is determined by the value of the fitness function of the problem.

4. The radius of the search of each firefly depends on the number of fireflies in this area. If a large number of fireflies have gathered in the area of the search, then

the radius of the search decreases. If there are a small number of fireflies in the area of the search, then the radius of the search, on the contrary, increases.

Thus, the Firefly Algorithm includes four main stages: the formation of an initial swarm of fireflies and its distribution in the search space, updating the level of the light for each firefly, moving each firefly according to the established rule, and searching for the optimal solution throughout the algorithm iterations.

The search principle in the algorithm is based on a nonlinear decrease in the brightness of a firefly with increasing distance between them. In the absence of such a nonlinear relationship, each firefly would move deterministically towards the firefly with the highest level of light. And under this condition, the firefly will choose not the brightest neighbor (after all, its light will be absorbed by the environment as the distance increases), but the less bright one in the general swarm, but the brightest one in its surroundings [17-18].

This fact explains the ability of the algorithm to divide a general swarm into smaller ones. This property of the algorithm is fulfilled precisely because of the nonlinear function of firefly light absorption versus distance. Thus, we can assume that this algorithm can show good results for clustering problems.

In this paper, it is proposed to use the Firefly Algorithm to solve the problem of segmenting satellite imagery in order to detect objects on them.

It is proposed to consider the input image for each color channel in the form of a data matrix in a method for detecting of objects on satellite images based on the Firefly Algorithm. In such a data matrix, each element is an image pixel with coordinates (x_i, y_i) and a corresponding brightness value in the range [0...255] [16].

The proposed method for detecting of objects on satellite imagery based on the Firefly Algorithm in one color channel is shown in Fig. 1.

The method consists of the following stages [17, 18]:

1. Entering input data and parameters of the proposed method:

$F(\mathbf{X})$ – the input color satellite image;

$f(\mathbf{X})$ – the image in a separate color channel, where $\mathbf{X}(x_i, y_i)$ – are the coordinates of the pixel on $f(\mathbf{X})$;

K – the number of segments;

T – the maximum number of iterations of the algorithm;

I – the number of agents (fireflies) used in the algorithm;

r_i – the initial value of the radius of the search for each agent;

γ – the coefficient that determines the attractiveness of the agent;

ρ – the coefficient that determines the level of absorption and attenuation of the light ($0 < \rho < 1$);

l_0 – the initial level of the light of the agent.

2. Separation of color channels on the input color satellite image $F(\mathbf{X})$ and converting the brightness intensity of the image pixels into a code in each $f(\mathbf{X})$.

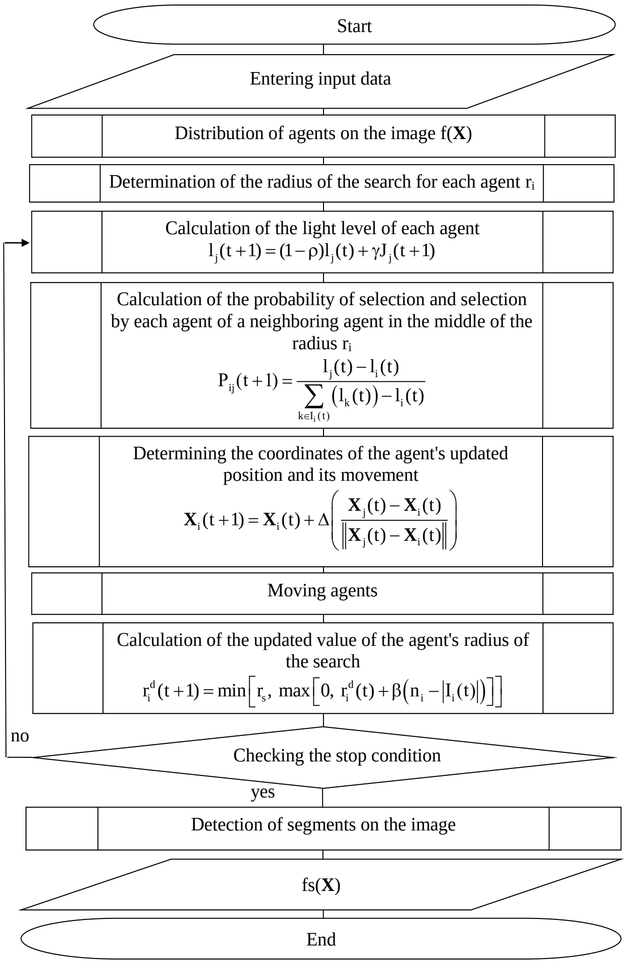

Fig. 1. The flowchart of the method for detecting of objects on satellite imagery based on the Firefly Algorithm in one color channel

Further stages of operation of the proposed method are applied to the image in each brightness channel.

3. Initialization of the population and random distribution of agents at initial positions throughout the image in the color channel $f(\mathbf{X})$ according to the expression (1):

$$\mathbf{X}_{i1} = rand(f(\mathbf{X})), \quad (1)$$

where $\mathbf{X}_{i1} = (x_{i1}, y_{i1})$ – the vector of positions of the agents on the first iteration of the operation of the method.

This operation is performed only on the first iteration of work of the proposed method, that is, when $t = 1$.

4. Determination of the radius of the search for each agent r_i randomly.

The beginning of the iterative process.

5. Calculation of the level of the light of each agent from the number I. All agents have the same level of the light l_0 at the first iteration of the proposed method. The level of the light of the agent is calculated according to the expression (2) starting from the next iteration:

$$l_i(\mathrm{t}+1) = (1-\rho) \cdot l_i(t) + \gamma \cdot \varphi_i(t+1), \quad (2)$$

where φ – the value of the fitness function; t – the current number of the iteration; i – the current number of the agent.

We calculate the fitness function according to the expression:

$$\varphi_i(t) = \frac{1}{1+\exp\left(D_i^m(t) / D_0\right)}; \quad (3)$$

where

$$D_i^m(\mathrm{t}) = \left|\Delta x_i^m(\mathrm{t})\right| + \left|\Delta y_i^m(\mathrm{t})\right| + \mathrm{k}\left|\Delta f_i^m(\mathrm{t})\right|, \quad (4)$$

$\Delta x_i^m(t)$ – moving the agent along the axis x in another m-th pixel of the image at the t-th iteration; $\Delta y_i^m(t)$ – moving the agent along the axis y in another m-th pixel of the image at the t-th iteration; $\Delta f_i^m(\mathrm{t})$ – the difference in values of the brightness at the t-th iteration; D_0 – the coefficient that takes into account the scale of the input image; k – the coefficient that takes into account differences in units of measurement, scales, brightness of pixels, etc.

6. Determination for each agent of that neighbor within the specified radius r_i, whose the level of the light l_i is higher than its own.

For this, the probabilities of movement of the i-th agent in the direction of the j-th agent are calculated according to the expression:

$$P_{ij}(\mathrm{t+1}) = \frac{l_j(\mathrm{t}) - l_i(\mathrm{t})}{\sum\limits_{n \in I_i(\mathrm{t})} \left(l_n(\mathrm{t})\right) - l_i(\mathrm{t})}, \quad (5)$$

where j – an agent with the level of the light l_i higher than that of i - th agent; $I_i(\mathrm{t})$ – the set of neighboring agents for the i-th agent at the t-th iteration.

An agent $j \in I_i(t)$ and is determined according to the expression:

$$I_i(t) = \left(j : d_{ij}(t) < r_i^d(t)\right), \quad (6)$$

where d_{ij} – is the Euclidean distance between agents i and j at the t-th iteration; $r_i^d(t)$ – the updated measurement value of the radius of the search for the i-th agent at the t-th iteration.

7. Determination of the coordinates of the updated position of the agent i, provided that this agent moves in the direction of the agent j according to the expression:

$$\mathbf{X}_i(t+1) = \mathbf{X}_i(t) + \Delta \cdot \left(\frac{\mathbf{X}_j(t) - \mathbf{X}_i(t)}{\left\|\mathbf{X}_j(t) - \mathbf{X}_i(t)\right\|}\right), \quad (7)$$

where Δ – the size of the movement step, measured in pixels.

8. Calculation of the updated value of the radius of the search of the agent i according to the expression:

$$r_i^d(t+1) = \\ = \min\left[r_s,\ max\left[0,\ r_i^d(t) + \alpha\left(n_i - \left|I_i(t)\right|\right)\right]\right], \quad (8)$$

where n_i – the coefficient affecting the number of possible neighboring agents for the i-th agent; α – the adjustable coefficient determined experimentally.

9. Checking of the condition for stopping the operation of the iterative process.

The only condition for stopping the operation of the algorithm is to reach a given number of iterations T. If the condition is met then it move to the next point. In case of non-execution then it move to point 5 of the next iteration of the work ($t+1$).

10. Division of the image into segments according to the value of the brightness in the updated positions of the agents. The result of the work is $fs(\mathbf{X})$.

11. Combining the results of the algorithm on individual brightness channels.

12. Determination of the resulting segmented image $Fs(\mathbf{X})$.

A color RGB image from the environment-monitoring satellite WorldView-2 was chosen as a test for the experimental study [19]. Such an initial image is presented in Fig. 2. The size of the input satellite image (1894×1367) pixels. Objects of interest in Fig. 2 are the objects, namely auxiliary facilities, equipment, etc.

Fig. 2. The input color satellite image [19]

Experimentally, the following values of input data and parameters were selected for the operation of the Firefly Algorithm. They are constant at each iteration and are equal to:

$I = 50$; $K = 5$; $r_i = 200$; $\rho = 0{,}1$; $\gamma = 0{,}2$; $l_0 = 0{,}01$.

The number of iterations is selected 20.

Experimental researches were carried out using the high-level programming language and interactive environment for programming, numerical calculations and visualization of results – MATLAB R2017b.

The result of the method for detecting of objects on satellite imagery based on the Firefly Algorithm for the test image (Fig. 2) with the above parameters is shown in Fig. 3. Visual analysis of the resulting image (Fig. 3) showed that the proposed method allows segmentation of the color satellite presented in the RGB color space. The number of segments is five. They are detected in pseudo-colors.

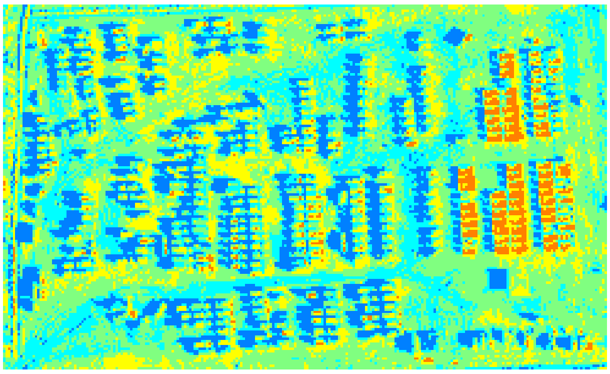

Fig. 3. The segmented input color satellite image (Fig. 1) by the proposed method

Let's calculate errors of the first kind and errors of the second kind for quantitative assessment of the quality of the resulting image using the proposed method. The error of the first kind for evaluating the quality of the resulting image by the proposed method is calculated according to expression [20]:

$$\alpha_1 = \frac{S_1\left(fs(\mathbf{X})\right)}{S_2\left(f(\mathbf{X})\right)}, \qquad (9)$$

where $S_1\left(fs(\mathbf{X})\right)$ – the total area of the background that falsely detected to objects on the segmented satellite image; $S_2\left(f(\mathbf{X})\right)$ – the real area of the background on input satellite image.

The error of the second kind for evaluating the quality of the resulting image by the proposed method is calculated according to expression [20]:

$$\beta_2 = 1 - \frac{S_3\left(fs(\mathbf{X})\right)}{S_4\left(f(\mathbf{X})\right)}, \qquad (10)$$

where $S_4\left(f(\mathbf{X})\right)$ – the real area of the objects on input satellite image; $S_3\left(fs(\mathbf{X})\right)$ – the total area of correctly segmented objects on the segmented satellite image.

We will choose the segmentation method based on the particle swarm algorithm for comparison [21].

The values of the error of the first kind and the error of the second kind were calculated according to expressions (9) and (10). Fig. 4 and Fig. 5 show the dependence of the calculated value of the error of the first kind and the value of the error of the second kind, respectively, for 10 iterations of work of the algorithm (Fig. 1).

In Fig. 4 and Fig. 5 the yellow curve indicates the values of the error of the first kind and the values of the error of the second kind when processing the input image (Fig. 2) using the improved method. The green curve indicates the values of the error of the first kind and the values of the error of the second kind when processing the input image (Fig. 2) by the method based on the particle swarm algorithm.

The analysis of the calculated values clearly shows (Fig. 4 and Fig. 5) that the proposed method for detecting of objects on satellite imagery in comparison with the method based on the particle swarm algorithm:

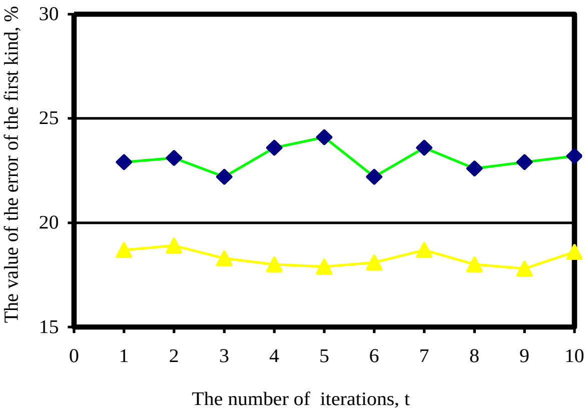

Fig. 4. The dependence of calculated value of the first kind of error for the two methods of segmentation

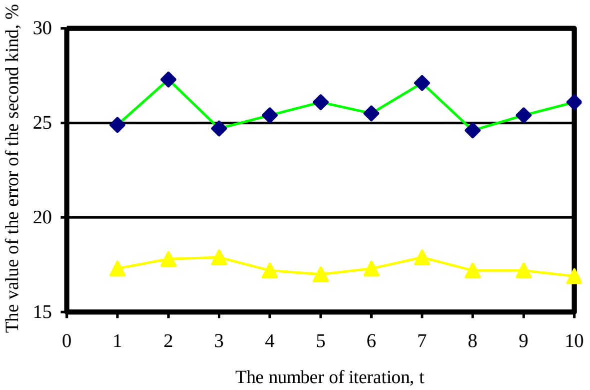

Fig. 5. The dependence of calculated value of the second kind of error for the two methods of segmentation

– reduces the error of the first kind by approximately 11 %;

– reduces the error of the second kind by approximately 9 %.

Conclusions and the directions of further research

The article examines the issue of automatic processing of satellite images as one of the main sources of operational, reliable and detailed information about the enemy that enters the situational awareness centers. Methods and approaches to automatic processing of satellite images are analyzed. Their main advantages and disadvantages are established.

It is proposed to use swarm intelligence algorithms to detect objects of equipment on input satellite images. This is due to the assumption that this group of algorithms shows good results when solving problems with the following features, namely, with a high dimensionality of the search space and computational complexity, with a complex topology of the domain of admissible values, and the absence of an analytical expression. And precisely such features are inherent in the problem of image segmentation.

In this paper, it is proposed to use one of the swarm intelligence algorithms, namely the Firefly Algorithm, to solve the problem of segmentation of satellite images in order to detect objects on them.

The basic operating principle of the Firefly Algorithm is discussed in detail. This article presents a flowchart of the method for detecting of objects on satellite imagery based on the Firefly Algorithm in one color channel.

The following values of input data and parameters were selected for the operation of the Firefly Algorithm experimentally.

This article presents the result of a method for detecting of objects on satellite images based on the Firefly algorithm on a real test image with selected values of parameters. The values of the error of the first kind and the error of the second kind were calculated to quantify the quality of the resulting image using the proposed method and using the method based on the particle swarm algorithm. The analysis of the calculated values clearly shows that the proposed method for detecting of objects on satellite imagery in comparison with the method based on the particle swarm algorithm:

– reduces the error of the first kind by approximately 11 %;

– reduces the error of the second kind by approximately 9 %.

The directions of further research is to study the problem of selecting algorithm parameters, such that their value greatly influences the result of the algorithm. In this work, these parameters were chosen experimentally and such a choice does not have any mathematical justification.

References

1. Honchar, Ia. (2023), *How the Delta Troop Management System Works*, available at: https://mil.in.ua/uk/articles/yak-pratsyuye-systema-upravlinnya-vijskamy-delta-interv-yu-zi-spivzasnovnykom-go-aerorozvidka-yaroslavom-goncharom/
2. Munir, A., Aved, A. and Blasch, E. (2022), “Situational Awareness: Techniques, Challenges, and Prospects”, *AI*, vol. 3 (1), pp. 55–77, doi: https://doi.org/10.3390/ai3010005
3. Fedorov M. (2023), *Ukraine presented its situational awareness system at the NATO Tide Sprint event*, We are Ukraine, available at: https://www.weareukraine.info/ukraine-presented-its-situational-awareness-system-at-the-nato-tide-sprint-event/
4. Khizhnyak, I. (2019), “Applied Information Technology of Thematic Segmentation of Optical-Electronic Images from On-board Systems of Remote Sensing of the Earth”, *Advanced Information Systems*, vol. 3, no. 2, pp. 40–46, doi: https://doi.org/10.20998/2522-9052.2019.2.07
5. Al-Azawi, R. J., Al-Jubouri, Q. S. and Mohammed, Y. A. (2019), “Enhanced Algorithm of Superpixel Segmentation Using Simple Linear Iterative Clustering”, *IEEE 12th International Conference on Developments in eSystems Engineering (DeSE)*, vol. 19568614, doi: https://doi.org/10.1109/DeSE.2019.00038
6. Pestunov, I. A., Rylov, S. A. and Berikov V. B. (2015), “Hierarchical clustering algorithms for segmentation of multispectral images”, *Optoelectronics Instrumentation and Data Processing*, vol. 50 (4), pp. 329–338, doi: https://doi.org/10.3103/S8756699015040020
7. Pesaresi, M. and Benediktsson, J. A. (2001), “A new approach for the morphological segmentation of high-resolution satellite imagery”, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 39 (2), pp. 309–320, doi: https://doi.org/10.1109/36.905239
8. Avenash, R. and Viswanath, P. (2019), “Semantic Segmentation of Satellite Images using a Modified CNN with Hard-Swish Activation Function”, *14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP)*, pp. 413–420, doi: https://doi.org/10.5220/0007469604130420
9. Neupane, B., Horanont, T. and Aryal, J. (2021), “Deep Learning-Based Semantic Segmentation of Urban Features in Satellite Images: A Review and Meta-Analysis”, *Remote Sensing*, vol. 13(4), 808, doi: https://doi.org/10.3390/rs13040808
10. Long, J., Shelhamer, E. and Darrell, T. (2015), “Fully convolutional networks for semantic segmentation”, *IEEE Conference on Computer Vision and Pattern Recognition*, pp. 3431–3440, doi: https://doi.org/10.1109/CVPR.2015.7298965
11. Lopez, J., Branch, J. W. and Chen, G. (2019), “Line-based image segmentation method: a new approach to segment VHSR remote sensing images automatically”, *European Journal of Remote Sensing*, vol. 52 (1), pp. 613–631, doi: https://doi.org/10.1080/22797254.2019.1699449
12. Xue, Y., Zhao, J. and Zhang, M. (2021), “A Watershed-Segmentation-Based Improved Algorithm for Extracting Cultivated Land Boundaries”, *Remote Sensing*, vol. 13 (939), doi: https://doi.org/ 10.3390/rs13050939
13. Safarov, F., Temurbek, K., Jamoljon, D., Temur, O., Chedjou, J. C., Abdusalomov, A. B. and Cho, Y. I. (2022), “Improved Agricultural Field Segmentation in Satellite Imagery Using TL-ResUNet Architecture”, *Sensors*, vol. 22 (24), 9784, doi: https://doi.org/10.3390/s22249784
14. Meeboonmak, N. and Cooharojananone, N. (2020), “Aircraft Segmentation from Remote Sensing Images using Modified Deeply Supervised Salient Object Detection with Short Connections”, *IEEE International Conference on Mathematics and Computers in Science and Engineering (MACISE)*, 20504366, doi: https://doi.org/10.1109/MACISE49704.2020.00040
15. Hassanien, E. and Emary, E. (2016), “Swarm Intelligence Principles, Advances, and Applications”, CRC Press, 220 p., doi: https://doi.org/10.1201/9781315222455
16. Ruban, I., Khudov, H., Makoveichuk, O., Khizhnyak, I., Lukova-Chuiko, N., Pevtsov, G., Sheviakov, Y., Yuzova, I., Drob, Y. and Tytarenko, O. (2019), “Method for Determining Elements of Urban Infrastructure Objects Based on the Results from Air Monitoring”, *Eastern-European Journal of Enterprise Technologies*, № 4/9 (100), pp. 52–61, doi: https://doi.org/10.15587/1729-4061.2019.174576
17. Chen, K., Zhou, Y., Zhang, Z., Dai, M., Chao, Y. and Shi J. (2016), “Multilevel Image Segmentation Based on an Improved Firefly Algorithm”, *Mathematical Problems in Engineering*, pp. 1–12. doi: https://doi.org/10.1155/2016/1578056
18. Hema C., Sankar S. and Sandhya. (2017), “Performance comparison of dragonfly and firefly algorithm in the RFID network to improve the data transmission”, *Journal of Theoretical and Applied Information Technology*, vol. 95 (1), pp. 59–67, available at: https://www.jatit.org/volumes/Vol95No1/7Vol95No1.pdf
19. (2023), “WorldView-2 Satellite Image Gallery Satellite”, *Imaging Corporation*, available at: https://www.satimagingcorp.com/gallery/worldview-2/

20. Khudov, H., Makoveichuk, O., Khizhnyak, I., Glukhov, S.,, Shamrai, N., Rudnichenko, S., Husak, M. and Khudov, R, (2022), "The Choice of Quality Indicator for the Image Segmentation Evaluation", *International Journal of Emerging Technology and Advanced Engineering*, No. 12 (10), pp. 95–103, doi: https://doi.org/10.46338/ijetae1022_11
21. Khudov, H., Makoveichuk, O., Khizhnyak, I., Oleksenko, O., Khazhanets, Y., Solomonenko, Y., Yuzova, I., Dudar, Y., Stetsiv, S. and Khudov, V. (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*, No. 2 /9 (116), pp. 6–13, doi: https://doi.org/10.15587/1729-4061.2022.255203

Received (Надійшла) 11.11.2023
Accepted for publication (Прийнята до друку) 13.02.2024

ABOUT THE AUTHORS / ВІДОМОСТІ ПРО АВТОРІВ

Худов Геннадій Володимирович – доктор технічних наук, професор, начальник кафедри тактики радіотехнічних військ, Харківський національний університет Повітряних Сил імені Івана Кожедуба, Харків, Україна;
Hennadii Khudov – Doctor of Technical Sciences, Professor, Head of Department of Radar Troops Tactic, Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine;
e-mail: 2345kh_hg@ukr.net; ORCID ID: https://orcid.org/0000-0002-3311-2848;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57196079841.

Хижняк Ірина Анатоліївна – кандидат технічних наук, професор кафедри тактики радіотехнічних військ, Харківський національний університет Повітряних Сил імені Івана Кожедуба, Харків, Україна;
Irina Khizhnyak – Candidate of Technical Sciences, Professor of Department of Radar Troops Tactic, Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine;
e-mail: khizh_ia@ukr.net; ORCID ID: https://orcid.org/0000-0003-3431-7631;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57196075236.

Глухов Сергій Іванович – доктор технічних наук, професор, завідувач кафедри військової та технічної підготовки, Військовий інститут Київського національного університету імені Тараса Шевченка, Київ, Україна;
Sergey Glukhov – Doctor of Technical Sciences, Professor, Head of Department of Military and Technical Training, Military Institute of Taras Shevchenko Kyiv National University, Kyiv, Ukraine;
e-mail: serg.glukhov@gmail.com; ORCID ID: https://orcid.org/0000-0002-4918-3739;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57365576700.

Шамрай Назар Миколайович – старший науковий співробітник відділу військово-технічних та інформаційних досліджень, Військовий інститут Київського національного університету імені Тараса Шевченка, Київ, Україна;
Nazar Shamrai – Senior Reseacher of Department of Military Technical and Information Research, Military Institute of Taras Shevchenko Kyiv National University, Kyiv, Ukraine;
e-mail: shamrainazar_1981@ukr.net; ORCID ID: http://orcid.org/0000-0001-8387-3277;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57218796748.

Павлій Владислав Олександрович – кандидат технічних наук, науковий співробітник Наукового центру Повітряних Сил, Харківський національний університет Повітряних Сил імені Івана Кожедуба, Харків, Україна;
Vladislav Pavlii – Candidate of Technical Sciences, Reseacher of Scientific Air Force Centre, Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine;
e-mail: v_pavlii_1968@ukr.net; ORCID ID: https://orcid.org/0000-0003-3992-3884;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57208329027.

Метод виявлення об'єктів на супутникових знімках на основі алгоритму світлячків

Г. В. Худов, І. А. Хижняк, С. І. Глухов, Н. М. Шамрай, В. О. Павлій

Анотація. Предметом вивчення в статті є метод виявлення об'єктів на супутникових знімках на основі алгоритму світлячків. **Метою** є розробка методу виявлення об'єктів на супутникових знімках на основі алгоритму світлячків. **Завдання:** аналіз існуючих методів виявлення об'єктів інтересу на супутникових знімках, розробка методу виявлення об'єктів на супутникових знімках, практична перевірка роботи методу виявлення об'єктів на супутникових знімках на основі алгоритму світлячків та кількісна оцінка якості роботи запропонованого методу. Використовуваними **методами** є: методи цифрової обробки зображень, методи кластеризації даних, математичний апарат теорії матриць, методи ройового інтелекту, методи математичного моделювання, методи теорії оптимізації, аналітичні та емпіричні методи порівняння зображень. Отримані такі **результати.** Визначені переваги та недоліки основних методів та підходів до обробки супутникових знімків з метою виділення об'єктів інтересу на них. Розглянуто загальний принцип роботи алгоритму світлячків. Розроблено блок-схему алгоритму для методу виявлення об'єктів на супутникових знімках на основі алгоритму світлячків в одному кольоровому каналі. Експериментально підібрано значення вхідних даних і параметрів для роботи алгоритму. Проведені експериментальні дослідження щодо роботи методу виявлення об'єктів на реальному супутниковому знімку на основі алгоритму світлячків. Розраховано значення похибок першого та другого роду для обробленого зображення запропонованим методом та методом на основі алгоритму рою частинок. **Висновки.** Аналіз розрахункових значень показав, що запропонований метод виявлення об'єктів на космічних знімках у порівнянні з методом на основі алгоритму рою частинок: зменшує похибку першого роду приблизно на 11 % та похибку другого роду приблизно на 9 %. Напрямками подальших досліджень є вивчення проблеми підбору вхідних параметрів та даних для роботи методу на основі алгоритму світлячків.

Ключові слова: супутникові знімки, об'єкт, сегментація, алгоритм ройового інтелекту, алгоритм світлячків.