Problems of identification in information systems

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THE SMALL AERIAL OBJECTS SEGMENTATION METHOD ON OPTICAL-ELECTRONIC IMAGES BASED ON THE SOBEL EDGE DETECTOR

Abstract. The **subject matter** in the article is the stage of segmentation of small aerial objects on images obtained from an optical-electronic system. The **goal** is to develop a small aerial object segmentation method based on optical-electronic images based on the Sobel edge detector. The **tasks** are: analysis of existing methods of segmentation of optical-electronic images; development of a method of segmentation of small aerial objects on images obtained from an optical-electronic system; practical verification of the method of segmentation of small aerial objects on optical-electronic images based on the Sobel operator. The **methods** used are methods of system analysis, mathematical methods of image comparison, methods of digital image processing, methods of discrete mathematics, probability theory, mathematical apparatus of matrix theory, and methods of analytical geometry. The following **results** are obtained. The features of the images obtained from optical-electronic systems when searching for a multi-dimensional aerial object are considered, and the segmentation methods that allow the detection of the object of interest on the optical-electronic images are analyzed. It has been established that it is necessary to use image segmentation methods that are easy to implement and calculate. It is proposed that segmentation be carried out using a method based on the Sobel edge detector. The proposed method includes two successive stages. This is processing with a Gaussian filter and applying the histogram equalization operation in the first stage, and applying the Sobel edge detector to the results of the first stage in the second. A block diagram of the proposed segmentation method is presented. Experimental studies on the detection of a small aerial object on authentic optical-electronic images have been carried out, and the results of segmentation using the classical Sobel edge detector and the proposed method are given. A visual assessment of the quality of segmentation results using these methods was carried out. **Conclusions.** A method of segmentation of small aerial objects on optical-electronic images based on the Sobel edge detector has been developed. The direction of further research is to evaluate the quality of segmented images by numerical indicators.

Keywords: image segmentation; optical-electronic system; small aerial object; unmanned aerial vehicle; Sobel edge detector; Gaussian filter; Sobel filter.

Introduction

Formulation of the problem. The development of optical-electronic technologies opens up wide opportunities for observation and analysis of air space in various fields, in particular in air navigation, environmental monitoring, air traffic control, and scientific research of the atmosphere. One of the important tasks in this context is the segmentation of small aerial objects on optical-electronic images. This allows the detection and identification of natural and man-made objects such as birds, weather probes, or unmanned aerial vehicles (drones) [1].

The most relevant today is the identification and detection of drones precisely because of their active use in war. The experience of previous armed conflicts showed that such a number of drones as in Ukraine had not been used in the entire history of wars [2, 3].

In this article, the main attention is paid to solving the problem of finding a small-sized aerial object using an optical-electronic surveillance system. By small aerial object, we mean an unmanned aerial vehicle.

To solve this problem, it is necessary to perform the task of processing the image received from an optical-electronic system in order to detect a small aerial object on it, namely an unmanned aerial vehicle. At the same time, the main problem is the peculiarities of image processing obtained from an optical-electronic system. The image obtained from an optical-electronic system of an unmanned aerial vehicle is often of poor quality due to the limitations of the low-resolution camera and the fact that both the drone and the aerial object are moving [4, 5]. When solving, for example, the specific task of searching for a large-sized aerial object using an optical-electronic surveillance system installed on an unmanned aerial vehicle, it is greater than when solving the task of reconnaissance of a stationary object of interest.

The process of image processing includes several stages, but one of the most important is the stage of image segmentation. The quality of detecting the object of interest in the optical-electronic image depends on the segmentation result.

Therefore, the relevance of this issue is due to the need to increase the accuracy and speed of automated image analysis in conditions of changing lighting, atmospheric obstacles, and low contrast of objects. Improvement of segmentation methods will contribute to the solution of issues as well as improvement in other areas of human activity, namely environmental monitoring, control of bird migration, optimization of air navigation systems, and development of artificial intelligence in the field of computer vision.

Analysis of recent research and publications. The analysis of well-known segmentation methods showed that there are a large number of them today [6]. However, the authors conclude that it is necessary to use algorithms for the segmentation of digital images that are simple to implement and calculate. This conclusion is connected to the given features of the received original image from an optical-electronic system [7, 8].

In [6] is considered the group of methods for detecting edges in an image using filters. These are operators of Prewitt, Roberts, Kirsch, Sobel, etc. The main difference between these operators is the weighting coefficients in the kernels. The advantage is the processing of the entire image without gaps. The disadvantage of spatial filtering is the difficulty in selecting coefficients for the kernel.

The well-known Canny edge detector also belongs to the group of edge detection methods based on spatial filtering. In [9], it is proposed to use an improved method of detecting by Canny edge detector. However, the improved method requires a lot of time, and the resulting image has a large number of edges, even "weak" ones, which are irrelevant for this task.

In [10], a method of image segmentation is proposed, which is obtained using an RGB camera located on an unmanned aerial vehicle. The advantage [10] is remote image segmentation and decision-making without human intervention. The disadvantage [10] is the limited range of problems that can be solved using this method, namely the task of identifying safe and dangerous places for landing a drone.

In [11], it is proposed to use machine learning methods based on ensemble decision trees with an object-oriented approach to detect objects of interest on images obtained from unmanned aerial vehicles. The advantage of [11] is the high speed and accuracy of detection of objects of interest. The disadvantage is the detection of only a certain list of objects of interest.

In [12], the use of a network based on U-Net is proposed for the segmentation of images from an unmanned aerial vehicle. The advantage of [12] is the accuracy of pixels and the smoothness of the edges in the resulting image. This was made possible by replacing the transposed convolutional layer with a subpixel one in the U-Net upsampling block. The disadvantage of [12] is the time spent on training the deep segmentation network.

In [13], it is proposed that the method of support vectors be used for the segmentation of images from an unmanned aerial vehicle. The disadvantages of [13] are obtaining good results only on high-resolution images and segmentation of orthophotos. The advantage of [13] is the high quality of segmentation of orthophotos already at the first stage.

In [14], it is proposed that the k-means method be used for processing images of remote sensing of the earth in order to detect the objects of interest. The advantage of [14] is the speed of image processing, even of a large size. The disadvantages of [14] are solving only the problem of clustering. In [15], one of the methods of the group of swarm intelligence algorithms, namely the firefly algorithm, is proposed for the segmentation of remote sensing images of the earth. The advantage of [15] is good segmentation results even for large images. The disadvantage of [15] is high computational costs.

In [16], the method of detecting objects of interest on images of the earth's surface using the Hough transformation is considered. The advantage of [16] is the high result of object detection on RGB images from spacecraft. The disadvantage of the method [16] is the re-segmentation of the resulting image, that is, the detection of a large number of edges, even those that do not represent objects of interest, for example, shadows from them.

Thus, the authors of the work propose to pay attention to the selection of the method of detection of the object of interest, namely a small aerial object, on the image obtained by an optical-electronic system.

Thus, the **goal** of the article is to improve the small aerial objects segmentation method on optical-electronic images based on the Sobel edge detector.

Main results

One of the methods of spatial filtering, the Sobel edge detector, is proposed to detect a small aerial object in an image obtained from an optical-electronic system. The Sobel filter can be implemented using the most uncomplicated software and hardware tools [17, 18]. This choice is explained by the advantages of this operator among other gradient methods [6, [9, 18]. The main advantages include high implementation speed and predictable time for image segmentation. These are the main requirements when solving the task of finding a small aerial object on images from an optical-electronic system.

So, we will segment the real image obtained from an optical-electronic system by the Sobel edge detector. This image is presented in RGB color space. It has a size of 1280x720 pixels. You can visually see the presence of a small aerial object in the image, namely an unmanned aerial vehicle of the type "Lancet" [19].

The Sobel edge detector, like other spatial filtering methods, is based on the main property of the luminance signal, namely discontinuity. To find gaps in spatial filtering methods, it is proposed to process the entire area of the input image with a kernel (filter, mask). This kernel is a square matrix with defined coefficient values.

The process of Sobel edge detector is based on moving the kernel from pixel to pixel along the entire plane of the input image. In each pixel of the image (x, y) the response is calculated. Such a response is given by the sum of the products of the corresponding brightness value of the pixel under the square matrix (kernel) and the corresponding values of the coefficients. Square matrices for the Sobel edge detector are presented in the form (1) for calculation using the convolution operation of the values of the horizontal and vertical derivatives, respectively [20]:

$$\begin{bmatrix} 1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}, \quad \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}. \qquad (1)$$

It is necessary to convert it from the RGB color space to grayscale before starting the convolution operation of the original image (Fig. 1). The result of such a transition to another input image presentation mode is shown in Fig. 2.

Fig. 1. The original image [19]

Fig. 2. Conversion image (RGB to Grayscale)

Fig. 3. The segmented image detector by Sobel edge

After receiving the input image in grayscale, we will obtain gradient components G_x and G_y, respectively, according to expressions (2):

$$G_x = \begin{bmatrix} 1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} * I,\ G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * I. \quad (2)$$

where I – grayscale image; * – two-dimensional convolution operation.

To calculate the value of the gradient in each pixel, we apply expression (3):

$$G = \sqrt{G_x^2 + G_y^2}, \quad (3)$$

We calculate the direction of the gradient:

$$\Theta = \arctan\left(G_y / G_x\right). \quad (4)$$

The result of applying the Sobel edge detector to the image is a two-dimensional gradient map for each pixel. The segmented input image (Fig. 1) by the Sobel edge detector is shown in Fig. 3.

Visual analysis of the resulting image (Fig. 3) showed that the segmentation quality is poor. It is very difficult for the operator-decipherer to detect an aerial object on a segmented image.

Thus, the authors propose to improve the image segmentation method of small aerial object from an optical-electronic system based on Sobel edge detector.

For this, it is proposed to apply Gaussian filter to Fig. 2, which is a low-pass filter at the first stage:

$$G(x, y) = \frac{1}{2\pi\sigma^2} \cdot \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right), \quad (5)$$

where x, y – the coordinates of the pixel; σ – the standard deviation of the normal distribution.

This processing is performed in order to reduce the level of noise in the input image. The result of applying the Gaussian filter to the input image in grayscale is shown in Fig. 4.

In the second stage, it is proposed to perform the operation of histogram equalization to the result of filtering with a Gaussian filter (Fig. 4). This operation is used to increase image contrast. This operation is performed by redistributing the intensity of pixels on the histogram. This is done to maximize detail and overall brightness. The redistributed histogram ensures that every pixel in the image has the same probability of appearing in the image [21]. As a result, this leads to an image with increased contrast [22].

A possible disadvantage of the histogram alignment operation is the loss of details in the image. But such a disadvantage is irrelevant for the task of searching and detecting an aerial object such as an unmanned aerial vehicle due to the size of such an object of interest. And such a disadvantage can even be an advantage, because unnecessary small details are lost.

The result of applying the operation of histogram equalization to the result of filtering with a Gaussian filter (Fig. 4) shown in Fig. 5.

Therefore, this operation normalizes the brightness of the image pixels and increases the contrast of the image. However, in this article, it is difficult to visually notice it due to the large size of the original image (1280x720 pixels) and the limitation of paper.

At the next stage, it is proposed to apply the classic Sobel edge detector, which was described above, to the image after the operation of histogram equalization (Fig. 5).

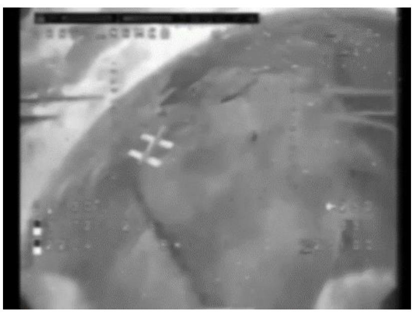

Fig. 4. Processed Fig. 2 by Gaussian filter

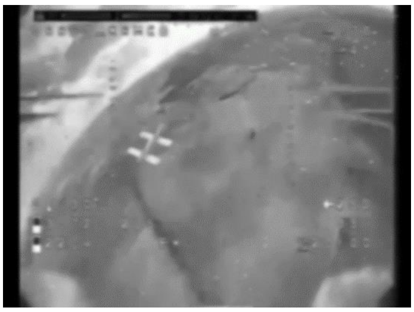

Fig. 5. Image after application to Fig. 4 of operation of histogram equalization

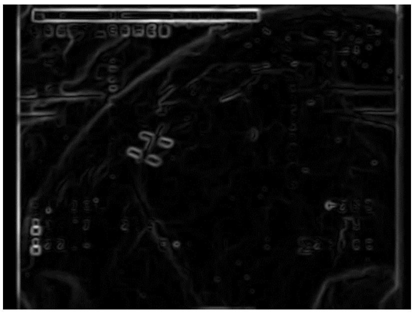

Fig. 6. Segmented image by the proposed method

The result of image segmentation by the Sobel edge detector after performing the Gaussian filtering operation and the operation of histogram equalization is shown in Fig. 6. Visual analysis of the segmented image by the proposed method (Fig. 6) allows the operator-decipherer to detect the contours of the aerial object in the image.

At the same time, small edges in the image, which arise as a disadvantage of many well-known segmentation methods, have disappeared. For a more detailed visual comparison of the results of segmentation by the classic Sobel edge detector and the proposed method, we will cut out the objects of interest from the resulting images and enlarge these regions.

Thus, Fig. 7 shows the region of the object of interest or small aerial object from the segmented image by Sobel edge detector (Fig. 3). Fig. 8 shows the region of the object of interest or small aerial object from the segmented image by the proposed method (Fig. 6).

Fig. 7. Object of interest or small aerial object from Fig. 3

Fig. 8. Object of interest or small aerial object from Fig. 6

A visual comparative analysis of Fig. 7 and Fig. 8 allows us to claim a significant improvement in the result of segmentation by the proposed method of the image obtained from an optical-electronic system when performing the task of searching and detecting a small aerial object in the input optical-electronic image.

Thus, the sequence of all stages of the proposed method of segmentation of small aerial objects on optical-electronic images based on the Sobel edge detector is shown using the block diagram in Fig. 9.

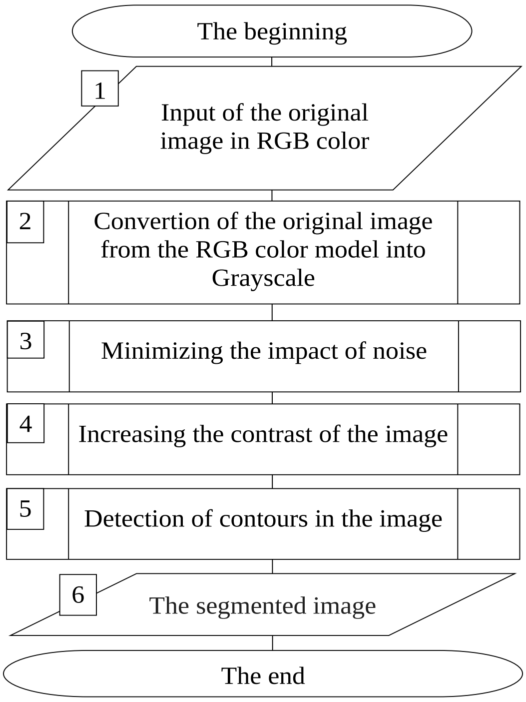

Fig. 9. The block diagram of the proposed method of segmentation of small aerial objects on optical-electronic images based on the Sobel edge detector

Calculations were performed when processing the original image with Matlab software version 7.11 (R2010b) on an Intel Core i7-10700K technical device with an NVIDIA RTX A2000 video card. The processing results give the right to claim minimal time costs. This fact is very relevant in the task of searching and detecting a small aerial object by an optical-electronic system.

To date, results of segmentation (Fig. 3 and Fig. 6) have only been assessed visually. In the near future, the authors will evaluate the quality of segmented images using numerical indicators.

Conclusions and the directions of further research

Thus, the article examines the relevance of using optical-electronic technologies, which open wide opportunities for monitoring and analyzing airspace in various fields. In this article, the main attention is paid to solving the problem of finding a small-sized aerial object using an optical-electronic surveillance system. By small aerial object, we mean an unmanned aerial vehicle.

The features of images obtained from optical-electronic systems when searching for a small aerial object were considered and the segmentation methods that can detect an interesting object on optical-electronic images were analyzed. It is established that it is necessary to use image segmentation algorithms that are easy to implement and calculate.

In this article, the main attention is paid to solving the problem of finding a small-sized aerial object using an optical-electronic surveillance system. By small aerial object, we mean an unmanned aerial vehicle.

Known methods of segmentation are considered. Their disadvantages and advantages are established when segmenting an image obtained from an optical-electronic system. We propose segmentation using the classic Sobel edge detector and an improved method based on the Sobel edge detector. The improved method includes two previous consecutive stages. This is processed with a Gaussian filter on the first and a histogram alignment operation on the second. A block diagram of the proposed segmentation method is presented. The results of segmentation using the classic Sobel edge detector and the proposed method are presented. A visual assessment of the quality of the segmentation results showed the possibility of detecting small aerial objects only after segmentation by the proposed method.

The direction of further research is to evaluate the quality of segmented images using numerical indicators.

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Метод сегментування малорозмірних повітряних об'єктів на оптико-електронних зображеннях на основі оператору Собеля

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Анотація. Предметом вивчення в статті є етап сегментування малорозмірних повітряних об'єктів на зображеннях, отриманих з оптико-електронної системи. **Метою** є розробка методу сегментування малорозмірних повітряних об'єктів на оптико-електронних зображення на основі оператора Собеля. **Завдання:** аналіз існуючих методів сегментування оптико-електронних зображень; розробка методу сегментування малорозмірних повітряних об'єктів на зображеннях, отриманих з оптико-електронної системи; практична перевірка роботи методу сегментування малорозмірних повітряних об'єктів на оптико-електронних зображення на основі оператора Собеля. Використовуваними **методами** є: методи системного аналізу, математичні методи порівняння зображень, методи цифрової обробки зображень, методи дискретної математики, теорії ймовірності, математичний апарат теорії матриць, методи аналітичної геометрії. Отримані такі **результати.** Розглянуто особливості зображень, отриманих з оптико-електронних систем при пошуку мароозмірного повітряного об'єкта, проаналізовано методи сегментування, які дозволяють виділити об'єкт інтересу на оптико-електронних зображеннях. Встановлено, що необхідно використовувати методи сегментування зображення, які легко реалізувати та розрахувати. Запропоновано проводити сегментування за допомогою методу на основі оператора Собеля. Запропонований метод включає два послідовних етапи. Це обробка за допомогою фільтра Гауса та застосування операції вирівнювання гістограми на першому етапі, та застосування оператора Собеля до результатів роботи першого етапу на другому. Наведена блок-схема запропонованого методу сегментування. Проведені експериментальні дослідження щодо виділення малорозмірного повітряного об'єкту на реальних оптико-електронних зображеннях, наведено результати сегментування за допомогою класичного оператора Собеля та запропонованого методу. Проведена візуальна оцінка якості результатів сегментування даними методами. **Висновки.** Розроблено метод сегментування малорозмірних повітряних об'єктів на оптико-електронних зображення на основі оператора Собеля. Напрямками подальших досліджень є оцінка якості сегментованих зображень за числовими показниками.

Ключові слова: сегментування зображення; оптико-електронна система; малорозмірний повітряний об'єкт; безпілотний літальний апарат; оператор Собеля; фільтр Гауса; фільтр Собеля.