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V. Yesilevskyi, A. Koliadin, O. Sereda

DEVELOPMENT OF A VIDEO PROCESSING MODULE FOR THE TASK OF AIR OBJECT RECOGNITION BASED ON THEIR CONTOURS

The subject of research in the article is the module of automatic segmentation and subtraction of the background, which is created, based on the sequential application of methods of image preprocessing and modified method of interactive segmentation of images and implemented in the system of optical monitoring of the air situation. **The aim** of the work is to develop an image segmentation module to increase the efficiency of recognition of an air object type on a video image in the system of visual monitoring of the air environment by means of qualitative automatic segmentation. To solve this problem, a modified interactive algorithm in the mode of automatic selection of an object in the image, which allows more accurately, without the participation of the operator, to determine the foreground pixels of the image for further recognition of the type of airborne object. The following **tasks** are solved in the article: the analysis of existing methods of binarization of color images for semantic segmentation of images, which are used in image recognition systems; the development of a pipeline of methods for automatic segmentation of images in the system of optical monitoring of the air environment. In the work, the following methods are used: methods of digital image processing, methods of filtering and semantic segmentation of images, methods of graph analysis. The following **results** are obtained: the results of image processing with the proposed module of segmentation and background subtraction confirm the performance of the module procedures. The developed pipeline of methods included in the module demonstrates correct segmentation in 93% of test images in automatic mode without operator participation, which allows us to conclude about the effectiveness of the proposed module. **Conclusions**: The implementation of the developed module of segmentation and background subtraction for the system of optical monitoring of the air environment allowed to solve the problem of segmentation of video images for further recognition of aerial objects in the system of optical monitoring of the air environment in automatic mode with a high degree of reliability, thus increasing the operational efficiency of this system.

Keywords: image segmentation; background subtraction; recognition of air objects; optical monitoring of the air situation.

Introduction

The task of recognition of air objects (AO) as a part of the task of monitoring the air situation is of great importance in the combat situation during military operations. Its solution can also be used in peacetime to monitor the air situation at airports and protected facilities. In addition to (or even instead of) classical radar systems, optical video surveillance systems are increasingly being used for monitoring the air situation. This approach makes it possible to increase the mobility of AO detection systems and to overcome some known problems of radar monitoring associated with masking the characteristics of air objects in the radar detection area.

Information about the type of aerial threat is necessary for a correct assessment of the air situation and for making an operational decision. Currently, the list of types of detected AO has significantly expanded due to the use of artillery shells, various types of missiles, unmanned aerial vehicles (UAVs), quadcopters, helicopters. This has fundamentally changed the range of detectable AO parameters, from shape and size to the dynamic characteristics of motion. In this case, in the case of optical video surveillance, the task of monitoring the aerial situation becomes a class of tasks that can be solved by methods of digital video image processing and automatic pattern recognition using machine learning and artificial intelligence.

In the field of automatic image recognition, the following terminology is adopted to define tasks (Fig. 1).

Classification – definition of a class of one object on the image with indication of degree of reliability of the accepted automatic decision.

Classification with localization – classification of one object and indication of its place on the image.

Detection – definition of a class of each object on the image.

Video image processing includes a pipeline of tasks, among which detection of a moving flying object, determination of AO type, determination of object characteristics. In the proposed approach, we are in the framework of the task of determining the type of AO, pre-detected by the signs of motion and localized on the digital image. In accordance with the above terminology, the task of determining the type of AO refers to image classification problems.

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a) b) c)

Fig. 1. Classification **(a)**; classification with localization **(b)**; detection **(c)**

Their solution is usually based on the use of deep convolutional neural networks. Such a solution for the problem we study is somewhat redundant due to its universality. Obviously, in the field of AO-type recognition object contours provide enough information to solve the problem even without taking into account the color and texture. In human visual AO-type recognition, the geometric shape of the object, represented by the outer contour, is usually a minimally sufficient feature for recognition even under the condition of geometric distortion (displacement, orientation, scale).

This problem was solved by the authors in previous studies [1], where it was assumed that the image of the object is in some idealized form: not hidden by clouds and well distinguishable on the background. However, in such conditions and under different illumination conditions, the problem of separating the background of the image from the object under study arises. In the field of image analysis, this is called the background subtraction problem, which is part of the broader problem of semantic segmentation.

This paper discusses the problem of processing video frames from an air monitoring camera mounted on a turntable to construct a binary image with the object under study highlighted. This image is necessary for further solving the problem of AO type recognition by the obtained numerical characteristics of its contour.

The problem of applying different algorithms of segmentation and background subtraction is relevant for real applications, which is confirmed by the works [2, 3], which are devoted to the issues of segmentation and background subtraction for video images, including the tasks of AO tracking.

Analysis of the problem and existing methods

The problem of optical AO recognition and tracking is the subject of many years of research due to the interest in its solution for both civil and military applications [4]. Classical recognition methods were based on comparing an unknown image or its specific characteristics with a library of known images [5].

Outstanding results in computer vision related to deep neural networks and increasing computer performance have made the task of computer visual tracking one of the most prominent research topics. A study [6] provides a detailed review of advances in the use of deep convolutional neural networks for arbitrary image recognition.

However, as shown in [7, 8], deep learning methods require a large number of training sets and significant computer time to train the network.

The study [9] shows that the use of transfer learning, based on inexpensive additional training of pre-trained network, allows solving part of the problems of deep neural networks. However, at the same time there remains the problem of redundancy of the universal deep neural network-based approach in the recognition of airborne object types. The description of an object image by its contour is enough for the task of air object type recognition. In this case, much less redundant information is used than in the analysis using deep neural networks, which gives a number of advantages. In addition, as noted in [2], in the application of image processing algorithms, there is indeed a gap between the methods used in basic research and in real-world applications. Recently, in practical systems, there is an interest in the use of improved classical image processing methods.

To solve the problem of recognition of types of airborne objects in the general task of air monitoring, we use a camera attached to a turntable. Therefore, the algorithm for the foreground object extraction must take into account the changing illumination of the object and the background. This means that the algorithm must be time-critical in terms of execution time. Classical image processing methods meet these requirements well [10]. In [11] the use of these methods to recognize types of air objects is investigated in detail.

In our study, we consider one of the tasks of image preparation for recognition – the task of image

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segmentation and background subtraction. This problem is solved after moving objects are detected and localized in a sequence of video frames by optical flow methods, based on the study of frame difference [12, 13].

Optical flow is one of the most widely used tracking algorithms for computer vision. Solutions are known for background subtraction algorithms in the case of shooting a fixed scene with a static camera [14].

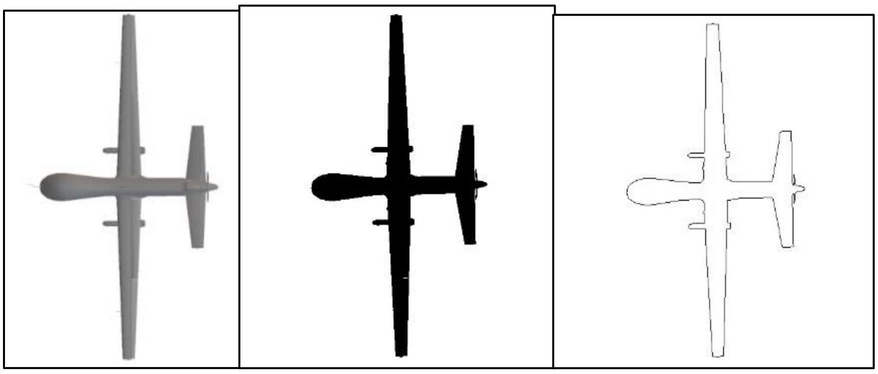
However, in the conditions of our problem, the background is constantly changing, which interferes with the detection of moving targets [15]. Estimates a nd comparisons for background subtraction methods are studied in detail in [16], among which weighted moving mean, Gaussian mixture model (GMM), adaptive background learning, etc.

Highlighting the previously unsolved parts of the overall problem. Aim of the work

The system of visual monitoring of the air situation is an intelligent hardware-software complex, which includes a camera fixed on a rotating stand, and a computer control and information processing unit. The software for information processing consists of various interconnected functional modules of video image processing. Among these modules we can distinguish a pipeline of software modules, which solve the problem of determining the type of AO as an image classification problem, as defined in the introduction. The solution of this problem is based on the input information received from the moving air object detection and localization module by optical flow methods, as already described above.

In an ideal situation, image preprocessing with localized AO should be reduced to image binarization followed by contour calculation, as presented in fig. 2.

To obtain the numerical characteristics of a contour, the localized image (fig. 2, a) must first be reduced to the black-and-white form (fig. 2, b). Then it is necessary to select a set of points of a contour (fig. 2, c) and represent it as a sequence of their coordinates. As a result of such processing the image of an air object will look like an ordered sequence of points $z(k)=(x_k, y_k)=f(t_k)$, $k=0,...,N-1$, which is a discretized representation of a continuous two-dimensional curve $f(t)\subset R2$, describing the contour. The further procedure of air type recognition is described in detail in our paper [1] and is reduced to obtaining a vector of features based on Fourier descriptors for the curve $f(t)$. The feature vector is the input for a pre-trained classifier based on a traditional multilayer neural network.



a) b) c)

Fig. 2. Stages of image preprocessing:
a – initial image of localized object; **b** – black and white image; **c** – contour image of object

Generally speaking, a block diagram (fig. 3) can represent the algorithm of the air object type recognition procedure.

When implementing this algorithm, a number of problems arise. The AO image can be obtained with varying degrees of distortion, which is associated with the size of the image, its blurring due to the aberration of light rays (see fig. 4).

In addition, the image of the object may be partially hidden by clouds or poorly distinguishable against their background (fig. 5). The task is to automatically, without human involvement, by means of the software

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highlight a clear outline in conditions of visual disturbances (illumination, cloud cover).

Segmentation of objects and background subtraction under conditions of changing background and illumination, occlusion, shape distortion, motion blur, zooming, etc. are important areas of research in computer vision.

The aim of this article is to develop a video image processing module, which allows to select air objects for their further classification based on contours and to increase the efficiency of air object type recognition in a visual air monitoring system. To solve this problem, a modified interactive algorithm in the mode of automatic object silhouette extraction is used.

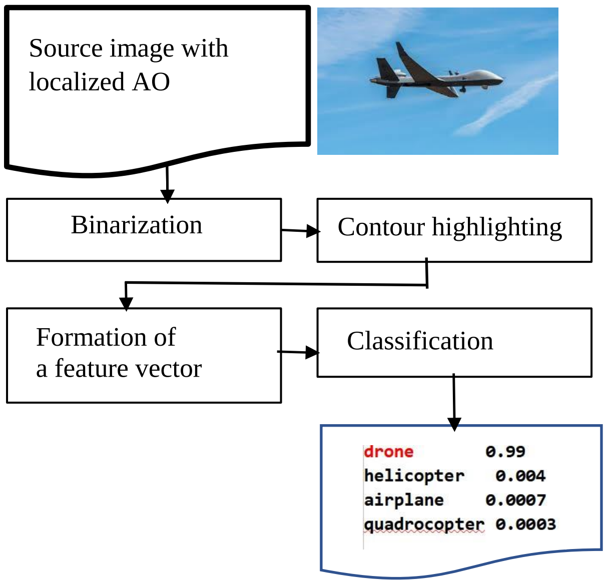

Fig. 3. Generalized block diagram of the air object type recognition procedure algorithm

Fig. 4. A good-resolution image of the MQ-9 Predator UAV, the actual image, and its enlarged view

Fig. 5. Image of the MQ-9 Predator UAV in the ideal view for recognition and in conditions of visual interference

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Materials and methods

When preparing an image for outline extraction, the main focus is on the brightness characteristics of the pixels in all three color channels of the color image. The optimal way to simplify this problem is to reduce the color three-channel RGB image to a grayscale view (fig. 6). Such a brightness scale conveys 256 gradations from 0 – black, to 255 – white.

According to [17], the conversion to grayscale is performed by the formula

$$y = 0,2126\, r + 0,7152\, g + 0,0722\, b\,, \qquad (1)$$

where *r*, *g*, *b* are the color components of the original image, and y is the output value for a pixel of the image in grayscale.

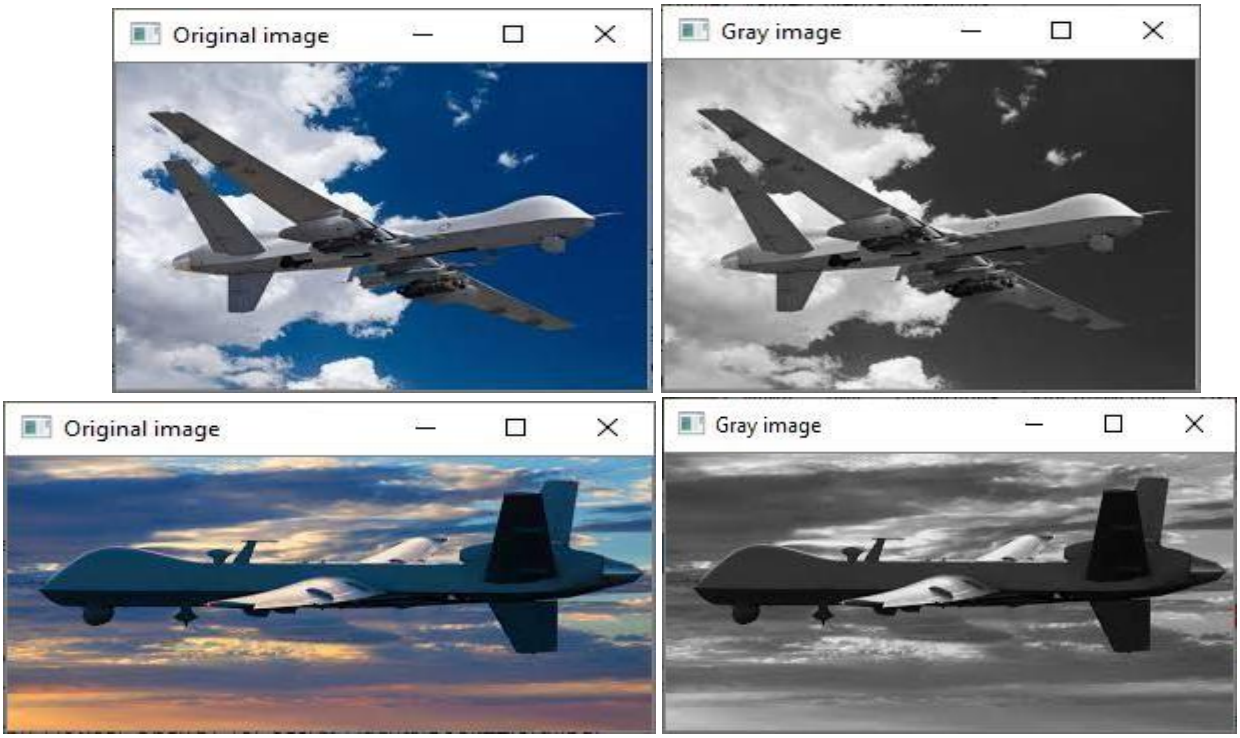

Fig. 6. The result of converting the image to grayscale mode

In an air monitoring system, the camera's shutter and iris control system may not have time to respond to too rapid changes in light intensity when the camera is rotating on a turntable. Sometimes the contrast range is too large for the sensors. In addition, it usually requires different exposure times for dark and light areas for a "perfect" image. In artistic and special photography for better transfer of details there is even a technique of high dynamic range (HDR), which allows to combine several frames of the object with different exposures.

In the project that we are implementing, it is possible to expand the dynamic range of the image and improve the contrast of the image by applying the algorithm of histogram correction. For this purpose a graphical distribution of image intensity in the form of a histogram is created, which determines the number of pixels for each considered value of intensity in the grayscale range from 0 to 255.

With the correction, the original distribution becomes a broader and more homogeneous distribution of intensity values, so that they are distributed more evenly over the entire range. The algorithm normalizes brightness and increases image contrast (fig. 8).

For contour detection, a good result can be obtained after conversion to a binary (black and white) image, as shown above (fig. 1, b). In this case, the boundary point is unambiguously found by the change in the pixel color.

The binarization transformation can be determined by assigning a threshold value. The original image converted to a grayscale view with a pixel brightness range of 0 to 255 must be reduced to a binary view (0 or 1). If the pixel value is less than the threshold value, it is set to 0, otherwise to 1.

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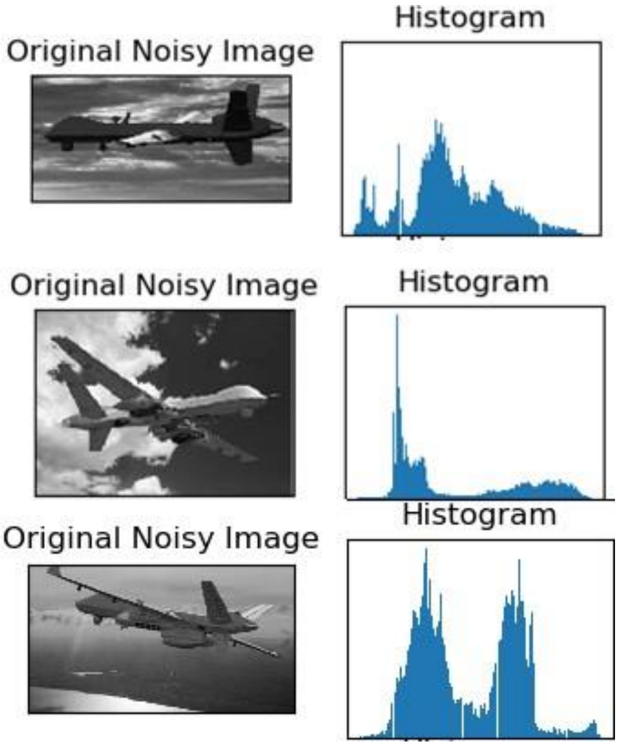

Fig. 7. Determining intensity histograms for grayscale images

Different variations of the threshold binarization algorithm (with lower and upper threshold, with double restriction, incomplete thresholding, etc.) presented in fig. 9 can be used.

Naturally, the result of the threshold conversion depends on the value of the threshold. Fig. 10 shows binarization results for different threshold values.

Using a fixed threshold may not be justified for different lighting conditions in different areas. In this case, adaptive threshold setting is used. The algorithm determines the threshold for a pixel based on a small area around it. In this way, we obtain different thresholds for different areas of the same image, which gives better results for images with different illumination for different averaging modes (fig. 11).

As a binarization method, the adaptive Otsu method oriented to a bimodal image, in which the histogram has two distinctly expressed peaks, has proven itself well. In such images, the optimal threshold is in the middle of these two values. Otsu method determines a global threshold value from image histogram.

Fig. 12 shows examples of the algorithm in the case of a bimodal image.

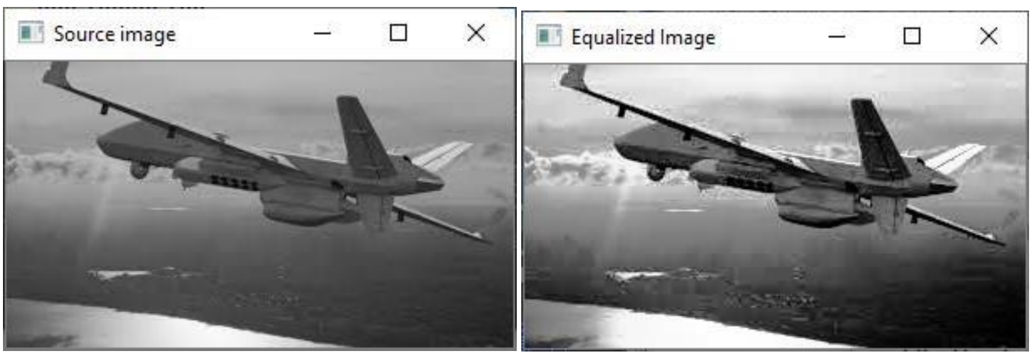

Fig. 8. The result of the alignment of the gray-scale image histogram

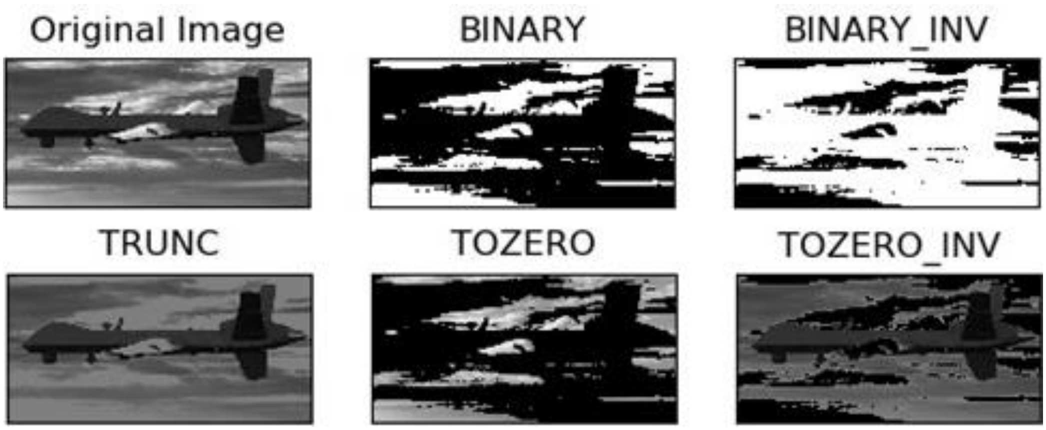

Fig. 9. Results of applying different types of threshold conversion

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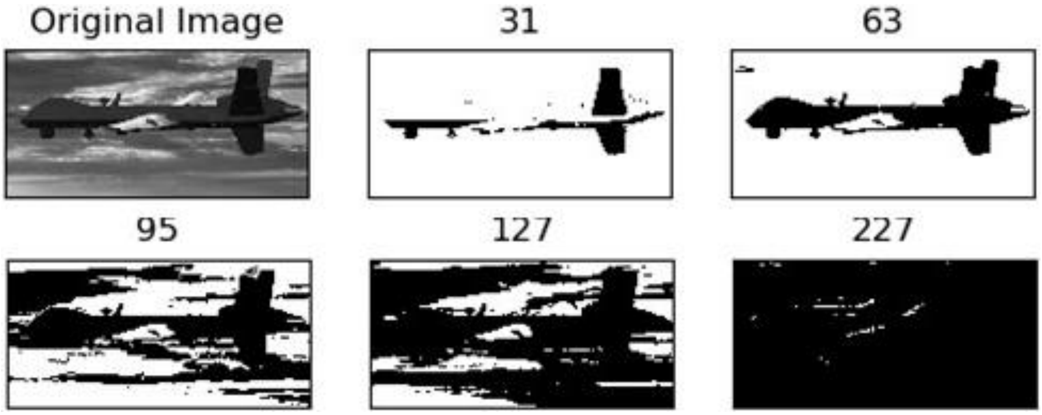

Fig. 10. Binarization results for different threshold values

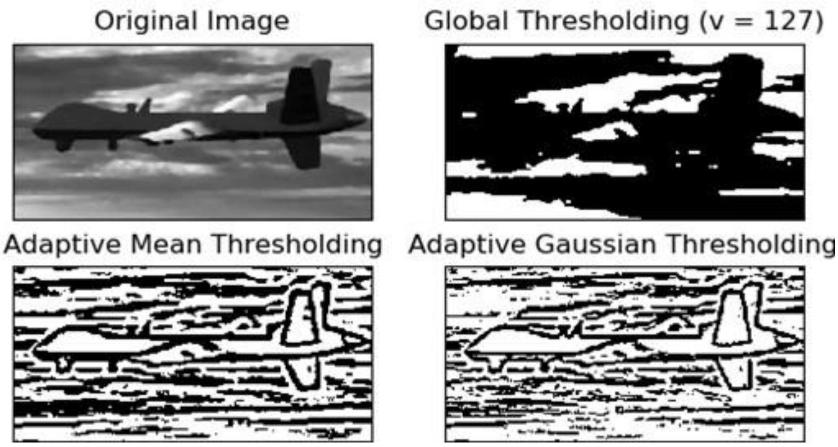

Fig. 11. Adaptive binarization results for different averaging modes

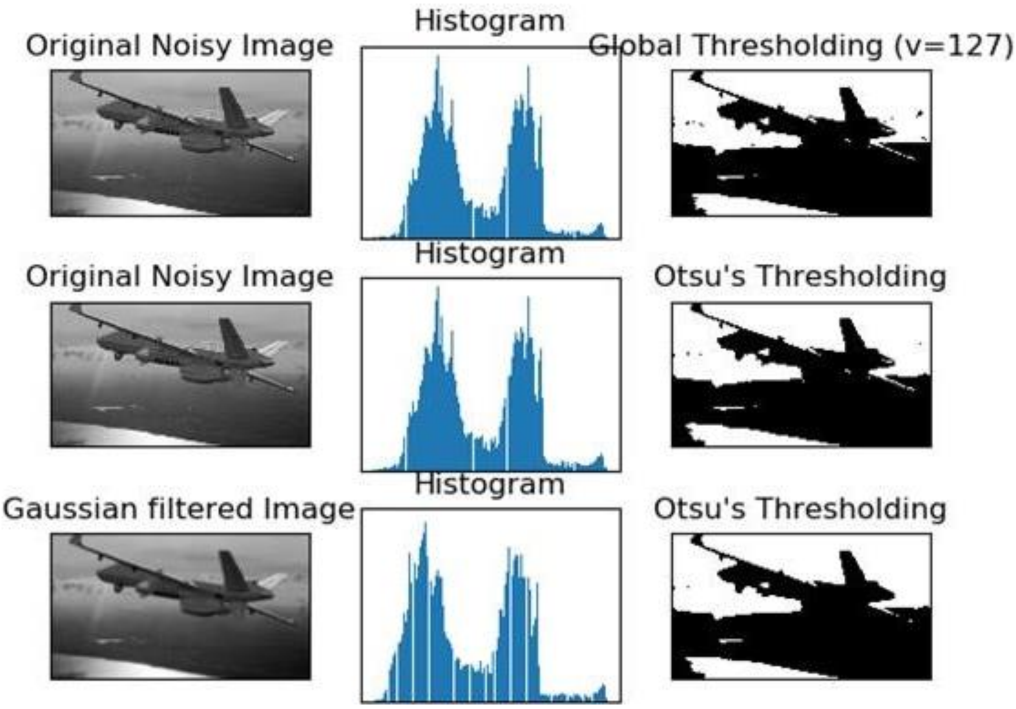

Fig. 12. Otsu binarization results for bimodal image

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The disadvantage of finding objects using threshold filtering is the need to individually select the threshold value for each image, and even in this case, the separation from the background is not always possible, as seen in fig. 12.

It is possible to propose a method that goes through all possible thresholds and builds a recognition procedure for each of them. This would be possible when searching for any one particular contour, which is not suitable, for air objects having different contour shapes depending on the position with three degrees of freedom in relation to the camera.

Research results and their discussion

The recognition of airborne object types is based on the procedure of object contour extraction on the binary image obtained as a result of the initial image preprocessing. In this case, the GrabCut algorithm [18] is used. In this algorithm, user labeled foreground and background areas were used to build distribution histograms for these two classes of areas. The algorithm itself assumes that the remaining unlabeled pixels have a distribution similar to one of the two distributions. The energy functional was constructed based on the assumption that the pixels in each of the regions are connected. The assignment of a pixel to one of the regions was performed as a result of minimization of the energy functional.

The algorithm is based on the Gaussian mixture model (GMM), which is used to model the foreground and background. Depending on the data that represents the background and foreground areas, the GMM learns and creates a new pixel distribution. That is, unknown pixels are labeled either probable foreground or probable background, depending on their relationship to other, strictly labeled pixels in terms of color statistics.

The interactivity of the algorithm can be excluded if we make the following assumptions:

1) everything within a given indent from the edge of the image is the background;

2) everything within a given area in the center of the image is the foreground.

Fulfillment of these conditions is possible because the system architecture is designed in such a way that the preliminary stage of video processing the system of moving object detection by optical flow method selects pixels that determine the area of interest.

A computational experiment was conducted on a test set of 40 images, which showed the correct result in 37 cases (93%), which confirms the possibility of using the proposed method. The results of the algorithm are shown in fig. 13.

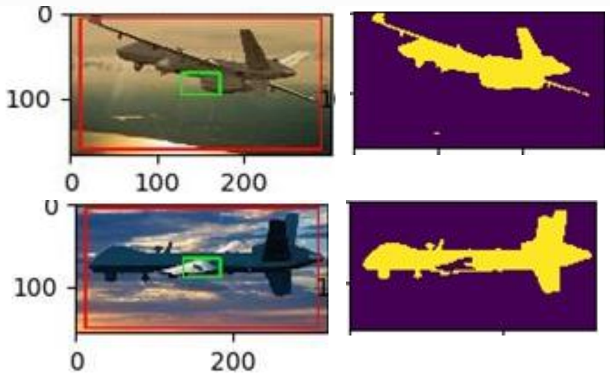

Fig. 13. Results of the background removal algorithm

Conclusion

Implementation of the developed background segmentation and subtraction module for the system of optical monitoring of the air situation allowed to solve the problem of video images segmentation with high reliability for further recognition of air objects in the system of optical monitoring of the air situation in automatic mode, thus increasing the operational efficiency of this system.

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Есілевський Валентин Семенович – кандидат технічних наук, доцент, Харківський національний університет радіоелектроніки, доцент кафедри прикладної математики, Харків, Україна; e-mail: valentyn.yesilevskyi@nure.ua; ORCID ID: https://orcid.org/ 0000-0002-5935-1505

Есилевский Валентин Семенович – кандидат технических наук, доцент, Харьковский национальный университет радиоэлектроники, доцент кафедры прикладной математики, Харьков, Украина.

Yesilevskyi Valentyn – PhD (Engineering Sciences), Associate Professor, Kharkiv National University of Radio Electronics, Associate Professor at the Department of Applied Mathematics, Kharkiv, Ukraine.

Колядін Антон Володимирович – Харківський національний університет радіоелектроніки, молодший науковий співробітник кафедри прикладної математики, Харків, Україна; e-mail: anton.koliadin@nure.ua; ORCID ID: https://orcid.org/0000-0001-5552-5080

Колядин Антон Владимирович – Харьковский национальный университет радиоэлектроники, младший научный сотрудник кафедры прикладной математики, Харьков, Украина.

Koliadin Anton – Kharkiv National University of Radio Electronics, Junior Researcher at the Department of Applied Mathematics, Kharkiv, Ukraine.

Середа Олена Григорівна – Харківський національний університет радіоелектроніки, старший викладач кафедри прикладної математики, Харків, Україна; e-mail: olena.sereda@nure.ua; ORCID ID: https://orcid.org/0000-0003-3579-0092

Середа Елена Григорьевна – Харьковский национальный университет радиоэлектроники, старший преподаватель кафедры прикладной математики, Харьков, Украина.

Sereda Olena – Kharkiv National University of Radio Electronics, Senior Lecturer at the Department of Applied Mathematics, Kharkiv, Ukraine.

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РОЗРОБЛЕННЯ МОДУЛЯ ОБРОБКИ ВІДЕО ДЛЯ ЗАВДАННЯ РОЗПІЗНАВАННЯ ПОВІТРЯНИХ ОБ'ЄКТІВ ЗА ЇХНІМИ КОНТУРАМИ

Предметом дослідження в статті є модуль автоматичної сегментації та віднімання фону, створений на основі конвеєра методів попереднього оброблення зображення та модифікованого методу інтерактивної сегментації зображень, і впроваджений у систему оптичного моніторингу повітряної обстановки. **Метою** роботи є розроблення модуля сегментації зображень для підвищення ефективності розпізнавання типу повітряного об'єкта на відеозображенні в системі візуального моніторингу повітряної обстановки шляхом якісної автоматичної сегментації. Для вирішення цього завдання використовується модифікований інтерактивний алгоритм у режимі автоматичного виділення об'єкта на зображенні, що дає змогу точніше без участі оператора визначати пікселі переднього плану зображення для подальшого розпізнавання типу повітряного об'єкта. У статті вирішуються такі **завдання**: аналіз наявних методів бінаризації кольорового зображення для семантичної сегментації зображень, що використовуються в системах розпізнавання образів; розроблення конвеєра методів автоматичної сегментації зображень у системі оптичного моніторингу повітряної обстановки. У роботі використовуються **методи** цифрового оброблення зображень, фільтрації та семантичної сегментації зображень, аналізу графів. Отримано такі **результати**: унаслідок оброблення зображень за допомогою запропонованого модуля сегментації та віднімання фону підтверджено працездатність процедур модуля. Розроблений конвеєр методів, вміщений у модуль, демонструє правильну сегментацію 93% тестових зображень в автоматичному режимі без участі оператора, що дозволяє зробити висновок про ефективність застосування запропонованого модуля. **Висновки**: упровадження розробленого модуля сегментації та віднімання фону для системи оптичного моніторингу повітряної обстановки дозволило з високим ступенем достовірності вирішити завдання сегментації відеозображень для подальшого розпізнавання повітряних об'єктів у системі оптичного моніторингу повітряної обстановки в автоматичному режимі, завдяки чому збільшилася ефективність експлуатації цієї системи.

Ключові слова: сегментація зображень; віднімання фону; оброблення зображень; розпізнавання повітряних об'єктів; оптичний моніторинг повітряної обстановки.

РАЗРАБОТКА МОДУЛЯ ОБРАБОТКИ ВИДЕО ДЛЯ ЗАДАЧИ РАСПОЗНАВАНИЯ ВОЗДУШНЫХ ОБЪЕКТОВ ПО ИХ КОНТУРАМ

Предметом исследования в статье является модуль автоматической сегментации и вычитания фона, созданный на основе конвейера методов предварительной обработки изображения и модифицированного метода интерактивной сегментации изображений, и внедренный в систему оптического мониторинга воздушной обстановки. **Целью** работы является разработка модуля сегментации изображений для повышения эффективности распознавания типа воздушного объекта на видеоизображении в системе визуального мониторинга воздушной обстановки путем качественной автоматической сегментации. Для решения этой задачи используется модифицированный интерактивный алгоритм в режиме автоматического выделения объекта на изображении, который позволяет точнее без участия оператора определять пиксели переднего плана изображения для дальнейшего распознавания типа воздушного объекта. В статье решаются следующие **задачи**: анализ существующих методов бинаризации цветного изображения для семантической сегментации изображений, которые используются в системах распознавания образов; разработка конвейера методов для автоматической сегментации изображений в системе оптического мониторинга воздушной обстановки. В работе используются **методы** цифровой обработки изображений, фильтрации и семантической сегментации изображений, анализа графов. Получены следующие **результаты**: результаты обработки изображений с помощью предложенного модуля сегментации и вычитания фона подтверждают работоспособность процедур модуля. Разработанный конвейер методов, включенный в модуль, демонстрирует правильную сегментацию в 93% тестовых изображений в автоматическом режиме без участия оператора, что позволяет сделать вывод об эффективности применения предложенного модуля. **Выводы**: внедрение разработанного модуля сегментации и вычитания фона для системы оптического мониторинга воздушной обстановки позволило с высокой степенью достоверности решить задачу сегментации видеоизображений для дальнейшего распознавания воздушных объектов в системе оптического мониторинга воздушной обстановки в автоматическом режиме, благодаря чему увеличилась эффективность эксплуатации данной системы.

Ключевые слова: сегментация изображений; вычитание фона; обработка изображений; распознавание воздушных объектов; оптический мониторинг воздушной обстановки.

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