METHOD OF AUTOMATING THE PROCESS OF OBJECT DETECTION TO INCREASE THE EFFICIENCY OF DECIPHERING AERIAL RECONNAISSANCE DATA

Problem factors that have a significant impact on the effectiveness of the process of deciphering aerial reconnaissance data obtained under the conditions of the use of unmanned aerial vehicles of the tactical level are analyzed, taking into account the experience of conducting combat operations on the territory of Ukraine. Requirements for operational efficiency and reliability of the process of recognition (detection) of aerial reconnaissance objects are being formed. Modern computer vision algorithms and deep machine learning technologies are studied from the point of view of integration into the process of deciphering aerial reconnaissance data. A method of automating the process of detecting aerial reconnaissance objects is being developed to increase the effectiveness of deciphering aerial photographs. The essence of the developed method is the integration of modern computer vision technologies, implemented on the basis of algorithms of artificial neural networks, in the process of deciphering aerial photographs. Analysis of the effectiveness of the developed method from the point of view of ensuring the required level of reliability shows that the use of the developed method allows obtaining the required values of the probability of recognition of aerial reconnaissance objects on aerial photographs. In turn, the analysis of quantitative evaluations of the efficiency of deciphering aerial reconnaissance data shows that the use of the developed method allows you to significantly reduce the time for deciphering an aerial photograph on average, up to 2 seconds per aerial photograph under the conditions of using rather low computing power. The features of the developed method: practical implementation of the specified automation method does not require high computing power; integration into the decryption process does not require significant personnel training and high technical requirements.

Keywords: unmanned aerial vehicle, aerial reconnaissance, aerial photo, deciphering, aerial reconnaissance object, detection, responsiveness, reliability.

Introduction

Formulation of the problem. The era of modern transformation of society is accompanied by an active struggle with the challenges that arise in the world and exert a destructive influence on its development (global Covid-19 pandemic, local armed conflicts) [1–6]. Thus, the threat that arose in society from the point of view of the health care sector, related to the Covid-19 epidemic, which led to numerous human casualties, is accompanied by significant rates of digitalization of the spheres of services in the medical field (electronic prescriptions, online doctor's appointments, online ordering of medicines, etc.) [2; 3]. It should be noted that in many cities of the world, significant changes have taken place in the field of drug delivery, which is characterized by a dynamic transition to contactless means. For this purpose, unmanned aerial vehicles (UAVs) began to be actively used [7–9]. This is due to significant quarantine restrictions, which led to the minimization of the use of the human factor in overcoming the specified crisis.

On the other hand, in recent years in the modern world, unfortunately, preference is given to solving debatable (conflict) issues through the use of weapons, rather than diplomacy, which has led to a significant increase in the number of armed conflicts [4–6].

In turn, the active use of UAVs for both reconnaissance and strike purposes is characteristic of recent armed conflicts. Thus, Azerbaijan's use of the Bayraktar TB2 UAV for reconnaissance and strike purposes made it possible to gain an advantage in the theater of operations in a short period of time by inflicting significant losses on the armed forces of Armenia [10; 11]. In turn, combat operations on the territory of Ukraine have been accompanied by the active use of UAVs since the first days of the full-scale invasion of the troops of the Russian Federation and illegal armed formations on the territory of Ukraine [12; 13]. It should be noted that from the first days of the war, the use of tactical-level UAVs of the Chinese DJI Mavic line gained special importance, which are actively used to this day to obtain intelligence information about the locations of enemy military formations and adjust artillery [12–14]. This is due to the large length of the combat collision line and the following advantages of quad copters of the specified line [15; 16]:

– high-quality on-board optical and electronic equipment (surveillance cameras), which allows obtain-
ing intelligence information of the required quality;
- relatively low cost (depending on the on-board
  opto-electronic equipment).

It should be noted that the on-board optical and
electronic equipment installed on board the studied
UAVs allows obtaining intelligence data with the fol-
lowing characteristics [15, 16]:
- aerial photographs in JPEG/RAW formats with a
  resolution from FHD to 4K [15];
- video resource with FHD resolution [16].

However, along with the advantages of using a
UAV of this type, in modern conditions of combat
operations, it has a significant problematic drawback – the
impossibility of saving streaming video (video in real
time) to the operator's tablet, since the video infor-
mation resource is recorded on a storage device installed
on board the UAV. This, in turn, leads to time delays
between the process of obtaining intelligence infor-
mation and its detailed decryption. Taking into account
the fact that the use of UAVs of the specified type pro-
vides for a flight duration of 30–40 minutes, in the con-
ditions of hostilities, which are characterized by dynam-
ic variability of the situation on the line of contact, an
increase in the time costs associated with the sequential
execution of delivery operations and decryption can
lead to the loss of relevance of intelligence.

It should be noted that today the decryption of in-
telligence received from the UAV of the specified type
takes place in “manual mode”, that is, by a person (the
UAV operator). This is due to the high cost of commer-
cial computer vision software products that are actively
used by foreign specialists [17; 18]. In turn, the process
of decoding intelligence (detection of enemy objects) by
the operator in manual mode has a number of problem-
atic aspects, which include the following: considerable
time spent on the decryption process; the presence of
the human factor, which can lead to erroneous decoding
of objects of interest.

Therefore, the issue of finding new approaches
that will reduce the time spent on the process of deci-
phering air reconnaissance data is becoming urgent.

Therefore, increasing the efficiency of deciphering
air reconnaissance data from the standpoint of ensuring
the required level of operational efficiency is an urgent
scientific and applied task.

For this purpose, the paper [19] proposed a model
for the automation of the process of deciphering air re-
connaissance data using the technologies of the artificial
intelligence system. The purpose work is the search for
approaches to increase the efficiency of deciphering air
reconnaissance data.

Analysis of recent research and publications. An-
alysis of the latest scientific research testifies to the
fact that the use of object detection methods and tech-
nologies today has developed quite rapidly in all spheres
of life [20–23]. It should be noted that a significant part
of scientific research is devoted to image recognition
using artificial intelligence, where a person acts as the
object of recognition (face, posture, emotions, clothes,
etc.) [20; 21]. Vehicle recognition technologies occupy
a separate niche in scientific research in this area [21].
This is due to the rapid implementation of the “Smart
City” and “Safe City” concepts in modern cities of the
world, which are implemented through the use of these
technologies both for monitoring vehicle traffic on city
roads, and for finding and determining the location of a
vehicle (recognition of automobile rooms) [22; 23].

Modern armies of the world quite actively use arti-
ficial intelligence technologies in order to increase the
efficiency of military management by automatizing the
process of collecting, processing and transmitting infor-
mation. It should be noted that the Armed Forces of
Ukraine actively use modern models of weapons and
military equipment from foreign partner countries, in
which artificial intelligence technologies are imple-
mented [24]. In turn, a number of scientific studies
aimed at increasing the compression rates of air recon-
naissance data and ensuring their reliability [25–31].

In turn, domestic manufacturers are also engaged
in the development and implementation of computer
vision and artificial intelligence technologies in the
military sphere, but there is practically no information
on the implementation of this direction in open sources
[32]. Today, these object detection technologies are
actively implemented on the basis of neural networks
[33]. Distinctive features of the indicated direction are
the possibility of balancing between the indicators of
accuracy and speed of detection of objects on the infor-
mation resource (image, video resource) in the condi-
tions of the availability of the necessary computing
power. From this point of view, quite high results were
shown by algorithms of the Yolo family, which allow
obtaining the necessary indicators of accuracy and speed
[34]. In this regard, to solve the above-mentioned
problem, it is suggested to use computer vision tools
and artificial intelligence systems implemented on data
detection (recognition) technologies using modern algo-

rithmic programming languages.

Therefore, the purpose of the article is to develop
a method of automating the process of detecting objects
to increase the effectiveness of deciphering aerial recon-
naissance data from the standpoint of increasing efficien-
cy in terms of ensuring the required level of reliability.

Statement of the main material

It is proposed to develop a method of automating
the process of detecting objects of aerial reconnaissance
based on the model proposed in the paper [19], taking
into account the requirements for the process of detect-
ing objects of interest from the point of view of ensuring
the necessary indicators of efficiency and reliability.

The fulfillment of the above requirements is pro-
posed to be organized by integrating the algorithms of the Yolo family into the decryption process in combination with the Pytorch deep machine learning framework. This is due to the fact that the algorithms of the specified family have a number of advantages compared to others, in terms of speed, simplicity, convenience and demand for computing power [34].

The structural and functional scheme of the proposed method of automating the process of detecting aerial reconnaissance objects (ARO) is shown in Fig. 1.

The implementation of the proposed method of automating the process of decrypting ARO involves the following stages:

- preparation for training artificial neural network (ANN);
- training of ANN;
- evaluation of the effectiveness of the developed method of detecting ARO.

![Diagram](image)

**Fig. 1. Structural and functional diagram of the proposed method of automating the process of detecting aerial reconnaissance objects on aerial photographs**

Source: developed by the authors.

*First stage:* preparation for training ANN. This stage includes the following components: formation of a database (a set of aerial photographs); formation of classes of researched ARO; formation of an array of ARO labels on aerial photographs. The process of formation of the first two components is described in detail in the work [19].

In turn, the label refers to the placement of objects found on an aerial photograph. A set of labels for an aerial photograph is generally described by the following expression:

\[
M(m)_{tr} = \{M_1, \ldots, M_i, \ldots, M_m\}, \quad i = 1, m, \quad (1)
\]

where \(M(m)_{tr}\) is a set of ARO labels found in the data array \(A(m)_{tr}\), used for training (training), \(i = 1, m\);

\(M_i\) is the number of ARO marks on an aerial photograph \(A_i\).

*Second stage:* training of ANN. The purpose of the specified stage is to obtain the necessary values of accuracy (reliability) and efficiency of detection of the investigated classes of ARO.

At this stage, the values of individual indicators
that set the conditions for training are adjusted - the duration of the training process (the number of epochs), the frames into which the aerial photos of the base are divided are determined $A(m)_t$, data in the process of training to identify objects of the studied classes and determine the reliability of the obtained results.

**Third stage:** evaluation of the effectiveness of the developed method of detecting aerial reconnaissance objects. This stage includes the following components:

- formation of a set of test data given by the following expression:
  \[
  B(\emptyset)_{\text{test}} = \{B_1, \ldots, B_j, \ldots, B_\emptyset\}, \quad j = \overline{1, \emptyset},
  \]
  where $B(\emptyset)_{\text{test}}$ is an array of test data, $j = \overline{1, \emptyset}$;

- formation of arrays of labels and OPR classes for a set of test images $B_j$, which is described by the following expression:
  \[
  M(\emptyset)_{\text{test}} = \{M_1, \ldots, M_j, \ldots, M_\emptyset\}, \quad j = \overline{1, \emptyset},
  \]
  where $M(\emptyset)_{\text{test}}$ is a set of labels for ARO found in the data array $B(\emptyset)_{\text{test}}$, used for testing the developed model;

- calculation of quantitative estimates of reliability and efficiency of recognition of ARO on aerial photographs, i.e. indicators $T_{\text{odDM}}$ and $P_{\text{odDM}}$ for the developed method of automating the process of decoding ARO on aerial photographs.

Next, it is proposed to evaluate the effectiveness of the proposed method of automating the process of deciphering the ARO on aerial photographs from the point of view of operational efficiency in terms of ensuring the necessary level of reliability of ARO recognition.

In order to evaluate the effectiveness of the developed method from the point of view of efficiency and reliability (accuracy of ARO recognition), a number of experimental studies were conducted:

- to create a database $A(m)_t$ data $A_i$ and in order to prepare for the training of the ANN, the open platform Roboflow was used [35]. This is due to the fact that today the specified platform is the largest collection of open source computer vision data sets, which allows you to create projects on object detection, their classification and segmentation.

The main advantage of the specified platform is the possibility of significantly reducing the time spent on preparing data for ANN training:

- an array was used for ANN training $A(m)_t$ data $A_i$, consisting of 700 aerial photos, in which the objects of aerial reconnaissance are aircraft (planes), that is, one class of ARO was used: $m = 700$, $\eta = 1$.

Examples of typical training set data are shown in Fig. 2. A distinctive feature of the aerial photographs (AP) shown in Fig. 2 are the different degrees of saturation with aerial reconnaissance objects.

![Fig. 2. Examples of aerial photos (reduced size) of the data array $A(m)_t$ used to train ANNs:](Image 326x192 to 513x374)

Fig. 2. Examples of aerial photos (reduced size) of the data array $A(m)_t$, used to train ANNs:

- a – highly saturated aerial photo; b – low saturated aerial photo

Source: [36].

The degree of saturation means up to 10 (Fig. 2a) and more than 10 ARO (Fig. 2b) on an aerial photograph. The simulation of the developed method of automating the process of detecting aerial reconnaissance objects on aerial photographs was carried out as follows:
1) at the initial stage, a database for training ANNs is formed. For this purpose, the database from the Roboflow platform was used [36]. In order to increase the number of aerial photographs for training, their augmentation was used, that is, the transformation of the original data (overturning the aerial photograph, reducing-increasing the AP, changing the values of brightness, saturation, contrast and exposure);

2) at the second stage, ANN training was carried out based on the algorithms of the Yolo V5 family with the determination of weighting coefficients. The duration of training was 30 epochs;

3) at the final stage, a number of experimental studies were carried out to evaluate the effectiveness of the developed method of automating the process of detecting ARO (in this case, airplanes) on aerial photographs. A set of test data was used as the initial data $Z(\kappa)_{test}$, consisting of 34 aerial photographs, i.e.: $9 = 34$. Examples of aerial photos (reduced size) of the test set $B(\theta)_{test}$ used to evaluate the effectiveness of the developed method are shown in Fig. 3 [36].

![Aerial photographs](image1)

**Fig. 3.** Examples of test aerial photographs (reduced size) used to evaluate the effectiveness of the developed method: a – weakly saturated aerial photograph; b – highly saturated aerial photograph

### Evaluation of the effectiveness of the developed method from the standpoint of ensuring the required level of reliability

In turn, to evaluate the effectiveness of the developed method from the standpoint of ensuring the required level of reliability, the following quantitative indicator was used – the probability of recognizing aerial reconnaissance objects, which is given by the following expression [37]:

$$ P_{od} = \frac{n_1}{n_2}, $$

where $n_1$ is the number of correctly recognized air reconnaissance objects;

$n_2$ is the total number of aerial reconnaissance objects on the aerial photograph.

The results of evaluating the effectiveness of the developed method from the standpoint of ensuring the necessary level of reliability are shown in Fig. 4. It should be noted that a satisfactory result of decryption is the value of the probability of recognition of the ARO, which is in the following range [37]:

$$ P_{od_{Yolo}} = 0.8 \ldots 0.9. $$

The analysis of the results shown in Fig. 4 shows that the average value of the probability of recognition of aerial reconnaissance objects for the array $B(\theta)_{test}$ test aerial photographs $B_j$ for the developed method of automating the decryption process is 0.87, i.e.:

$$ \bar{P}_{od_{DM}} = 0.87, $$

where $\bar{P}_{od_{DM}}$ is the average value of the probability of recognition of aerial reconnaissance objects.

This means that the requirement for the reliability of the decryption process. However, a problematic aspect of using the specified method is the fact that not all APs have a quantitative indicator of the reliability of the ARO decryption that meets the above-mentioned requirement – 5 highly saturated aerial photographs.

In turn, examples of qualitative assessment of the effectiveness of the developed method from the point of view of ensuring the necessary level of reliability are shown in Fig. 5. Qualitative assessment means the following aspects: detection of ARO of the studied class on aerial photographs with marking of the specified objects in the form of frames; indication of the probability with which these objects belong to the studied class.
Fig. 4. Diagram of the dependence of the probability of recognition of aerial reconnaissance objects depending on the test aerial photograph using the developed method
Source: developed by the authors.

Fig. 5. Examples of qualitative assessment of recognition of aerial reconnaissance objects for test aerial photographs (reduced size) using the developed method:
- a – weakly saturated aerial photograph;
- b – highly saturated aerial photograph
Source: developed by the authors.

The analysis of the examples results of the qualitative effectiveness assessment of the developed method from the standpoint of ensuring the necessary level of reliability, shown in Fig. 5, shows that the developed method allows to detect ARO with a fairly high reliability (average value is more than 0.8) and carry out their graphic designation on aerial photographs.

**Evaluation of the effectiveness of the developed method from the point of view of ensuring the required level of efficiency**

In turn, the results of the quantitative assessment of the developed method from this point of view are shown in Fig. 6 and indicate that even in the conditions of using computing equipment with low technical characteristics (during the experimental studies, a personal computer based on a processor was used i3 of the third generation) the average detection time of aerial reconnaissance objects on the test aerial photograph was less than 3 seconds – an average of 2077.8 ms.

This shows that the developed method meets the requirements for operational efficiency and reliability of air reconnaissance data decryption and has significant advantages compared to the existing methods, which require a decryption time calculated in minutes.
Fig. 6. Diagram of the dependence of the time of recognition of aerial reconnaissance objects depending on the test aerial photograph using the developed method
Source: developed by the authors.

Thus, it can be concluded that the developed method of automating the process of detecting aerial reconnaissance objects allows increasing the efficiency of deciphering aerial photographs under the conditions of ensuring the required level of reliability.

Conclusions

Thus, the developed method, the essence of which is the use of modern computer vision tools implemented in the system of artificial intelligence (artificial neural networks), allows to increase the effectiveness of deciphering aerial reconnaissance objects on APs, namely:

1) to ensure an increase in the efficiency of object recognition on aerial photographs. The analysis of the quantitative evaluations of the efficiency of decoding obtained as a result of experimental studies shows that the use of the developed method allows to significantly reduce the time of decoding an aerial photograph – on average 2077.8 ms (approximately 2 seconds) per aerial photograph under the conditions of using rather low computing power;

2) to ensure the required level of reliability of recognition (detection) of aerial reconnaissance objects on aerial photographs. The analysis of quantitative reliability estimates obtained as a result of experimental studies shows that the use of the developed method allows obtaining the necessary values of the probability of recognition of aerial reconnaissance objects. The average value of the probability of recognition of aerial reconnaissance objects for the developed method is 0.87 and is a satisfactory decryption result.

It should be noted that the practical implementation of the specified automation method and its integration into existing decryption technologies do not require high computing power. This is evidenced by the results of the automation of decryption using computer technology, which was involved in the course of conducting a number of experimental studies. Another key advantage of the developed method is that its integration into the decryption process does not require significant personnel training and high technical requirements.

Further research will be aimed at increasing the reliability of the developed method by increasing the duration of the ANN training process (up to 300 epochs); study of the possibilities of using the specified direction to increase the efficiency of deciphering aerial reconnaissance objects for the video resource obtained in the course of conducting aerial reconnaissance and evaluating the possibilities of integration into the process of conducting aerial reconnaissance on a real time scale.

Список літератури


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МЕТОД АВТОМАТИЗАЦІЇ ПРОЦЕСУ ВИЯВЛЕННЯ ОБ’ЄКТІВ ДЛЯ ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ДЕШИФРУВАННЯ ДАНИХ ПОВІТРЯНОЇ РОЗВІДКИ

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Аналізуються проблемні фактори, що мають суттєвий вплив на ефективність процесу дешифрування даних повітряної розвідки, отриманих в умовах використання безпілотних зітканих апаратів тактичного рівня з урахуванням досвіду ведення бойових дій на території України. Формуються вимоги до показників оперативності та достовірності процесу розпізнавання (виявлення) об’єктів повітряної розвідки. Досліджуються сучасні алгоритми комп’ютерного зору та технології глибокого машинного навчання з позиції інтеграції в процес дешифрування даних повітряної розвідки.

Метод автоматизації процесу виявлення об’єктів дозволяє отримувати необхідні значення ймовірності розпізнавання об’єктів повітряної розвідки, які дозволяють визначати наступні показники оперативності та достовірності: достовірність розпізнавання, оперативність розпізнавання. Оцінка використання дешифрувального методу дозволяє визначати наступні: практична реалізація зазначеного методу автоматизації з не потребує високих обчислювальних ресурсів.

Це дозволяє залучати до процесу дешифрування даних повітряної розвідки, безпілотний зітканий апарат, аерофотознімок, дешифрування, об’єкт повітряної розвідки, виявлення, оперативність, достовірність.

Ключові слова: безпілотний зітканий апарат, повітряна розвідка, аерофотознімок, дешифрування, об’єкт повітряної розвідки, виявлення, оперативність, достовірність.