Remote Monitoring of Mines in Fields with Using Neural Networks

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Abstract

The method of work was the development of methods for express monitoring to ensure the visibility of mines in the fields. Operational surveillance of large areas is possible thanks to remote monitoring technologies, in addition to thermal imaging. When setting up the experiment, part of the ammunition was immediately buried in the soil to a depth of 2-5 cm. neither has been identified. The maximum temperature difference for min was recorded in the morning, and for massive projectiles it was recorded over the evening. Before the mines and shells were buried, during thermal imaging monitoring, buried areas and mounds in the area were recorded. Based on the low sampling rate of thermal imaging monitoring, neural measurements were used to indicate the placement of mines in a mechanical way on the ground. Positive results were obtained, which showed the effectiveness of image recognition at 82.5%.

Keywords

thermal imaging monitoring, humanitarian demining, UAV, neural networks, training, location search, graphic object analysis

1. Introduction

The problem of humanitarian demining, as well as the search for unexploded ordnance (UXO) are very relevant today. According to review works by M.K. Habib (2008) [1] and Carolay Camacho-Sanchez et al (2023) in [2], the number of installed and inactive mines in the world is tens of millions of units. Since the problem of demining has been extremely relevant since the Second World War, demining technologies have been developed to a certain extent, but marginal lands have traditionally received less attention. In the 21st century, as a potential threat to logistics chains, along with the focus of a number of countries on renewable energy sources, interest in biogas and fuel briquettes has increased. When building strategies for the development of energy independence of communities according to Giuseppe Pulighe et al (2019) in [3] from India and Sheikh Adil Edrisi et al (2022) in [4] from the EU and N. Pasichnyk et al (2021) in [5] in Ukraine emphasize that even in conditions of growing food demand, it is marginal lands that are a real source for growing bioenergy raw materials.

Even in areas relatively far from the front or battle lines, the threat of the appearance of minefields, including on marginal lands, is quite significant. According to Matthew Bolton (2015) in [6], the concept of mine warfare changes for modern armies when they move from mine barriers to mine spaces. This is explained by the fact that the armed forces of the army and paramilitary formations have a large number of wheeled and tracked vehicles capable of relatively easy movement

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Information Technology and Implementation (IT&I-2023), November 20-21, 2023, Kyiv, Ukraine
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CEUR Workshop Proceedings (CEUR-WS.org)

on off-road terrain, which made deep breakthroughs of mobile units possible. To counter this threat, the army uses mine barriers that are simply laid out on the ground. For this, special equipment was developed, namely Tracked minelayer GMZ-3 (USSR), Minenverleger 85 (BRD), etc. Such barriers are relatively poorly detected especially on marginal lands, as they are, as a rule, distant from populated areas and, accordingly, their installation by local residents is not visually recorded.

Taking into account the urgent need for the introduction of marginal lands into agricultural practices for the needs of biogeneration, the development of express monitoring methods for the presence of mines in the fields is urgent, ***which was the goal of the work***.

2. The aim of the study

In the wars of the 20th century, mines were used to reinforce the line of defense and, apparently, to enhance their effectiveness, they dug into the ground and disguised themselves in various ways. Apparently, from the remote control of satellites and flights, the most important locations of mine fields were identified as emerging from the growth of fortification of spores. Ground-based monitoring equipment was previously insured for mine burial. For this purpose, a large number of physical and biological methods were described in the survey robot Yossef Kabessa et al (2016) in [7], which shows the main problems and the scale of physical methods and vibrancy (electromagnetic induction) This is also the low accuracy of biological research methods. The authors do not see a single most promising approach for monitoring mines, although all methods are being developed and refined. Let's take a look at these methods: Biological methods are based on the unique smell of the extractor. In the work of Adee Schoon et al (2022) in [8], the evidence of the selection of dogs for detection in Cambodia was described, where positive results were obtained, during the next hour we spent time preparing the animals and additionally required a canine specialist to handle the animals.

Before that, the fields are thrown into the legacy of the battlefields and become overgrown with tea leaves in which practice is physically important for dogs. After removing such boundaries, robots were carried out in order to eliminate them to indicate vibration-unsafe items. Thus, in the work of N. Ross et al (2021) in [9] they assessed honey from specially adapted cells for the presence of excess vibration to estimate the number of minutes. This technology was developed in the work of Janja Filipi et al (2022) in [10] where, with the help of webcams, they directly monitored the floor of the body to directly identify dangerous objects. This approach is effective over time and its accuracy for sealed ammunition may be questionable. For street smarts in the robot, Aharon J. Agranat et al (2021) in [11] developed a special biosensor for countering terrorists to mask the vibration in clothing.

With a high selection rate of scaling this technology for areas of several tens or hundreds of hectares, it will be difficult to organize with a UAV for the permissible range of monitoring in a few meters. There are other technical reasons.

Physical methods include active electromagnetic sounding of the surface ball of soil with the help of electromagnetic pulses and sinusoidal fields (such as metal detectors in the range of 2 - 50 kHz and ground penetrating radar in the range of 10 0 - 900 MHz), seismic disturbances and neutron vibration, registration of anomalies and fractions of other physical methods. Physical methods, as a rule, were developed for the needs of military people who need to know in the shortest possible time what they can do in their farms. Humanitarian exchange does not cause any harsh differences between the hours and the weather of minds against the tamed great areas and the creation of a minimum of ruin.

Press the search for vibration-unsafe devices using traditional physical methods of tying with an influx of significant losses. As shown in the work of S. M. Shrestha and I. Arai (2003) in [12], the suppression of the presence of mass presence in the last plots of third-party metal objects that are detected by detectors. For better nutrition in development, X. Yan et al (2009) in [13] proposed a metal equivalent method, which allows you to see metal objects by weight and storage. Analogue PIDHID is shown in the robot O. A. Abdel-Rehim et al (2016) in [14] de-aircraft in the base of the magnetic floor polarizability (The Magnetic Dipole Polarizabily Tensor) TERIAL OVKTU. By changing the number of negative results, it is possible to combine a number of different sensors in a single device, as shown in the work of H. Frigui et al (2010) in [15], in which case it is necessary to ensure the presence of security Rarely at the last stage.

Due to the regulation of the scale of the fields, there is a power supply and energy supply, so there is no waste of energy, for the ground-based acquisition of frequent solutions, pulsed modes of robotic detectors can be used, as shown in H. Çıtak (2020) in [16]. These arrangements, designed for military personnel who want to have a high degree of sensitivity, appear to be incontrovertible and powerful, often break down and require physical presence in the mine field, which creates significant risks for life and a mine of a special nature. technology. For humanitarian development, it is necessary to develop both organizational and new monitoring techniques, so in the work of Carolay Camacho-Sanchez et al (2023) in [17], an analysis of practical evidence shows that it is necessary to develop optimally and the routes of the teams for monitoring are always under great obligation.

In the work of Guillermo Rein et al (2017) in [18], for the needs of humanitarian aid, a controlled waste of locality is advocated; in practical terms, the authors noted that the use of plastic mines was carried out, which is not necessary. In addition to this fact, the burning of significant areas can also cause environmental problems. Now, after analyzing the literature, it is possible to draw conclusions about the need to develop new non-traditional methods for humanitarian outreach, which can be scaled up across large areas and activities in the minds of the public. visibility in the fields of third-party metal objects. In the wake of the war in Ukraine, speculation was raised about the possibility of identifying mines and shells in the fields with the help of thermal imagers. Physically, the method is based on the fact that the heat capacity of the metal and the vibrating agent is separated from the soil and, therefore, when heated throughout the day under constant pressure, the temperature of these objects will be different. can also be recorded remotely. According to data from the Internet of volunteers from the front, the maximum difference could be recorded both day and night. Such an approach, given the use of thermal imagers installed on UAVs, could potentially be useful for large areas of agricultural enterprises. To test this idea, a full-scale experiment was carried out.

American researchers Baur, J. et al. [19] presented the results of a study of methods for remote detection of mines and identification of scattered anti-personnel mines when surveying large areas. This methodology is designed to detect scattered plastic mines that use a liquid explosive contained in a polyethylene or plastic casing. The findings are based on analysis of multispectral and thermal data sets collected through UAV observations. Scattered landmines of the PFM-1 type are used as test objects. The study presents the results of efforts to automate landmine detection based on supervised learning algorithms using Faster R-CNN. In this case, a testing accuracy of 99.3% was obtained for the partially hidden test set and 71.5% for the completely hidden test set.

British researchers I. Giannakis et al. [20] present an example of numerical modeling for the use of artificial neural networks (ANN) to the problem of detecting landmines using ground penetrating radar (GPR). The authors created and used a training set consisting of simulated data from a wide range of models with various: topography, soil heterogeneity, mines, false alarm targets, antenna height, mine laying depth. An article by German researchers J. Schorlemer et al. [21] discusses the correction of visualization errors in mine detection using portable devices caused by the propagation of electromagnetic waves in the environment. The authors have developed an analytical model that describes the behavior of refraction on flat and non-planar surfaces and determines the distance traveled by the wave. The results are tested on datasets suitable for deep neural network training, which are generated using a finite difference numerical simulator.

American researchers Chih-Chung Yang et al. [22] used neural networks to detect mines based on data generated by various types of sensors. The authors proposed a two-layer hybrid neural network structure, including supervised and unsupervised learning, for the detection and subsequent classification of landmine types. In an article by Italian researchers F. Picetti et al. [23], a mine detection method based on a convolutional autoencoder is proposed. The system uses an anomaly detection pipeline: an autoencoder examines the description of mine-free GPR B-scans and detects mine traces as anomalies. At the same time, during training, data containing traces of mines is not used. This makes it possible to detect new models of landmines.

As a mathematical apparatus, “State-probability of choice” models [24], ranking methods [25, 26], risk assessments with elements of fuzzy logic [27] can be used.

3. Experimental conditions

The research was conducted on September 8-9, 2023 on the basis of the military department of the National University of Life and Environmental Sciences of Ukraine. Specialists installed TM-62M anti-tank mines with removed detonators both directly on the ground and buried to a depth of 2-5 cm at the training ground of the department, according to the mine-explosives guidelines. Both samples were exposed to direct sunlight. The following samples were studied in parallel (Fig. 1):

- A shot of a 125-mm educational and training high-explosive tank projectile (weight 23 kg). 2 units under direct sunlight, where 1 sample is directly on the surface and the other is buried to a depth of 2-5 cm.
- Educational and training grenades F1 (weight 0.5 kg). 3 units - on the surface, and buried to a depth of 2-5 cm, as well as a sample in the shade.
- Shells from 23 and 30 mm projectiles (as possible metal contamination)

Figure 1. The training ground of the military department of NUBiP with simulators of explosive devices where: 1 and 2 - locations of buried anti-tank mines and high-explosive shells, respectively.

Figure 2. Conducting thermal imaging studies at 22 o'clock (from the left) solar radiation measurements at 12 o'clock (right).

On September 8, 2023, the weather was sunny and cloudless. According to meteorological observations, wind gusts were 2-3 m/s. The experimental objects were installed at 10 in the morning.

Research continued from 9 a.m. to 10 p.m. Using a penetrometer, the temperatures of objects were recorded in a non-contact manner. Along with the surface temperature, the intensity of solar radiation was determined (Fig. 2). Thermal imaging studies were carried out using the TROTECT model IC085LV device.

4. Results and Discussion

When conducting experimental research, it was not possible to identify a mine or projectile buried in the soil to a depth of 2-5 cm. During thermal imaging of anomalies for buried munitions, the unevenness of the terrain itself was actually recorded (Fig. 3). These data correlate in a certain way with the data of other researchers obtained from the Internet (Fig. 4). That is, for ammunition buried in accordance with the mine-explosives guidelines, monitoring by thermal imaging devices turned out to be ineffective. Similar results were obtained at the test site for a high-explosive projectile that was not detected by thermal imaging. The obtained results of object monitoring are shown in Table 1.

Table 1

Results of thermal monitoring of objects

Time	Projectile in the sun, ºC	Projectile in the soil, ºC	Mine, ºC	Grenade in the sun, ºC	Grenade in the shade, ºC	Soil in the sun, ºC	Illumination, lumen
12,19	26,6	30,9	35	32,5	22	31	73500
14,53	30,0	30,2	38	33,0	23	30,4	65300
17,14	29,7	23,4	31,7	29,7	21,5	24,2	26800
18,14	26,8	21,0	23,2	22,8	20,1	20,4	3640
20,10	17,7	15,4	15,1	15,4	15,2	15,3	0

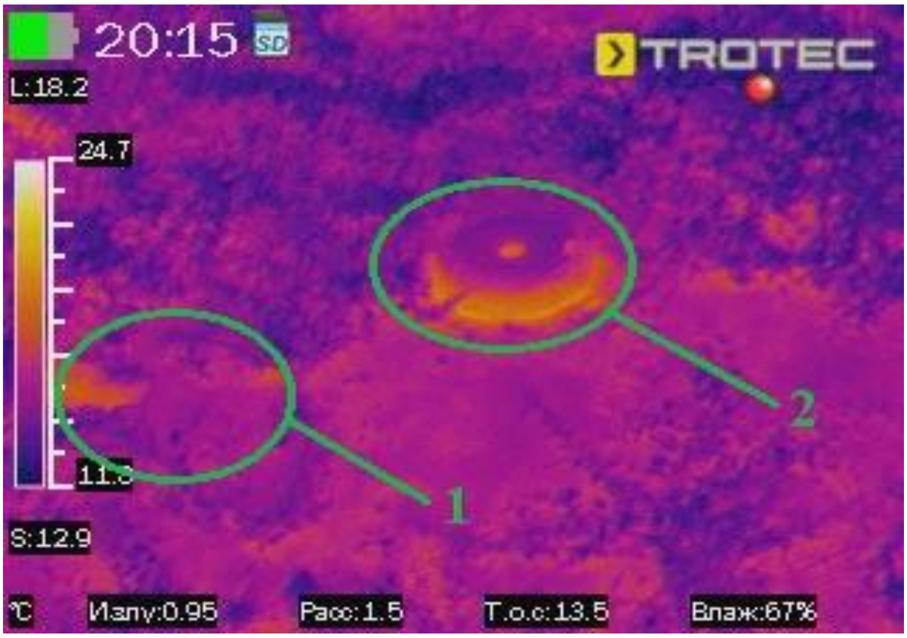


Figure 3. Thermal imaging at 20:15 on 09/08/2023 of anti-tank mines, where the number 1 and 2 indicate the place where the mine is buried and the mine on the surface, respectively.

Based on the results obtained in cloudy weather (the sample is in the shade), monitoring is impractical. It was experimentally established that during thermal imaging monitoring, the presence of metal pollution, unlike classic metal detectors, does not pose a problem. Due to the thin metal of the sleeves and their relatively large surface area, their heat capacity is low, thanks to which rapid cooling occurs (Fig. 5). The assumption about the expediency of monitoring in the evening or at night turned out to be wrong, the maximum temperature difference between the mine and the soil was recorded during the day. Prospects of practical use of thermal imaging monitoring for humanitarian demining.

Figure 4. Photographs of the field with funnels from the explosions of mines and shells in the visible and thermal imaging ranges of the spectrum from the left and right, respectively. (Source https://censor.net/ru/video_news/3437668/vsu_ispolzuyut_teplovizory_dlya_obnarujeniya_min_cnn_video)

Places of intense hostilities are easily identified by mass funnels from explosions and, accordingly, require classic demining. Places, in particular marginal agricultural land, can be investigated by thermal imaging means, but even in the absence of sinkholes, extraneous objects such as car tires, etc., can be recorded. That is, the presence of safe artificial objects is possible, which will cause identification errors. Since the main threat to random minefields is actually square minefields, it is possible to identify them based on the nature of the installation of GMZ-3 barriers or its analogues. According to the standards, such mine barriers can have from 2 to 6 rows of mines. A row of mines is usually not strictly rectilinear. When installing a row with the help of a mine spreader, depending on the terrain, the row can smoothly bend in any direction by approximately 5-30 degrees. The minimum distance between rows is 35 meters, and the maximum is 115 meters. The scheme of a minefield installed by a self-propelled minelayer is presented in Fig. 6. Analogous problems of analysis of graphic objects using the example of maps of the distribution of vegetation indices were solved in relation to the identification of technological stresses in the work of N. Pasichnyk et al (2021) in [28]. Similarly, identification technologies using neural networks can be used.

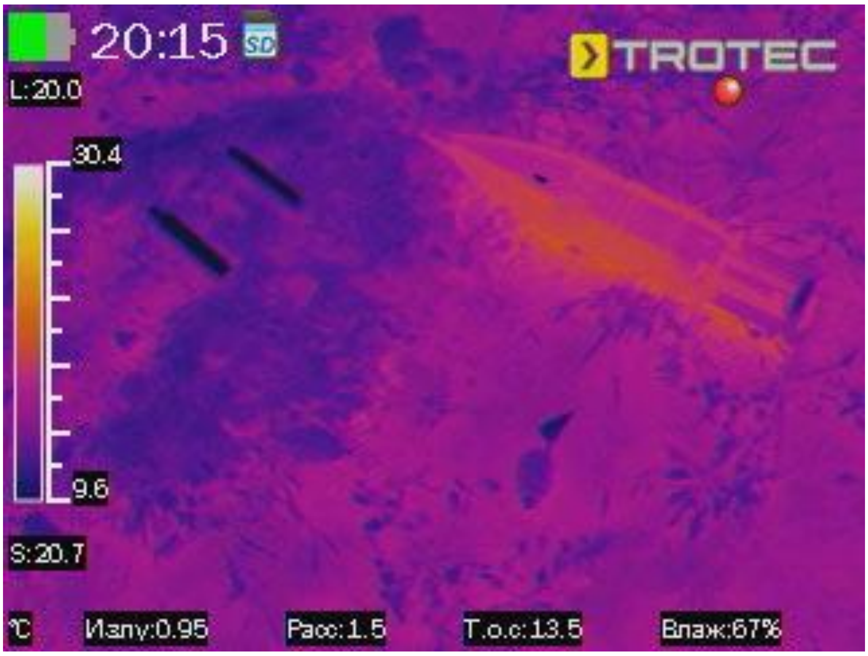


Figure 5. Results of thermal imaging of projectiles, grenades and casings. The minimum temperature corresponds to the casings, the maximum temperature corresponds to the projectile, the grenade approximately corresponds to the soil (photo taken at 8:15 p.m. on September 8, 2023.)

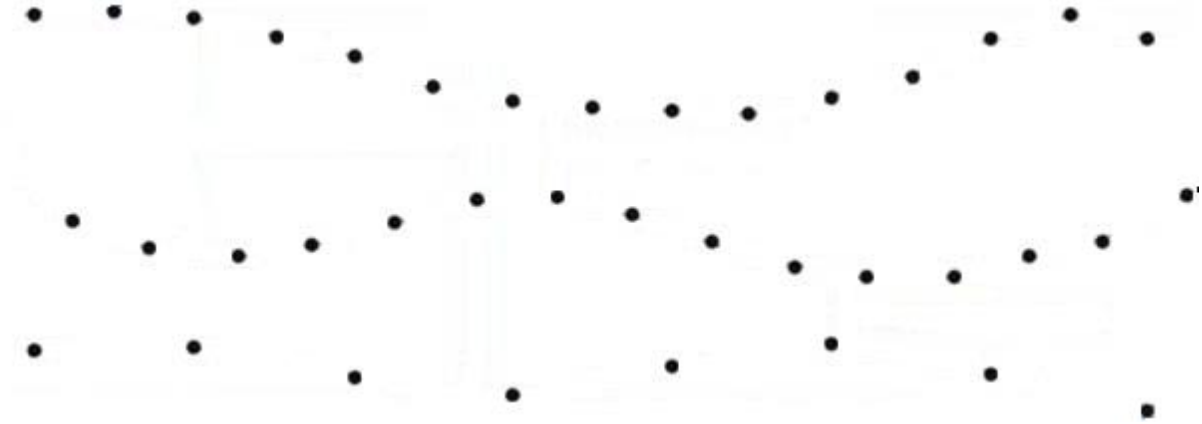


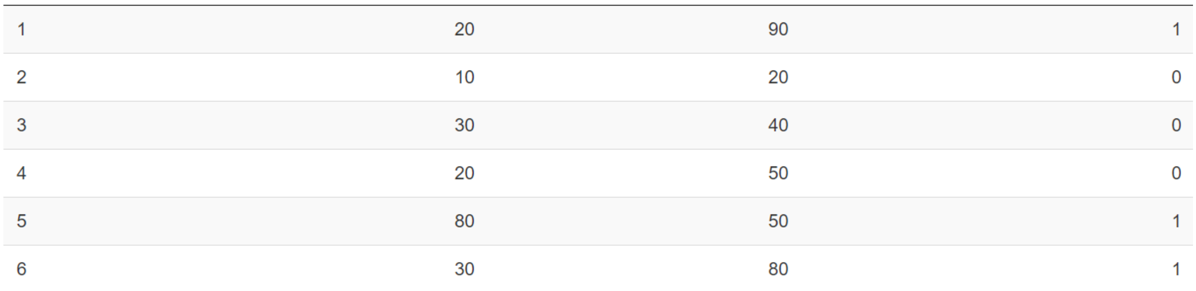
Figure 6. Map of a mine barrier installed by a minelayer, consisting of 3 rows of mines

Object recognition stands out as one of the most common applications in the field of computer vision. Researchers have invested considerable effort in improving object recognition over the years. It is important to understand the different types of object recognition tasks, as the required neural network architecture is highly task dependent. Object recognition tasks can generally be divided into three main types:

1. Classification of images.
2. Detection of objects.
3. Segmentation of instances.

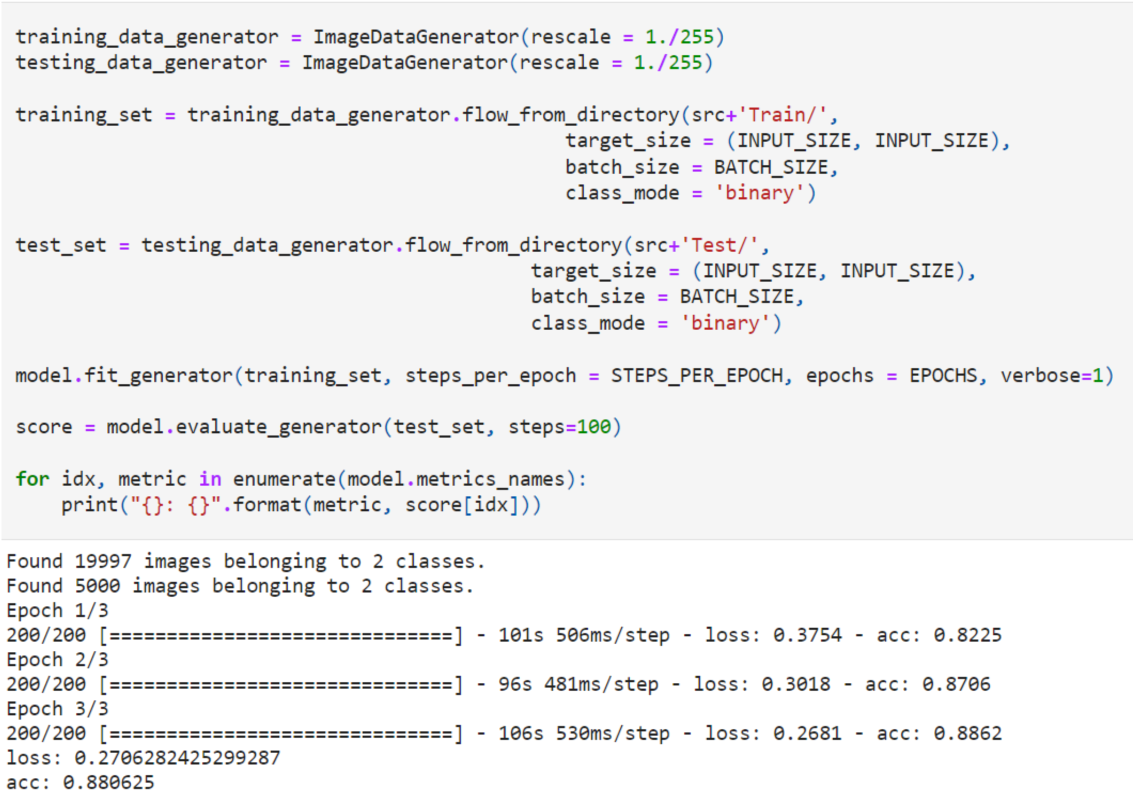
In the object detection task, images are used to train the network, and the model must establish where the objects are by drawing boxes around them. This is like a more advanced version of image classification. Instead of assuming that there is only one object in the image, the model is able to take into account that there may be many different objects. Therefore, the network needs to detect and draw the contours of each object in the image. This task is difficult for algorithmization and software writing, but it can be solved with the help of neural networks, which have already been applied to similar tasks and coped with them quite effectively. Convolutional neural networks (CNNs) successfully coped with this task, along with the necessary optimization of their settings or the task of variable images, or refinement of training parameters. Convolutional neural networks work by specifying potential regions where objects might be, and then using a trained model to determine which objects are within each region, i.e., which categories are most likely for each. For the purpose of training such a network, mine location schemes according to Fig. 6 were used, the probable distance between objects in the range of 35-50 m and the search for objects in the direction of propagation at an angle of 180° were also set. Figure 7 shows a fragment of data for training the network. To train and test the network, the Python language, the TensorFlow library, which makes it easy to build and train neural networks, was used. Part of the network training code is shown in Fig. 8. As a result of network testing, object identification accuracy was obtained at the level of 88%, which suggests the possibility of applying this approach to the task of identifying potentially dangerous objects on humanitarian land plots. The structure of the network is shown in fig. 9. From the given values of the network before and after optimization, an improvement in the search for objects can be seen (Fig. 9a and Fig. 9b).

It should be noted that the research described in this article can be applied in robotic demining complexes described in [29, 30].



1	20	90	1
2	10	20	0
3	30	40	0
4	20	50	0
5	80	50	1
6	30	80	1

Figure 7. Network training and testing



```
training_data_generator = ImageDataGenerator(rescale = 1./255)
testing_data_generator = ImageDataGenerator(rescale = 1./255)

training_set = training_data_generator.flow_from_directory(src+'Train/',
                                                target_size = (INPUT_SIZE, INPUT_SIZE),
                                                batch_size = BATCH_SIZE,
                                                class_mode = 'binary')

test_set = testing_data_generator.flow_from_directory(src+'Test/',
                                             target_size = (INPUT_SIZE, INPUT_SIZE),
                                             batch_size = BATCH_SIZE,
                                             class_mode = 'binary')

model.fit_generator(training_set, steps_per_epoch = STEPS_PER_EPOCH, epochs = EPOCHS, verbose=1)

score = model.evaluate_generator(test_set, steps=100)

for idx, metric in enumerate(model.metrics_names):
    print("{}: {}".format(metric, score[idx]))
```

```
Found 19997 images belonging to 2 classes.
Found 5000 images belonging to 2 classes.
Epoch 1/3
200/200 [==============================] - 101s 506ms/step - loss: 0.3754 - acc: 0.8225
Epoch 2/3
200/200 [==============================] - 96s 481ms/step - loss: 0.3018 - acc: 0.8706
Epoch 3/3
200/200 [==============================] - 106s 530ms/step - loss: 0.2681 - acc: 0.8862
loss: 0.2706282425299287
acc: 0.880625
```

Figure 8. Operator window

5. Conclusions

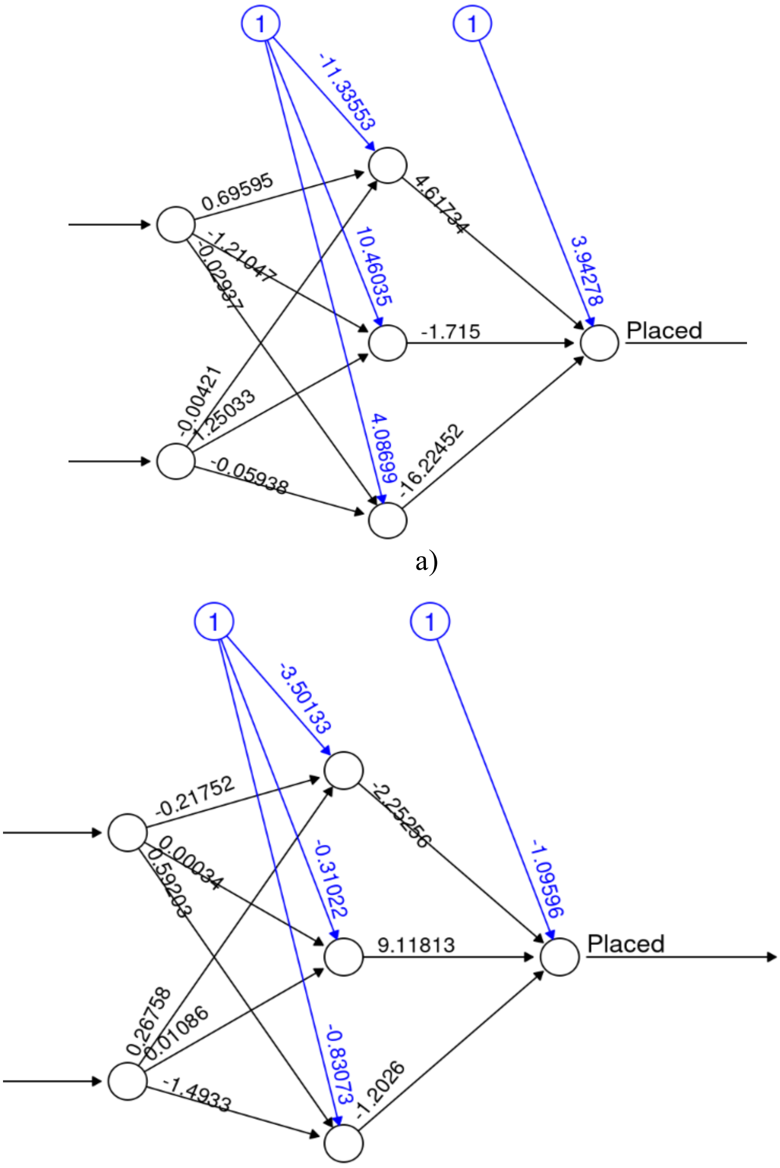
1. Identification of minefields laid out on the surface of the earth by thermal imaging means for the needs of humanitarian demining is possible.

2. During thermal imaging monitoring of mines and projectiles, the presence of random metal objects, such as shell casings of caliber up to 30 mm, does not create significant obstacles for monitoring.

3. Identification of mines by thermal imaging means is possible only in clear weather, buried munitions are fixed only by indirect signs due to unevenness of the ground.

4. The use of convolutional neural networks has certain prospects for detecting potential locations of mines and explosive devices, and can be useful in the problem of humanitarian demining.

5. The accuracy of identifying such objects according to network testing is 88%, which is a confirmation of the possibility of the combined use of thermal imaging and a neural network.



a)

б)

Figure 9. The structure of a neural network for object identification

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