Formulation of the problem of creating advanced remote-controlled demining systems

Volodymyr Kotsiuruba [*1 A]; **Volodymyr Krivtsun** [2 B]

***Corresponding author:** [1] Doctor of Technical Sciences, Professor, Professor of Department, e-mail: kotcuru@ukr.net, ORCID: 0000-0002-3907-5320
[2] Candidate of Technical Sciences, Senior Research, Head of Department, e-mail: vik-08-74@i.ua, ORCID: 0000-0002-3907-5320

[A] The National Defence University of Ukraine named after Ivan Cherniakhovskyi, Kyiv, Ukraine
[B] Hetman Petro Sahaidachnyi National Army Academy, Lviv, Ukraine

Received: December 6, 2022 | Revised: December 20, 2022 | Accepted: December 31, 2022

UDC 358:623.3

DOI: 10.5281/zenodo.7750447

Abstract

The experience of combat operations in modern military conflicts has shown that one of their dangerous consequences is the contamination of territories with explosive objects that pose a threat to both the military and civilians. At the same time, one of the main problematic issues is the significant excess of the rate of development of mine weapons compared to the rate of development of mine action equipment. Ukraine is no exception, which, due to the full-scale aggression of the russian federation, has become the most explosive contaminated country in the world.

The analysis of the use of explosive devices in the war of the russian federation against Ukraine shows that the enemy uses the entire range of mine weapons available to it, including those prohibited by international conventions. An analysis of the available demining equipment in the engineering units of the Armed Forces of Ukraine shows their obsolescence and low efficiency, as well as the lack of remote-controlled demining systems. At the same time, the main method of performing demining tasks both in the conditions of hostilities and in the absence of them is manual, which poses a great danger to sappers. Therefore, the creation of remote-controlled demining systems is an urgent task. The solution to this problem is proposed through the development of new principles of operation of advanced remote-controlled demining complexes, substantiation of possible options for the use of standard portable means of searching for explosive objects on remotely controlled mobile platforms according to the concept of "Forward Edge Sapper", substantiation of requirements for the structure and parameters of these complexes and implementation of the idea of creating a database of technical images of known explosive objects based on the obtained experimental data.

This article presents a model of functioning of a remote-controlled demining system based on the formalization of the scientific problem using the theoretical-set approach, considering the experience of the enemy's use of explosive objects during the war of the russian federation against Ukraine and the characteristics of means of their search and destruction.

Key words: combat operations, explosive ordnance, demining, remote-controlled demining system.

Introduction

Intense hostilities in the southeastern region of Ukraine have resulted in a large area of Ukraine being contaminated by explosive ordnance (EO). As of December 2022, the so-called "mine contamination" in Ukraine covered about 170 thousand square kilometers, about 40% of the country's total territory, which is incomparable even to Syria and Afghanistan, i.e. more than a quarter of the country's territory (Ukraina ye naibilsh). Every day, there are reports of deaths of both sappers and other military personnel from explosions at the EO.

As for the deaths of civilians, according to the Stockholm Peace Institute, Ukraine ranked 3rd place in terms of civilian casualties in 2017 and 5th in 2018, ahead of Afghanistan, Cambodia, Mali, and Pakistan (OON zaklykaie aktyvizuvaty). At the same time, an analysis of information from open sources shows that losses are increasing every day, including sappers who perform tasks both during and in the absence of hostilities.

Problem statement

The experience of performing demining tasks in modern military conflicts and peacekeeping operations (Zhukov S., №6 1998; Zhukov S., №8 1998) has shown that one of the main problematic issues is a significant excess of the rate of development of mine weapons compared to the rate of development of mine action equipment. This fact, given the growing intensity of the use of mines and improvised explosive devices (IEDs), has long been perceived in the leading countries of the world as a global problem that requires a comprehensive approach (Osoblyvosti humanitarnoho; Perspektyvna schema). At the same time, special attention in demining operations is paid to the quality of the area clearance from EO, which is determined by international demining standards (Mizhnarodni standarty). In general, there is currently no technical means that would ensure compliance with the requirements, which leads to the continued widespread use of manual demining, which is extremely costly and dangerous.

Therefore, taking into account all of the above, the need to improve the quality, efficiency and safety of processes, search, detection, destruction or neutralization of EOs in demining practice is significantly increasing. This issue is particularly acute in relation to advanced minefield reconnaissance equipment mine and explosive barriers (MEB), in particular, means of searching and detecting EOs.

Data and methods

An analysis of recent studies and publications [8-15] has shown that they raise and consider partial scientific tasks. For example, well-known works (Shcherbakov H. N., 2011; Yasko V.A., 2010; Karev, A., 2000; Shcherbakov H.N., 2003; Salamakhyn T. M., 1983; Pidsumkovyi zvit pro, 2012) are devoted to highlighting the results of scientific research aimed at modeling processes and substantiating the requirements for means of searching and detecting EOs by various methods, and consider aspects of remote destruction of EOs. Paper (Mosov S.P., 2019) presents the results of theoretical studies of methods of aerial reconnaissance of mined areas.

The analysis of the known available studies and publications has led to the conclusion that the task of conducting comprehensive research on the possibility of using advanced means of searching and detecting EOs using remotely operated platforms, taking into account the nature of mining and the type of EOs used in hostilities, has not been fully resolved to date. At the same time, the issue of systematic analysis of the technical aspects of detecting mines and other EOs in the current situation in the combat zone remains relevant and requires further research.

The purpose of the article is to present the results of the analysis of the use of EOs on the territory of Ukraine as a result of the war with russian federation, on the basis of which the problem of creating advanced remotely controlled demining complexes is mathematically formulated.

Results and Discussion

During the ATO/JFO, and today in the course of russian federation's large-scale armed aggression against Ukraine, the enemy uses EO both in the form of minefields and individually to destroy regional infrastructure and IEDs (Collection of materials, 2022; Scientific and technical, 2022; Experience of the use, 2022). The most common practice is for sabotage and reconnaissance groups

of the aggressor army to first study the location and type of minefields installed to protect the positions of our troops or the routes of deployment of reserve groups, and then set booby traps for sappers and IEDs on the routes of deployment, which in most cases are extremely difficult to detect.

In recent years, the enemy has been using the most widely used remote mining method with both anti-tank and anti-personnel mines. The peculiarity of such mining is the haphazardness of mine placement and the particular danger of mines that have different principles of target detection (seismic, tension, pressure, optical). These mines can be set to self-deactivate after different periods of time or without self-deactivation, which poses an additional danger to military personnel and civilians.

The nature and extent of UXO contamination in the combat zone and in the liberated territories is quite different, i.e., significantly different from the classical post-Soviet approach to mining. In this sense, special attention should be paid to the shift in priorities towards the use of IEDs compared to industrially produced engineering mines. This fact was confirmed by the results of statistical research conducted at the Ivan Chernyakhovsky National Defense University of Ukraine (Statistical survey based). The statistical survey involved 100 officers of the Armed Forces of Ukraine who have significant combat experience in performing combat (special) tasks in the ATO (JFO) area. However, with the beginning of russia's large-scale aggression against Ukraine in February 2022, the emphasis began to shift towards the installation of classic minefields and the use of remote mining. At the same time, the danger has increased due to the number of unexploded munitions of various types. For example, the russian army alone uses about 444,000 artillery shells every month (The Ministry of Defense).

It has also been established that mines and explosive devices (EDs) are laid by the enemy with elements of non-removal or non-detonation. Mines are laid both on the contact line and in populated areas in crowded places (Collection of materials, 2022; Scientific and technical, 2022; Experience of the use, 2022). The abandonment of transit mining and the transition to a volumetric model of unsystematic mining with the use of targeted explosive ordnance is becoming a feature.

The danger lies in the fact that their use is not limited by scale, time, or terrain. The enemy mainly uses engineered ammunition of Soviet and russian production: anti-personnel mines (explosive devices) – PMN of all modifications (PMN, PMN-2, PMN-3, PMN-4), MON-50 (90, 100, 200), OZM-72 (3, 4, 160), POMZ-2M, explosive devices NVU-P "Okhota" (NVU-P2); "booby traps" – MS-3, MS-4, ML-7, ML-8; anti-tank mines – TM-57, TM-62 of various modifications, TM-72, TM-83, TM-89, as well as EOs, such as artillery shells, mortar shells, multiple rocket launchers, fragmentation grenades, and various IEDs (Collection of materials, 2022; Scientific and technical, 2022; Experience of the use, 2022). However, recent hostilities have shown that the enemy has begun to widely use new mines that are installed remotely. This is primarily the POM-3 anti-personnel mine, which is deployed both by the Zemledelie-I mine system and by aviation, artillery and portable mine systems at a distance of several meters to hundreds of kilometers (Scientific and technical, 2022). In addition to the POM-3, the enemy widely uses other mines that are installed by remote mining means – anti-personnel PFM-1, PFM-1S, POM-1, POM-2 and anti-tank PTM-1, PTM-3, PTM-4. The peculiarity of using these mines is that they can be installed deep in the rear of our troops, in settlements, at economic and agricultural facilities, etc.

The enemy is also using new ways to detonate anti-personnel mines and IEDs. In addition to "tripwires", they hang fishing hooks in the bushes that catch on clothing. In this case, the sappers warn that one should be very careful to notice and pass the "tripwire" in time, but one may not notice several such hooks hanging in the bushes, which can get into the clothes, leading to an explosion.

The enemy usually puts landmines and mines on roads. They prefer guided improvised explosive devices of three types: to destroy military equipment, to destroy manpower, and

combined. In populated areas and forests, IEDs with various types of "tripwires" can be installed, for which the so-called "spider web" (horizontal, vertical, mixed) is used. It can be made of wires from the control system of an anti-tank guided missile, fishing line, tree branches, and bushes. The height and length of the tripwires can vary. False tripwires are also used; mines and booby traps can be installed to be unremovable. In this case, the enemy uses hand grenades along with a conventional fuse, the fuse levers of which are fixed by the mine bodies. In addition, the enemy is extremely cunning – they use various "surprise mines", IEDs disguised as civilian objects, various forms of so-called "tripwires" that use mines and grenades, and even so-called "intelligent" mines with seismic sensors, and remote control of detonation is widely used, which indicates a fairly high level of professionalism of the enemy and its unlimited supply of necessary equipment.

Guided and unguided landmines, individual mines and groups of mines, as well as hand grenades laid on tripwires, have become widespread in the combat zone; the vast majority of them are laid on roads and roadsides; the main means of mine warfare are not only engineered ammunition, but also artillery and aviation ammunition, hand grenades adapted with improvised means to be used as landmines (traps).

In addition, a significant proportion of casualties are caused by soldiers or equipment hitting their own or unaccounted for mines while performing engineering reconnaissance tasks, moving between positions, conducting engineering work (engineering equipment of positions), extinguishing fires, evacuating the wounded, etc.

Under these conditions, the issue of performing demining tasks in the areas of combat operations and in the liberated territories became acute. In this regard, the units of the Armed Forces of Ukraine use probes, mine and bomb detectors, reconnaissance and demining kits, engineering and reconnaissance vehicles, optical surveillance equipment, and night vision devices.

The disadvantages of the existing ground-based technical means of engineering reconnaissance of the Armed Forces of Ukraine (IMP-2, RVM-2, IMB, INM) should be considered their moral and physical obsolescence (they were adopted in the Soviet times). In the context of the global trend of creating and using robotic complexes and systems in the military sphere, foreign metal detectors (with the help of volunteers and partner countries) are more modern.

In these circumstances, it should be noted that today in Ukraine the most commonly used method of demining is manual. Even with the mechanical method of conducting engineering reconnaissance, the engineering reconnaissance vehicle is also directly controlled by a person. There are no remote mine detection devices. This leads to losses of personnel in the engineering and demining units of the Armed Forces of Ukraine.

Thus, the Armed Forces of Ukraine do not have modern remote-controlled (robotic) reconnaissance and demining systems, which slows down the demining process in Ukraine and requires changes in approaches to the provision of demining units and the rapid development (procurement) of modern means.

Therefore, the creation of domestic remotely operated demining systems (RODSs) is an extremely urgent task today that requires detailed research and the development of appropriate methodological foundations.

The main idea underlying the research is to develop new principles of operation of advanced remotely operated demining systems (RODSs), to substantiate possible options for the use of standard portable UXO search equipment on remotely operated mobile platforms (ROMPs) according to the "Forward Edge Deminer" concept, to substantiate the requirements for the structure and parameters of these complexes, and to implement the idea of creating a database of technical images of known UXOs based on the experimental data obtained on selected indicators (signal amplitude, period and frequency). This will ensure the necessary efficiency of performing

tasks on reconnaissance and demining of the terrain from UXOs and, most importantly, reduce the danger to the personnel of demining groups during the performance of their tasks.

To formalize the scientific problem, based on the theoretical-set approach (Kotsyuruba, V., 2017), a model of perspective RODSs is defined as

$$KR = \langle V, D, F, Z, \Pr, Sp, Ck, Q(Z), C(Z), t(Z) \rangle, \quad (1)$$

where KR – perspective RODS;
V – RODS set of elements;
D – a set of links between elements;
F – functions that are assigned to RODS elements;
Z – the set of RODS tasks;
P_r – a set of RODS processes;
S_p – the area to be demined;
C_k – complexity of demining processes;
Q(Z) – quality indicators of the task execution;
C(Z) – indicators of demining costs;
t(Z) – time spent on demining tasks.

The functioning of the RODS (1) can be represented:

$$V \times D \times F \times P_r \times S_p \times C_k \to Z. \quad (2)$$

One of the main requirements for the RODS is its efficiency. That is, the volume of tasks performed *Z*, which are realized by the relevant processes P_r, should be maximized while meeting the requirements for maintaining their required quantity and quality of performance *Q(Z)*, under resource and time constraints.

In other words, in a formalized form, the problem can be presented as

$$W(S_p; C_k) \to max, \quad (3)$$

$$\text{if } Z \in Z^*, Q(Z) \geq Q^*(Z), C(Z) \leq C*(Z), t(Z) \leq t^*, Ck_{ij} \leq Ck_j^*, Ck_i = \langle k, h, g \rangle,$$

where $Q^*(Z), C^*(Z), t^*, Ck_j^*$ – some thresholds set by operational and tactical requirements;
$\langle k, h, g \rangle$ – parameters of complexity of demining;
k – UXO density, he^{-1};
h – depth of installation or location of the IED relative to the surface of the concealing medium, *m*;
g – the type of IEDs that are installed or located on the ground.

Conclusions

Thus, Ukraine is currently one of the most explosive-hazardous countries in the world, and the main method of demining is manual, which is not effective enough and poses a great danger to the personnel of demining groups. One of the ways to increase the efficiency of demining processes and ensure the safety of deminers is to create and use RODS. It is possible to increase the efficiency of demining processes with the help of the RODS by adapting its elements to the scope of tasks of

varying complexity, taking into account resource constraints. In particular, the construction of this complex is proposed to be carried out on the basis of adaptation to the conditions of combat operations during mine warfare of modernized existing and created new demining means, as well as through the introduction of a justification for the rational parameters and structure of the prospective RODS. The direction of further research is the development of methodological foundations for the structural and parametric synthesis of the system of remotely operated demining means (systems) and the presentation of the results of experimental studies.

References

Collection of materials on the study of the combat experience of the Russian-Ukrainian war of 2022, collection No. 4, 2022. P 70-71, 217-232.

Experience of the use of troops (forces) during the operation of the operational and strategic grouping of troops "Khortytsia" from June 10 to July 01, 2022: Kyiv, 2022. P 38.

Husliakov O.M. (2012). Analiz svitovoho dosvidu zastosuvannia ta tendentsii rozvytku viiskovykh robototekhnichnykh kompleksiv [Analysis of the world experience of application and trends in the development of military robotic systems]. *Military Technical Collection*. Lviv. № 1 (6). P. 120-126.

Karev, A., Raevsky, V., Konyaev, Yu., Rumyantsev, A., Averchenko A. Mobile Complex for Detection of Explosives. Mine Clearance Technology of XXI Century. *Electronics: Science*. Technologies. Business, 2000. № 1. P. 54-58.

Kotsyuruba, V. (2017). Formulation of the problem and substantiation of the set of principles of constructing an adaptive mine-clearance system under conditions of resource constraints. *Journal of Scientific Papers "Social Development and Security"*, *2*(2), 3-11. https://doi.org/10.5281/zenodo.1117323

Mizhnarodni standarty protyminnoi diialnosti: orhanizatsiia natsionalnoi prohramy, [International Mine Action Standards: Organizing a National Program.] Available from : https://www.osce.org/ukraine/149431?download=true

Mosov S.P., Gurak S.P. Robots and UAVs against mines. Defense Bulletin. № 11, 2019.

OON zaklykaie aktyvizuvaty zusyllia z rozminuvannia na skhodi Ukrainy, [UN calls for increased demining efforts in eastern Ukraine] [Electronic resourse]. Available from : https://www.unian.ua/war/10502961-oon-zaklikaye-aktivizuvati-zusillya-z-rozminuvannya-na-shodi-ukrajini.html

Osoblyvosti humanitarnoho rozminuvannia, [Humanitarian demining features] [Electronic resource]. Available from : https://www.radiosvoboda.org/a/29685254.html (request date: 27.02.2020).

Perspektyvna skhema orhanizatsii protyminnoi diialnosti v Ukraini, [Prospective scheme for the organization of demining activities in Ukraine] [Electronic resource]. Available from : http://audm.org.ua/wpcontent/uploads/Shema-PMDU-perspektiva-1.pdf (request date: 04.03.2020).

Pidsumkovyi zvit pro vykonannia boiovykh zavdan sapernymy pidrozdilamy ZS Ukrainy v Islamskii Respublitsi Afhanistan u skladi Lytovskoi hrupy z rekonstruktsii provintsii Hor (HRP) za period z lystopada 2010 r. po lystopad 2011 r. [Final report on the performance of combat missions by the demining units of the Armed Forces of Ukraine in the Islamic Republic of Afghanistan as part of the Lithuanian Reconstruction Group for Gor Province (GRG) for the period from November 2010 to November 2011] Kyiv: HSh ZSU, 2012. 47 p.

Salamakhyn T. M. Boevaia effektivnost inzhenernykh boeprypasov i elementov sistemy zahrazhdenyi [Combat effectiveness of engineering ammunition and barrier system elements]: textbook. Moscow: VIA named after Kuybyshev, 1983. 424 p.

Scientific and technical examination of the trophy sample of the POM-3 anti-personnel fragmentation mine and the remote mining engineering system codenamed “Zemledelie-I”. Interim report: Kamianets-Podilskyi, 2022. 228 s.

Shcherbakov H. N. Novye metody obnaruzhenyia skrytykh obyektov [New methods of detection of hidden objects]: monography. Moscow: Elf IPR Ltd, 2011. 503 p.

Shcherbakov H.N. (2003). Metody obnaruzhenyia min – primenitelno k probleme humanitarnoho razminirovanyia. [Mine detection methods as applied to the problem of humanitarian demining] *Special Technique*, № 3. P. 24-31.

Statistical survey based on the results of the classes [Electronic resource]. Available from : https://adl.mil.gov.ua/mod/feedback/view.php?id=4452 (request date: 03.06.2020).

The Ministry of Defense announced the real need for ammunition and how many 155-mm shells the Ukrainian Armed Forces fire per month [Electronic resource]. Available from : https://defence-ua.com/news/minoboroni_ozvuchilo_realnu_potrebu_u_bojepripasah_ta_skilki_155_mm_snarjadiv_zsu_vistriljujut_na_misjats-10834.html (request date: 09.03.2023).

Ukraina ye naibilsh zaminovanoiu krainoiu u sviti, [Ukraine is the most mined country in the world – Sky News.] Available from : https://www.unian.ua/war/ukrajina-ye-naybilsh-zaminovanoyu-krajinoyu-u-sviti-sky-news-12126051.html

Yasko V.A. Suchasnyi stan ta perspektyvy rozvytku zasobiv inzhenernoho ozbroiennia. [Current state and prospects of development of engineering weapons]. Collection of scientific works National Academy of the State Border Guard Service of Ukraine named after B. Khmelnytsky. Khmelnytskyi: NADBSU, 2010. № 52. 98-100.

Zhukov S. (1998). Opyt razminirovaniia mestnosty v uslovyiakh lokalnykh voennykh konfliktov, [Experience of mine clearance in local military conflicts.] *Zarubezhnoe voennoe obozrenye*. № 6, P. 14-19.

Zhukov S. (1998). Opyt razminyrovanyia mestnosti v Bosnii i Hertsehovine, [Experience of mine clearance in Bosnia and Herzegovina.] *Zarubezhnoe voennoe obozrenye*. № 8, P. 18-22.