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ANALYSIS OF THE STATE OF CREATION OF ROBOTIC COMPLEXES FOR HUMANITARIAN DEMINING

The object of research is robotic military complexes used in the system of humanitarian demining. This work aims to study the requirements for robotic military complexes (including manipulators that are sucked into them) and to develop proposals for their use in humanitarian demining. The research is based on the application of a functional approach to the construction of models for the formation of requirements for robotic military complexes (RMC), which are sucked into the system of humanitarian demining. It is established that the creation of RMC requires a significant study of the core of the most important technologies that are needed to create the entire range of promising RMC. Thus the standard sample RMC can be presented in the form of set of functionally connected elements: the basic carrier, the mobile platform, the specialized hinged/built-in equipment in the form of a set of removable modules of useful (target) purpose, means of maintenance and service used at preparation for application and technical operation robot. The composition of specialized equipment is set based on the functional purpose of the RMC. The classification of RMC is given, which provides for their division into three categories: the first generation – controlled devices, the second generation – semi-autonomous devices and the third generation – autonomous devices. The analysis of modern RMC which are developed in Ukraine and the advanced countries of the world and the analysis of structure of components of system of humanitarian demining is carried out. It is established that the organization of the humanitarian demining system with the use of RMC should include of explosive objects (EO) reconnaissance, search, marking, their identification and direct demining. Unmasking signs of EO, as well as modern methods and detectors of EO detection are considered. One of the new promising methods of mine detection is parametric. However, in real application, the most promising is the use of a combination of electromagnetic, optical and mechanical methods. The application of the proposed approaches will increase the efficiency of humanitarian demining and reduce human losses in its implementation.

Keywords: *explosive object, robotic military complexes, humanitarian demining, mobile platform.*

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1. Introduction

All military conflicts are accompanied by the widespread use of anti-personnel mines and explosives object (EO) by the warring parties. One of the problems that countries in all regions where hostilities have taken place or there are military conflicts caused by international and international liberation movements (for example: Iraq, Syria, Afghanistan, the former Yugoslavia, Ukraine, etc.), face the problems of humanitarian demining.

According to a report by the International Campaign to Ban Landmines (ICBL) for 2020, 2019 was one of the most tragic years in terms of mortality from mine explosions in the world. Afghanistan, Colombia, Iraq, Mali, Nigeria, Ukraine and Yemen had the highest deaths from mine explosions. One third (33 %) of deaths from anti-personnel mine explosions in 2019 were recorded in 55 countries that joined the Ottawa Treaty. Anti-personnel mine explosions in 2019 claimed at least 2,170 lives worldwide, another 3,357 people were injured. More than 80 % of mine deaths are civilians, 43 % of whom are children [1].

For example, during the years of the military conflict in Donbass (Ukraine), which began in 2014, it has become one of the most mine and EO-rich areas in the world.

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The United Nations (UN) estimates that 1.6 million hectares of land have been mined during the war, 700,000 of them in the territory controlled by the Ukrainian government. The area of contaminated regions containing mines and EO is almost 7,000 km^2 in the controlled area and approximately 14,000 km^2 in the occupied territories of Donetsk, Luhansk oblasts and the Autonomous Republic of Crimea. There may be about 3.3 million antipersonnel mines and EOs in these areas. Demining of these areas will take at least 25–30 years.

Humanitarian demining is a measure taken to eliminate EO hazards, including non-technical and technical surveys of EO-contaminated areas, mapping, marking, search, identification and disposal of EO, assessment of demining quality, etc.

The implementation of humanitarian demining is characterized by increasing attention to the problems of creating robotic systems and systems for military, special and dual-use (RMC). This is due to the efforts of all advanced countries to save lives, in the context of which the use of RMC can achieve positive results. In addition, this trend is explained by the rapid development of new technologies in the information sphere, i. e. «robotization» of various human activities, in particular, the military sphere, which corresponds to the content of modern concepts of post-industrial society based on Industry 4.0.

Despite the significant number of scientific papers on this topic, today there is a tendency to distinguish between these issues [2].

The above problems, according to experts, should be solved only in a set of organizational and technical measures, which within the modern process of transformation in the Armed Forces are divided into two separate components:

– use of network-centric concept of combat operations;
– development of robotic complexes and systems of military, special and dual purpose.

Work on the creation of RMC is carried out in different countries. Thus, the United States has recognized that the use of RMC – one of the most promising areas of military development. The United States can be considered a leader not only in development but also in the practical use of robots, although many efforts are now being made by China, Great Britain, Israel, Turkey and Russia [3, 4].

A number of studies are devoted to the current state and prospects of RMC development [3, 5, 6]. There are also studies of theoretical and experimental nature related to the development of manipulators for mobile robots for special purposes, adapted to work with dangerous objects RMC [7], and research on methods of mine search and EO [8, 9]. As the analysis of these studies has shown, they relate only to the development and application of the RMC for hostilities, the fight against terrorism, and the search for EO. However, insufficient attention has been paid to the issue of integrated use of RMC for humanitarian demining (search, identification, neutralization of EO).

Thus, work on the creation of robotic military complexes for humanitarian demining is an urgent task. *The object of research* is military robotic complexes used in the system of humanitarian demining. *The aim of research* is to study the requirements for military robotic systems (including manipulators that are sucked into them) and to develop proposals for their use in humanitarian demining.

2. Methods of research

The research was performed according to the method presented in [10, 11].

According to the international standard ISO 8373:2012 «Robots and robotic devices. Terms and definitions», a robotic system (robot system) is a complex consisting of one or more robots, their working bodies and any mechanisms, equipment, devices or sensors that ensure the robot's functional purpose (task).

The leading countries of the world are actively involved in the creation of military robotic complexes, based on their scientific, technical and industrial accumulations [3, 12]. The creation of the RMC requires a significant study of the core of the most important technologies that are needed to create the entire range of promising RMC. In this case, a typical sample RMC can be represented as a set of functionally related elements.

In particular [5, 6]:

1. Base media – this can be a mobile platform, chassis or housing of any configuration, designed for use in different environments.

2. Specialized attachment (built-in) equipment in the form of a set of removable modules of payload (target).

3. Means of provision and maintenance used in preparation for use and technical operation of the robot.

The composition of specialized equipment is set based on the functional purpose of RMC and may include [5]:

– means of intelligence;
– weapons;
– navigation devices;
– special technological equipment;
– means of telecommunications;
– specialized computers and controllers with software and algorithmic software;
– means of electronic warfare (EW);
– protective equipment.

In addition, RMC need provision and maintenance, i. e. the complex additionally includes [5]:

– point of management, control and information processing;
– means of delivery, transportation and launch;
– equipment, refueling and charging;
– means of training specialists;
– a set of guiding documents;
– a set of spare accessories.

This idea of a typical RMC allows to identify technologies for the development of these elements. Critical robotics technologies can be decomposed into:

– basic, i. e. developed directly for robotic systems;
– auxiliary – developed for a wide range of weapons models and prospects for use during the creation of the RMC [5].

The main technologies include the following technologies [3]:

– systems of perception and processing of sensory information, situation assessment and behavior planning;
– automatic guidance and control;
– remote and autonomous traffic control;
– automatic recognition of images (goals), analysis of situations and dynamic scenes;
– artificial intelligence and training;
– human-machine interface;
– intelligent group control systems.

Auxiliary technologies include [5]:

– automated control;
– creation and operation of new promising structures;
– energy;

– creation and application of new materials and substances;
– geoinformation and accurate global positioning;
– creation of perspective systems of sensors and their elements;
– creation of optical and optoelectronic means.

Possession of such technologies is the key to success in ensuring the necessary degree of autonomy and intelligence of unmanned aerial vehicles (UAVs), ground-based RMC and autonomous naval aircraft.

Using the visual classification proposed by the staff of Oxford University, it is possible to systematize robotic systems by four generations [10]:

1. «Lizard level» – corresponds to the performance of processors of universal robots of the first generation, which is from 3000 to 1 million commands per second (MIPS). The main purpose of such robots is to receive and perform only one task, which is programmed in advance.

2. «Mouse level» – the second generation of work that can implement adaptive behavior, i. e. learning in the process of performing tasks.

3. «Monkey level» – third-generation robots, which are based on processors from 10 million MIPS. The peculiarity of such robots is that to get the task and training only need a demonstration or explanation.

4. «Human level» – the fourth generation of robots, which should be able to think and make independent decisions.

The classification of RMC according to the degree of their dependence on the operator is as follows:

1. 1st generation robots are devices with software and remote control that can only function in an organized environment.

2. Works of the 2nd generation – adaptive, having synthetic «senses» and able to function in previously unknown conditions, and to adapt to changing situations.

3. The works of the 3rd generation are intelligent, have a control system with elements of artificial intelligence (created so far only in the form of laboratory models).

Another classification of RMC provides for their division into three categories [3]:

1. «Human-in-the-loop» – this category includes unmanned vehicles capable of self-detection of targets and their selection, but the decision to destroy them is made only by the human operator.

2. «Man-on-the-loop» – this category includes systems that can independently identify and select targets, as well as make decisions to destroy them, but the human operator, acting as an observer, in may intervene at any time and correct or block this decision.

3. «Human-out-of-the-loop» – this category includes works capable of identifying, selecting and destroying targets independently without human intervention.

Today, the most common RMC first generation (controlled devices) and rapidly improving systems of the second generation (semi-autonomous devices). To move to the use of third-generation RMC (autonomous devices), experts are developing a system of self-learning with artificial intelligence, which will combine the capabilities of the most advanced technologies in navigation, visual object recognition, artificial intelligence, weapons, independent power supplies, camouflage and more.

The US military has used the smallest reconnaissance robot Recon Scout in Afghanistan. It weighs 1.3 kg and is 200 mm long, equipped with conventional and infrared cameras. This robot can be blamed for obstacles [3].

The most popular American military robot (released more than 3 thousand units) is a remote-controlled machine (RCM) «TALON», developed by Foster-Miller [13, 14]. U.S. researchers estimate that the robot neutralized 50,000 explosive devices. «TALON» is able to operate in any weather and insufficient lighting, to overcome blockages and wire barriers, to move in areas with difficult terrain, to operate underwater at depth.

The robot can act as a chassis to accommodate various specialized equipment, thanks to which it can perform various tasks on the battlefield and in the rear. The standard robot «TALON» is a modular system that includes a removable arm manipulator with a double hinge, 1.6 m long.

The robot is controlled by duplex radio or fiber-optic line. The remote control of the «TALON» machine is controlled by the operator from the remote control of a fiber-optic cable (but at a distance of up to 300 m) or by radio (up to 800 m), and when using a directional antenna the range increases to 1200 m. «TALON» in the normal mode is 8.5 hours. Combat weight «TALON» 52–71 kg (depending on configuration). «TALON» speeds range from a maximum of 8.3 km/h to creeping with the ability to run continuously for more than four hours. On-board equipment consists of day and infrared cameras, GPS-navigator, sensors, which are used to detect explosives and toxic substances, as well as assessment of radiation, chemical and biological conditions.

An important element of the design is that «TALON» can carry on board weapons (machine gun M240 caliber 7.62 mm, sniper rifle M82A1, four-barrel 66 mm missile system M202, 40-mm grenade launchers, multi-barrel Metal Storm).

The control panel is a diplomat, which also houses the power supply. Thanks to the seven cameras located on board, the screen of the control unit continuously displays information for accurate positioning of the car. The chassis robot can carry a load of more than 90 kg to provide maximum flexibility in any situation.

In addition to these robotic systems, the most common are the following RMC [4]:

1. Tracked robotic mini-machine FirstLook 110 made in the USA (weight – 2.2 kg; dimensions – 250×230×100 mm; equipped with 4 backlit video cameras).

2. Military reconnaissance robot Spybot made in Switzerland. The SpyRobot robot is available in two versions – with a 4×4 and 6×6 chassis (weight – 5 kg, reconnaissance equipment includes thermal and optical sensors, as well as a radar station with a synthesized aperture). As a result of the modernization of the SpyRobot machine, a remote-controlled platform (RCP) Dragon Runner [15] was created for reconnaissance within the effective range of small arms (weight – 9 kg, dimensions – 230×200×75 mm, equipped with IR sensors and a video camera).

3. Multifunctional robot platform Warrior 710 [16] made in the USA. Its main tasks are demining, road clearing, firefighting, reconnaissance, remote surveillance, emergency response, cargo handling and welding, and the evacuation of wounded soldiers from enemy fire.

4. Track robot PackBot-510 made in the USA is designed to neutralize explosive munitions. PackBot can work with the full range of EO and solve the problems of disposal of conventional ammunition. Its lightweight and reliable OmniReach manipulator system can be deployed up to two meters in any direction to safely penetrate hard-to-reach

places where improvised explosive devices, ammunition, mines and other explosive devices are located.

RMC is also developed in Ukraine [7, 17]. The main developers of military robotic systems in Ukraine include:

1. Lviv private company «Roboneers» (Global Dynamics) is developing a robotic, remotely controlled platform with a hybrid drive in two main versions – Hound and Ironclad.

2. Kyiv private joint-stock company «Kuznya on Rybalsky» has developed a robotic complex «Piranha» on a caterpillar platform.

3. Zaporizhzhia company «Infocom Ltd» has developed a robotic structure «Laska 2.0», designed for patrolling, reconnaissance, demining, delivery of ammunition and evacuation of the wounded. In addition, the company has developed an automatic robotic turret «Guard», the main purpose of which is to protect the protected perimeter (state border, important facilities, military units, etc.) from unauthorized access.

4. Lviv Polytechnic National University has created mobile robotic platforms MRP-05 «Borsuk» caterpillar platform with electromechanical drive and MRP-07 «Kubyk» on a wheeled platform (6×4). These platforms are designed for inspections, environmental monitoring or to perform special tasks.

5. National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute» is the developer of a multifunctional off-road robot for emergencies.

6. Kyiv private company Robotics Design Bureau has developed and tested a robotic observation and fire complex «Hunter», which is based on a remotely controlled platform. All of the above robot developments are at different stages of the product life cycle: design, manufacture or testing.

3. Research results and discussion

Studies have shown that the system of humanitarian demining should contain the following subsystems [4]:

– non-technical and technical inspection of the territories polluted by EO;
– search, identification and disposal of EO;
– mapping and marking of the territories polluted by EO;
– assessment of demining quality, etc.

Components of humanitarian demining systems with the use of robotic systems are shown in Fig. 1, include:

– technical means;
– technologies of humanitarian demining;
– decision-making systems;
– reconnaissance systems (aerial reconnaissance data, survey data and foreign intelligence);
– search systems, locations (topographic reference) of areas contaminated by EO;
– marking and mapping of areas contaminated with EO;
– identification of EO;
– development of a decision-making strategy, which includes assessment of the level of threat and decision-making on the destruction, disposal or disposal of EO;
– quality control of humanitarian demining of areas contaminated with EO.

Searching for and identifying EOs for humanitarian demining is a complex task. RMC for humanitarian demining must be equipped with appropriate manipulators and detectors (sensors, sensors), decision-making tools and used at the stages of reconnaissance, search, location, marking, identification, disposal and destruction of EO.

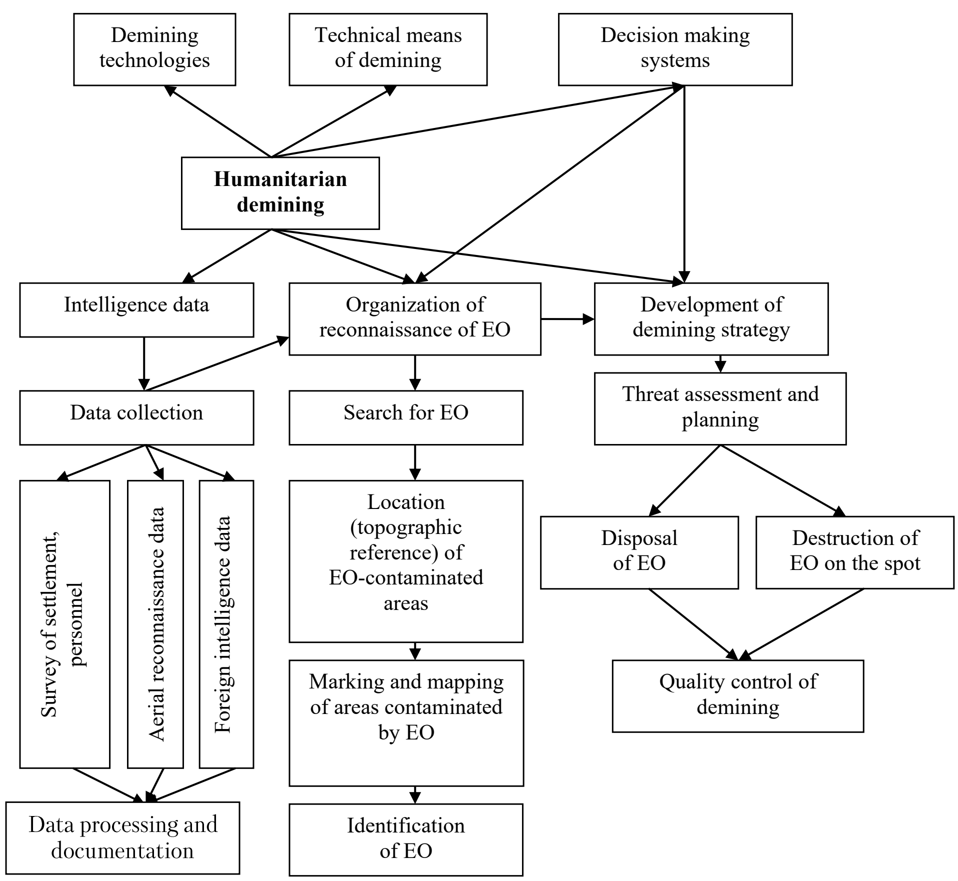

Fig. 1. Components of humanitarian demining systems [11]

Detection of EO means their search, due to factors that include [8]:

– presence of explosives and locally located mass of metal;
– specific form of mines, landmines and EO;
– heterogeneity of the environment where the EO is located (violation of the soil surface, road surface, violation of the color of vegetation or snow cover, etc.).

Additional unmasking factors:

– availability of control lines and antennas for EO radio receiving devices;
– presence of a clockwork or electronic timer placed on the EO;
– presence of a seismic, magnetic or optical sensor.

Thus, a mine or EO can be detected by the following factors:

– presence of a concentrated mass of explosives;
– construction of a mine or EO (specific shape, material from which the case is made);
– heterogeneity of the environment (color of vegetation, soil density, etc.).

Search for mines and EO should be carried out in two directions:

– search for individual mines and EO (search distances range from a few centimeters to several meters);
– reconnaissance of areas contaminated with EO and minefields (search distances range from tens of meters to several kilometers).

Currently, the most widely used methods of mine search and EO: electromagnetic (induction, radio, magnetometric, nonlinear), nuclear-physical, thermophysical and mechanical (mechanical sounding). They allow to create technical means of search of EO which can be suitable for humanitarian demining. Modern methods and detectors for the EO detection are given in Table 1 [6, 9].

Table 1

Modern methods and detectors of EO detection

Method	EO detectors and equipment
Electromagnetic	Metal detector (MD)
	Radar (GPR)
	Electric Impedance Tomograph (EIT)
	Millimeter wave radiometer (MMWR)
	Microwave radiometer (MWR)
	Infrared spectroscope (IR)
Optical method	Lidar – a detector for receiving and processing information about remote objects using active optical systems (LIDAR)
Nuclear physical	Neutron radiation detectors (NRD)
	Detectors based on the nuclear quadrupole resonance effect (NQR)
Acoustic	Acoustic and seismic wave detectors (AD), (SD)
	Sound and ultrasonic wave detectors (SWD), (UWD)
Mechanical	Engineering machines for detecting and detonating mines and explosive devices
	Probes
Gas analytical	Gas analyzers and detectors of explosive vapors
Thermophysical	Thermal imagers
Biological	Sensory system of animals (dogs, rats, etc.)

The problems that arise when using these methods are safety issues and reduction of time and material costs for demining. Other requirements: climatic, efficiency in the dark, resistance to mechanical influences, electromagnetic compatibility, etc.

Table 2 characterizes the depths of EO placement in the soil and non-contact EO search and identification methods that can be applied.

Table 2

Depths of EO placement in the soil and EO search methods that can be applied

Search depth	EO search methods	Types of EO
Soil surface	Electromagnetic, optical, gas analytical, mechanical, thermophysical, biological	All types of EO
Up to 0.1 m	Radio wave	All types of EO
	Induction	Metal EO
Up to 1 m	Short-pulse radar	All types of EO
	Magnetometric	Ferromagnetic EO

To increase the efficiency of mine and EO detection, it is advisable to combine different search methods in one RMC. One of the new promising methods of mine detection is parametric. It is based on the registration of the interaction of excitable (force) and probing (information) physical fields, on objects of search of artificial origin (mines). The combination of these fields can be different.

However, in real application, the most promising is the use of a combination of electromagnetic, optical and mechanical methods. A limitation of the research is that modern methods and detectors of EO detection have not passed the experimental test fully enough in the conditions of real circumstances that may be in the territories contaminated by EO.

A possible development of this study may be the development of RMC, which can search (not only on the soil surface, but also at a certain depth), identify and decide on the disposal of mines and EO.

4. Conclusions

In the course of work it is shown that the system of humanitarian demining should perform the following tasks:

– survey of areas contaminated with EO;
– search, identification and disposal of EO;
– mapping and marking of the territories polluted by EO;
– assessment of the quality of humanitarian demining.

Searching for and identifying EOs for humanitarian demining is a complex task.

In this regard, for humanitarian demining RMC must be equipped with appropriate manipulators and detectors (sensors), decision-making tools and used at the stages of reconnaissance, search, location, marking, identification, disposal and destruction of EO, and meet the established requirements. The research results can be used in the creation of robotic systems and systems for military, special and dual-use, which are used in the field of humanitarian demining.

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