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RESEARCH ON THE FUTURE OF COMBAT ROBOTICS ON THE EXAMPLE OF UKRAINE

The object of research is the architecture of any combat ground robot in the context of its individual systems and subsystems. The conducted research forms a transparent and clear understanding of the main logical links of a combat robot, individual technologies, and components used in the development and serial production. The paper summarizes the global experience and achievements of combat robotics and provides examples of the example of the development of teams from Ukraine. The mentioned are the main system players in this sector of defense technologies, long-term and productive activity of which resulted in the appearance of the first combat robot units in the armies of the leading countries of the world.

The author studied and presented the structural structure of any ground combat robot by the method of deduction and reproduction of functional capabilities. In the context of separate systems or subsystems of a ground combat robot recommendations on the equipment of those or other components, sensors, technologies, or their analogs and other equipment are given.

The work summarizes the experience of the head of Robotics Design Bureau LLC (Kyiv, Ukraine), associated with the attention of representatives of foreign companies and government agencies to the Ukrainian developments in this area. The leading idea of the research is the priority development of functions and algorithms of combat robots, associated with the development of vision and autonomous movement systems. Realization of these functions sharply increases the advantages of own combat robots, increases their survivability and combat efficiency, reduces dangers for operators of the equipment. Factors related to the package of impact module subsystems directly affecting the combat effectiveness of a ground robot are presented.

Compared to similar known studies on this topic, the research conducted immediately immerses the reader into the practical plane of developing a ground combat robot from the perspective of the engineer-creator, which provides quick basic knowledge and insights and inspires further exploration in this direction.

Keywords: *ground combat robot, robotics, vision system, autonomous movement, neural network.*

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1. Introduction

The topic of war and peace, especially as the world's population grows, is always relevant. And it is difficult for the untrained person to even imagine how difficult the ordeal of soldiers during combat operations is. For soldiers, war is a job they must do faithfully. During marching missions and other missions, soldiers have to go under the balls and carry heavy loads of up to 50 kilograms, ammunition, military equipment, and risk their lives.

Issues of soldier protection, better, faster, and more efficient execution of combat tasks have always been of interest to mankind.

The most famous inventors who devoted part of themselves to the subject of robotization of combat were:

– Leonardo da Vinci, who in the late fifteenth century created a prototype of a mechanical knight capable of moving his limbs and raising his visor;
– Nikola Tesla, who, at the end of the nineteenth century, created a miniature radio-controlled vessel;
– Vladimir Bekauri, who created the world's first teleoperated battle tank, used in World War II.

We can see that progress on this issue is evident and the development of technology is having a significant impact on the armed forces.

At the present stage, thanks to economic and technological progress, there are the latest electronic systems, robotic cargo platforms, exoskeletons, microscopic spies, unmanned military vehicles [1]. All these robotic devices have already begun to replace humans in complex combat situations, especially in conditions incompatible with human capabilities for reconnaissance, demining and combat operations.

Therefore, it is relevant to consider and analyze the current level of development of ground robotics to further form conclusions designed to further accelerate the development of this sector of defense technology. Thus, *the* *object of research* is the architecture of any ground combat robot in terms of its systems and subsystems. *The work aims* to find promising directions for the further development of ground robotics.

2. Research methodology

Spring 2015, cool and clear evening, a suburb of Horlivka, broken dirt road, a separate group of 10 fighters of a volunteer battalion of a special purpose of the Ministry of Internal Affairs (MIA) of Ukraine arrived at the control and observation point (COP) of the company of brigade of the Armed Forces of Ukraine (AFU) strengthening.

The combat order is clear and concise, but among the tasks at the time was to enter the «gray» zone, closing the gap between the remote positions of the brigade, reconnaissance, probable correction of fire of their artillery, counter-sniper combat.

The enemy is constantly disturbed by its sabotage and reconnaissance groups and artillery fire.

The next morning the group returns to the COP, the tasks are completed, everyone is alive, despite the frantic fire of 120-mm mortars and 152-mm artillery. Only the battalion's minibus became like a sieve.

Who are these intrepid warriors, why are they there?

In 2014–2015, the level of patriotic outburst as a response to Russian Federation (RF) aggression in Ukrainian society was simply frantic. The volunteer battalion included designers, journalists, teachers, lawyers, programmers, engineers, mathematicians, and others from various professions.

It was in this environment of people that a certain group was born, which, thanks to its sentiments, professional skills, and experience, decided to create something fundamentally different and more progressive than the outdated Soviet-era equipment that was in service with the Ukrainian Armed Forces.

Thus, the first high-precision, remotely operated stationary combat module for the NSVT 12.7 mm «Utyos» large-caliber machine gun, shown in Fig. 1, was born. In March 2016, a group of like-minded people is already conducting its first successful test immediately in combat conditions in Zaitsevo near Horlivka.

Fig. 1. Stationary combat module «Myslivets», March 2016, Zaitsevo village, Donetsk region (Ukraine)

Appropriate technical conclusions and proposals were made to modernize the stationary shooting module, integrating it with the mobile platform. Two significant issues influenced this decision. These are the need for safe replacement of the spent ammunition belt/maintenance of the module and the need to facilitate the delivery of the combat module itself to the firing position. It should be noted that in conditions of constantly bad weather, lack of roads, and enemy fire, it is already quite a non-trivial task to deliver a small combat module weighing 120 kg to a firing position.

Already in September 2016 a combat module on a mobile platform undergoes a baptism of fire near Mariupol, in the vicinity of Vodiane village, Fig. 2.

Fig. 2. First combat appearance of the combat robot, September 2016, Vodiane village, Donetsk region (Ukraine)

With the light hand of scientists of the Central Research Institute of Armaments (Kyiv, Ukraine) and military equipment, this volunteer product was strictly named the first Ukrainian combat robot.

In 2021 small-scale production samples of ground robotic complexes BRP (multi-purpose robotic platform) and RSVK-M (robotic observation and fire complex) of the fourth modification went. Continuous R&D processes, tests in real combat conditions, prototype production have led the Robotics Design Bureau LLC (Kyiv, Ukraine) to the position of a leader in the sector of Ukrainian ground robotics. An example of the evacuation of a simulated casualty using a state-of-the-art RSVK-M3 combat vehicle from the Robotics Design Bureau (DB Robotics) is shown in Fig. 3.

Fig. 3. Example of the evacuation of a simulated wounded person with the RSVK-M3 combat vehicle

Quite powerful teams of colleagues from Lviv (Global Dynamics) and Zaporizhzhia (Temerland), despite the advantage in size and budgets, are forced in the wake of DB Robotics. And if you consider the same fact that no team in Ukraine, except DB Robotics, has ever tested its developments in real combat conditions, does not have

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that invaluable experience and package of modernization solutions – the advantage becomes even more impressive.

3. Research results and discussion

This paper reviews the architecture of a ground-based robotic system, its components, approaches, and algorithms to solve certain problems.

A ground combat robot, like any machine, consists of several systems and subsystems. Guided by the deductive method, as well as the method of predicting functional saturation, let's form Table 1.

Table 1

Systems and subsystems of a ground combat robot

The main systems of a ground combat robot	
Body	Telecommunications system
Transmission	Control System
Power unit	Navigation system
Power supply system	Autonomous driving system
Computer vision system	Diagnostic system
Ventilation system	Combat module subsystems package

Of course, a full introduction to all systems would require a full academic year, but let's briefly touch on the main points.

The power unit of the products from DB Robotics has always been exclusively electrical. Thus, mobile platforms are invisible acoustically and in the infrared spectrum. They have no inflammatory fluids inside, do not require constant inspection and repair. Any solutions with an internal combustion engine (ICE) inside have no advantages, but many significant disadvantages. All samples of mobile platforms from DB Robotics have differential directional control [2, 3].

The power supply system of the mobile platform (MP), combat module (CM), and automated system operator workstation (ASOW) on the one hand is maximally simplified, but in practice, during the assembly of new samples, certain problems with electromagnetic compatibility are constantly registered. In the Methods of State tests or defining departmental tests, there is a separate section related to electromagnetic compatibility. During tests, the complex is constantly monitored by the appropriate experts. Any weapons are recorded and make it impossible to conduct the tests successfully.

During R&D processes, when all transducers, sensors, controllers, cameras, routers, transceivers are tested, everything is first tested separately, and usually, everything is functioning properly. When all the devices are put together in a real product, there are complications related to electromagnetic interference.

Given that the most powerful sources of such electromagnetic interference are usually stepper motor controllers or controllers of BLDC motors (brushless DC motors), then the solution to this issue is to separate the power harness from the signal, installing, if necessary, appropriate interference filters.

The computer vision system (CVS) can usually consist of day, night, and thermal cameras, ultrasonic and infrared sensors [4], a video stream processing server, and sensor inputs. CVS, as a rule, should export the incoming stream processing data to the operator or an autonomous motion system. Sufficiently convenient and effective solutions for processing CVS input streams using CNN (convolutional neural network or convolutional neural network) [5, 6] are NVIDIA products, starting from Jetson Nano, Jetson Xavier NX (Fig. 4, Table 2) and further in terms of performance growth.

Fig. 4. NVIDIA Xavier NX

Table 2

Nvidia Xavier NX features

Parameter	Parameter value
Size	103×90.5×34 mm
Power Consumption	Up to 10 W
Graphics Processor	NVIDIA Volta™ architecture with 384 NVIDIA® CUDA® and 48 tensor cores
Processor	NVIDIA Carmel 64-bit six-core ARM®v8.2 processor; 6 MB L2 and 4 MB L3
Memory	8 GB LPDDR4x128-bit, 59.7 Gb/s

Jetson Xavier NX is capable of solving Image Classification and/or Semantic Segmentation tasks [7, 8] in parallel mode using multiple neural networks at a frame rate of about 30 fps.

The telecommunication system usually consists of transceivers and their antennas, Ethernet routers and network modules, appropriate cables, and connectors [9]. Special mention should be made of the use of military equipment. By order of the Commander-in-Chief of the AFU, the priority is given to the American L3Harris equipment. The equipment is of high quality, has a wide range, and has appropriate performance according to MIL-STD-810G. However, among the disadvantages, it is important to cite the following: difficult organizational work to obtain permission for this equipment, delivery time of 5–6 months after registration and payment, the high price of equipment (50–60 thousand dollars) USD for the set of 2 receiving-transmitting devices and antennas). At the entry level it is possible to use appropriate devices of commercial purpose with subsequent preparation to meet the requirements of MIL-STD-810G. An important method of reducing susceptibility to adversary radio-electronic interference is to reserve the radio channel so that simultaneous communication between the operator and the combat robot is maintained using 2–3 channels of radio communication with programmatic frequency hopping (PFR) [10].

The control system of the mobile platform (MP) and/or combat module (CM) from the side of the automated system operator workstation, a small radio remote control (SRC) consists of several components:

- controls (buttons, joysticks, touchpads, keyboard);
- controllers;
- corresponding computers on the operator's side in the ARM OS, as well as on the side of the MP;
- special software.

The general software can be built on both Linux and Windows operating systems. As for microcontrollers, both AVR and ARM variants are acceptable [11]. Special software «Robotcontrol» from «DB Robotics» has many functions and features. Among the main ones, it is necessary to distinguish the work with electronic maps of different providers (Google, Microsoft, etc.), the construction and processing of autonomous routes (Fig. 5). An important function is the broadcast of the operator's video stream from the daytime and thermal imaging cameras, video stream processing, including the recognition of images of interference and targets. Displaying data from current, voltage, temperature, humidity, pressure sensors, gyroscopes, accelerometers, magnetometers, and satellite receivers helps the operator analyze system status and suitability for the following operations. Combat module (CM) control functions, including diverse and scalable reticle, rangefinder, ballistic calculator, gyrostabilization are essential for accurate and efficient fire support missions.

Fig. 5. RSVK-M ground robot in testing

The navigation system of mobile platforms from Robotics Design Bureau LLC consists of satellite SNR (satellite navigation receiver) and 9-weight microelectromechanical (MEMS) sensor (accelerometer, gyroscope, magnetometer), corresponding controller and part of the software, responsible for data reception, processing, and export, of course, using MEMS sensors is not always acceptable, but there are enough quality and stable samples, allowing to solve the necessary tasks.

When choosing an IMU (Inertial Measurement Unit) one should pay attention to the following companies: Analog Devices, Bosch Sensortech, SBG Systems, InertialLabs (Fig. 6).

The architecture algorithm of *the autonomous movement system* relies on incoming IMU and SNS (satellite navigation system) data or solely SNS as a passive sensor system. Since this is a military application, we should bear in mind the possible use of GPS Spoofing (substitution of signals from real satellites) technologies, which makes the task of autonomous movement much more difficult. In this case, using only IMU and SNS will lead to significant errors and possible losses. Solving this issue and building a full-fledged autonomous movement system is based on extensive use of Artificial Intelligence (AI) system elements with the solution of tasks of combat robot awareness in the environment.

a *b* *c*

Fig. 6. Examples of IMUs from the world's leading developers: *a*, *b* – IMU from SBG Systems; *c* – IMU from Analog Devices

Thus, a combat robot must recognize elements of the local landscape and build a traversed corridor map, distinguish targets and the maximum number of *ML (Machine learning)* interference classes, determine the sides of the world as an experienced pathfinder, analyze all incoming data and make acceptable decisions during autonomous movement [12].

The diagnostic system consists of a module for continuous checking the integrity and quality of connections of devices in the TCP/IP network (transmission control protocol/internet protocol), sensors of current and battery voltage (battery) of the MP, and ASOW, sensors of pressure, humidity, and temperature. Thus, the minimum necessary information on the operability of all functional blocks, permissible levels of the battery charge, climatic conditions inside and outside of the MP is collected.

When deciding on a combat exit, the operator must check the operability of all systems and decide the sufficient operability of the vehicle.

Subsystems of the CM. In addition to the systems listed above, the following subsystems should be separated in the CM section:

- machine gun fire control;
- alignment of the machine gun barrel axis and optical instruments;
- ballistic calculator;
- gyroscopic stabilization of the machine gun barrel;
- target recognition, target tracking rapture.

During a combat outing, the strike robot must remain stealthy, operate for long periods, and operate as accurately as possible. The mode of firing single shots is the main one, and the modes of firing in twos or threes are secondary. Generally speaking, firing in bursts has the following disadvantages:

- it is less accurate than firing single shots;
- rapid depletion of the ammunition;
- demeaning the location of the combat robot.

Specialists of the Robotics Design Bureau LLC, back in 2018, developed an electronic system that allows firing single shots while using a standard machine gun. It should be noted that no one in Ukraine or the Russian Federation has even come close to solving this issue. Similar work is continuing in the leading countries of the world, but there are no confirmed positive results of creating such systems without interfering with the mechanisms of standard machine guns. Firing exclusively in bursts, which is what any standard machine gun is designed for, is always inaccurate, leads to disguise, rapid depletion of ammunition, and reduction of overall effectiveness.

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An interesting task is the alignment of the machine gun barrel with the video-optical axis of the aiming device (AD). First, the video-optical axes of the AD chambers themselves must be set parallel in 2 axes. Secondly, the Robotics Design Bureau LLC has developed a system that, using a laser module, allows for «cold firing» quickly and qualitatively. Such a system allows performing alignment within 2–3 minutes. That is why it is possible to repeat this operation before each combat output.

According to the results of the study, the ground combat robot, its architecture, and components, in general, can be considered and structured by the systems of a modern serial electric vehicle. The latest achievements of Ukrainian combat robotics allow to assert the full-fledged formation of a new kind of troops and defense sector [13].

The conducted study rather briefly reviews the architecture of a ground combat robot and can be used to form a plan and algorithm for a further thorough study of each system or subsystem. From a practical point of view, developers need to take into account the already achieved level of technology development suitable for use in the combat robotics sector and form their vision of the most promising directions in mechanics, electronic components, sensors, and software. The issue of increasing the level of autonomy, functions of artificial intelligence of combat systems will be leading constantly as long as mankind exists.

The conducted research is intended for specialists and scientists in the field of robotics, navigation devices, software development, machine learning, and autonomous movement.

4. Conclusions

The study discovered the typical architecture of a ground combat robot, investigated its structure in terms of its main 12 separate systems and subsystems. The appropriateness of components, sensors, and technologies has been pointed out. Special attention should be paid by researchers and developers of ground robotic complexes to the development of elements of the artificial intelligence system. Associated with the development of this direction is the system of autonomous movement over rough terrain using inertial and non-inertial sensors, radars, scanners, and video analytics. Modern autonomous driving systems for road transport can only work effectively in a highly organized environment with road markings, signs, satellite navigation, and electronic road maps. In this sense, a significant challenge is to develop a full-fledged system of autonomous cross-country driving without the use of satellite navigation and other standard attributes of a highly organized environment, mentioned above. Specialized, ultra-compact computers such as the Jetson Xavier NX and more powerful solutions from NVIDIA allow multiple neural network models to operate in parallel mode with frame rates of at least 30 fps. All of this provides fast recognition of different classes of obstacles such as cars, people, trees, poles, ditches, water obstacles, and the process of making quick decisions, for example, on how to avoid obstacles. All this, of course, applies to target recognition of all known classes of military equipment and manpower, target delight, escort, and ballistic correction. The products of those science and technology centers and innovative companies that offer such complete solutions will have the advantage of rapid development and control of this sector of technology.

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