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Medical Aspects of Innovative Robotic Technologies for Evacuation of Victims from the Emergency Zone

Pivovarov Maxim A.[1] [1], Bodin Oleg N.[1] [2], Bezbolrodova Oksana E.[2] [3], Ignashkin Dmitry S.[1] [4]
[1]*Penza State Technological University, 1a/11 Baidukova passage/Gagarina street, Penza, Russia*
[2]*Penza State University, 40 Krasnay street, Penza, Russia*
makcimpivovarov24@gmail.com, bodin_o@inbox.ru, oxana243@yandex.ru, IgnashkinHomework@yandex.ru

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Abstract: One of the most important scientific and practical directions oriented to minimise human losses in emergency situations is disaster medicine. Its main task is to promptly provide victims with medical care and their evacuation from the emergency zone. The aim of the article is to develop an algorithm for medical triage of victims in the emergency zone with the possibility of first aid using robotic devices. The article analyses the existing robotic technologies for evacuation of victims from the emergency zone, considers the main characteristics of robotic devices for evacuation of victims from the emergency zone, develops algorithms for triage of victims and determination of traumatic shock in the victim. The distinctive feature of the algorithms is that based on the data of medical triage and labelling for each group of injured persons, they perform the necessary set of actions aimed at ensuring and maintaining their vital activity until their delivery to the hospital. It is shown that the use of medical triage of the injured increases the efficiency of medical aid provision.

1 INTRODUCTION

Analysis of the dynamics of emergencies (ES) shows the increasing dependence of the economies of all countries on the consequences of man-made disasters, natural hazards and military conflicts. Ensuring rapid and effective response to emergencies is an integral part of the overall system of protection of the population and territories of any country. Improvement of work in the field of technosphere safety, as well as protection of human health from the action of striking factors of emergencies should be considered from the point of view of improving the effectiveness of emergency rescue teams in search and rescue operations in emergencies.

At the present stage of development of science and technology, life without hazards is impossible. They can appear at any moment of time and in any point of the planet, endangering not only individuals, but also the entire civilisation. Consequently, preventing the realisation of hazards is an important task that must be addressed both on the scale of individual states and on a global scale.

Hazards arise in the system "man - environment" and their sources are diverse. Today the list of striking factors realised in relation to a person in any sphere of his activity is huge and constantly increasing. Realisation of striking factors leads to accidents, catastrophes, military conflicts.

The concept of "extraordinary" is understood by modern man as special, enormous, surpassing everything that has existed before in importance or magnitude. The term "emergency situation" refers to a set of dangerous events or processes leading to complication or exclusion of normal situation in the life of people and functioning of objects of the technosphere.

On this basis, the main damage from an emergency is loss of life and loss of inventory. Statistics shows that on average per year in the

[1] https://orcid.org/0009-0005-3314-8970
[2] https://orcid.org/0000-0001-9299-1005
[3] https://orcid.org/0000-0002-3728-7919
[4] https://orcid.org/0009-0001-7550-7127

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Russian Federation more than 30 thousand people die in road accidents; 13-18 thousand people die in fires; more than 70 thousand people die as a result of injuries and traumas at work.

Economic consequences of emergencies are expressed in the reduction of capacities of technogenic objects due to their failure or destruction, losses of social and cultural objects, disturbance or destruction of agricultural, forest and water objects, loss of life.

One of the most important scientific and practical directions, focused on minimizing human losses in emergencies, is disaster medicine. Its main task is to provide prompt medical assistance to victims and their evacuation from the emergency zone.

The world practice of liquidation of the consequences of emergencies shows shortcomings in the organisation of medical care: unpreparedness of medical institutions for mass flows of victims, slow evacuation of victims, difficulties with the organisation of registration of victims and disorderly provision of medical care.

The probability of saving the life of a person in a state of clinical death for up to three minutes is about 75%; when this time interval is increased to five minutes, the probability of saving the life is reduced threefold (Muravyev, 2007).

The most effective mechanism for overcoming the time and organisational barriers of the 'golden hour' of care is medical triage, developed and applied as far back as the 19th century. Its essence consists in prioritising the order of care for the injured based on the assessment of the severity of the condition (Kaznacheev, 2016) and during evacuation (in compliance with the principles of routing) (Baranova, 2022).

There are currently a large number of medical triage algorithms that use different sets of criteria and classify casualties into different categories. The most commonly used are *SALT*, *SAVE*, *START*, *Triage Sieve*. These algorithms are simple and allow to quickly organize evacuation of victims from the emergency zone, dividing them into several streams.

The development of information and communication technologies allows applying the tools of artificial intelligence (neural networks, agent-based approach, robotic devices) in various spheres of activity, including disaster medicine.

The aim of the article is to develop an algorithm for medical triage of victims in the emergency zone with the possibility of first aid using robotic devices.

For this purpose, it is necessary to solve the following tasks:

- to analyze the existing algorithms of medical triage;
- to select a medical triage algorithm suitable for use by robotic devices;
- adapt the algorithm for use on an unmanned device.

2 2 MATERIALS AND METHODS

The results of the analysis of peacetime and wartime emergencies are given in Table 1.

The analysis showed that, despite the different types and sources of emergencies, the mechanism of action, impact factors and objects of impact in peacetime and wartime emergencies are the same and, therefore, measures to prevent the consequences can be developed similar, taking into account, first of all, the intensity of the level of impact factors and the number of victims.

Table 1: Classification of peacetime and wartime emergencies.

Type of emergency	Source of emergency	Mechanism of action	The impact factor of an emergency	Object of influence
peacetime				
natural	geological	seismic	seismic shock, rock deformation, blast wave, volcanic eruption, wave surge (tsunami), gravitational displacement of rocks, snow masses, glaciers, surface water inundation.	biological objects, anthropogenic objects, ecosystems
		dynamic	shaking of the earth's surface, deformation of the earth's surface, ejection, eruption products, movement of lava, mud, stone flows, gravitational displacement	

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Type of emergency	Source of emergency	Mechanism of action	The impact factor of an emergency	Object of influence
			of rocks	
		thermal	scorching cloud, lava, tephra, vapour, gases	
		chemical	pollution of the atmosphere, soil, ground, hydrosphere	
		gravity	shaking of the earth's surface, dynamic, mechanical pressure of displaced masses, impact	
		dynamic	rock displacement	
		gravity	удар, механическое давление селевой массы	
	natural fires	thermal	flames, heat flux heating, heat stroke, air turbidity	
		chemical	hazardous fumes, pollution of the atmosphere, soil, ground, hydrosphere	
biological and social	epidemics	biological	microorganisms, viruses, products of their vital activity	
man-made	industrial accidents and disasters	physical	air shock wave, compression wave in the ground	biological objects, anthropogenic objects, ecosystems
			a wave of hydraulic fractures	
			debris	
			ionising radiation	
		chemical	toxic effect химических веществ	
	fires and explosions	physical	air shock wave, compression wave in the ground	
			seismic blast wave	
			debris	
		thermal	extreme heating of the medium	
			thermal radiation	
	опасные происшествия на транспорте	physical	debris	
		thermal	extreme heating of the medium	
		chemical	chemical toxicity	
wartime				
warfare	conventional weapons	thermal	thermal effect	biological objects, man-made objects, ecosystems
		dynamic	shrapnel injury	
		gravity	impact, mechanical pressure	
	bacteriological agents of destruction	biological	microorganisms, viruses, products of their vital activity	
	chemical warfare agents	chemical	toxic effects of chemical substances (vapour, aerosol, droplets)	
	nuclear and thermonuclear weapons	dynamic	shock wave	
		physical	light pulse, electromagnetic pulse, penetrating radiation	

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Statistical data characterising the consequences of emergencies in peacetime conditions are given in Table 2.

Table 2: Characteristics of emergency consequences in peacetime conditions.

Parameter	Natural	Biologica l and social	Technogeni c
Number of emergencies, %	4,4	6,1	89,5
Percentage of deaths as a result of emergencies, %	29,1	8,41	62,49
Percentage of people affected by emergencies, %	21	58	21
Distribution of declared damage from emergency situations, %	94	1	5

The application of robotic devices is most promising in those areas of activity where the efficiency of information for decision-making and its high reliability are required. These are, first of all, those spheres of activity where visual control over large territories is required for various purposes. In all of the above cases, video and / or photo recording is carried out and the information obtained after processing is documented.

PwC experts estimate that the prospective benefit from the use of robotic devices (aerial) in the Russian market in 2023 exceeds $127 billion. USD. Of this, in the sphere of maintenance and service provision more than $45 billion.

The prospective benefit from the use of robotic devices in the main types of economic activities is shown in Table 3 (in USD billion 2023).

Table 3: Prospective benefit from the use of robotic devices in the main types of economic activities.

Scope of use	Cost of solutions
infrastructure	45,2
transport	13,0
insurance	6,8
media and entertainment industry	8,8
telecommunication services	6,3
agriculture	32,4
mining industry	4,3

The most promising applications of aerial robotic devices depending on their functions are shown in Figure 1.

Reduced size and improved capture quality of mobile video and photo cameras have enabled the use of aerial robotic devices for the production of professional video information, while the installation of modern ones has enabled sophisticated information processing.

Improvements in the microminiaturisation of navigation, propulsion, and fuel equipment have significantly increased the time that aerial robotic devices stay in the air and their payload capacity.

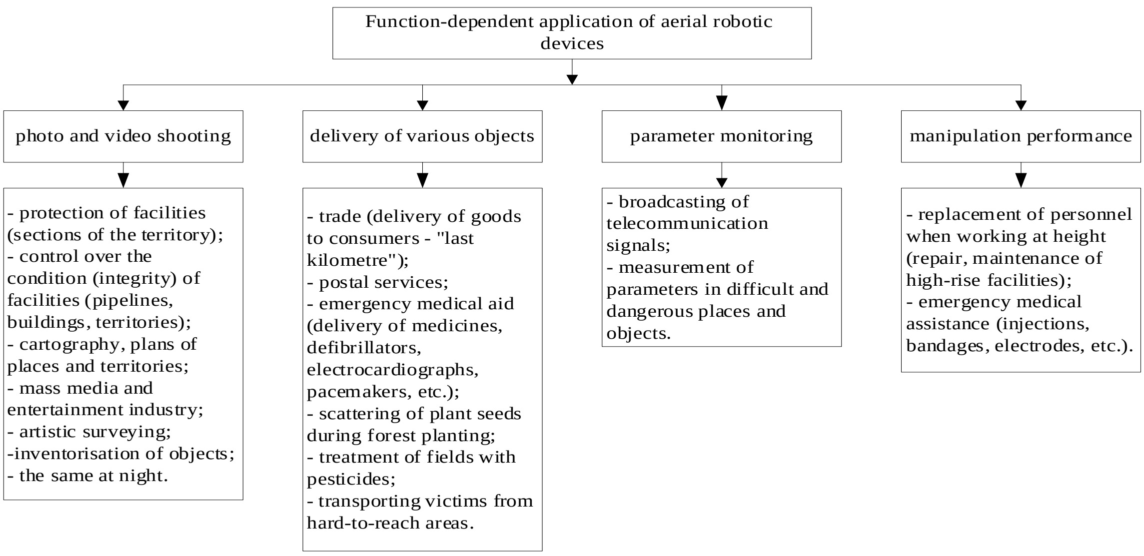

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Figure 1: Application of aerial robotic devices in industries.

When using aerial robotic devices for photo and video shooting it is possible to detect defects of structures without additional risk for personnel, and also an hour of work of one aerial robotic device is significantly cheaper than the work of a group of specialists at the object. And the software available today allows faster and more accurate processing and analyzing of the received information and, accordingly, making a more accurate and reliable assessment of the investigated objects.

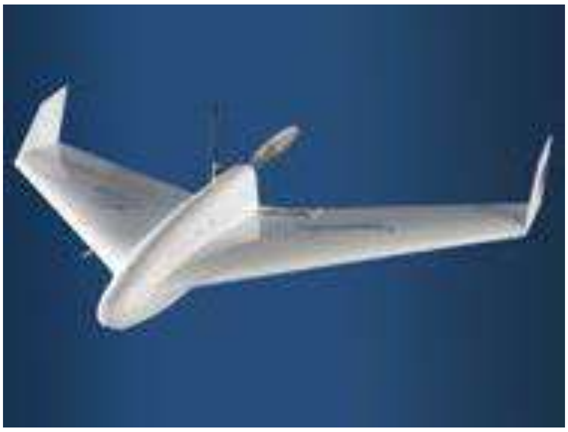
A series of flying micro-robots "Inspector - 101", "Inspector - 201", "Inspector - 301" have been developed in the Russian Federation for these purposes (see Figure 2). The presented models differ in their tactical and technical characteristics. "Inspector - 101" is the smallest flying robot in the Russian Federation, weighing 350 grams and with a wingspan of 30 centimetres. "Inspector - 201" is a flying robot with a take-off weight of 1.2 kilograms and a wingspan of 0.8 metres. "Inspector 301 is a flying robot with a take-off weight of 7 kilograms and a wingspan of 1.5 metres.

Having such characteristics, they can operate in confined spaces, including in urban areas. The target equipment of the Inspector-101 includes a microcomputer for processing and transmitting information, a fixed small-sized front or panoramic video camera. The device is launched by hand using a catapult.

"Inspector - 201" is equipped with a video camera with roll stabilisation (at least 520 TV lines) or a digital camera (10 megapixels), as well as an infrared camera.

As a payload "Inspector - 301" can be installed: various video cameras, digital camera of planned view (10 megapixels), infrared camera, gas sensors.

a



b

c

Figure 2: Flying micro-robots: a - "Inspector-101", b - "Inspector-201", c - "Inspector 301"

In addition, there are startups offering technical solutions using flying robotic devices for:

- cleaning the blades of wind turbines from dirt;
- filling cracks in the facades of high-rise buildings with their subsequent plastering and painting;
- applying decorative paintings on the mills of high-rise buildings.

Delivery of various objects to a given point (along a given trajectory) is not only delivery of cargo to the consumer. It is planting plants (spreading seeds from flying robotic devices in agriculture and forestry), treating them with fertilizers or pesticides.

At present, flying robotic devices are already used to deliver mail, goods ordered over the Internet, rapid transport of drugs and medicines to hard-to-reach areas (e.g., snakebite vaccines to the victim), spare parts to the place of breakdown and delivery of food on the day of order.

The ability to deliver cargo (medicines, components, personal protective equipment, etc.) to the emergency zone is also an important advantage.

Performing manipulations on a given object (if there is a special device - manipulator).

There are already models of portable defibrillators and cardiographs placed on flying robotic devices. Their work is carried out as follows. The patient, having felt pain in the heart, calls the flying robotic device by mobile phone and it, having determined the location of the patient by the signal of the mobile phone, flies to him.

The patient or a nearby person unbuttons their clothing, enabling the flying robotic device to take a cardiogram or perform defibrillation automatically.

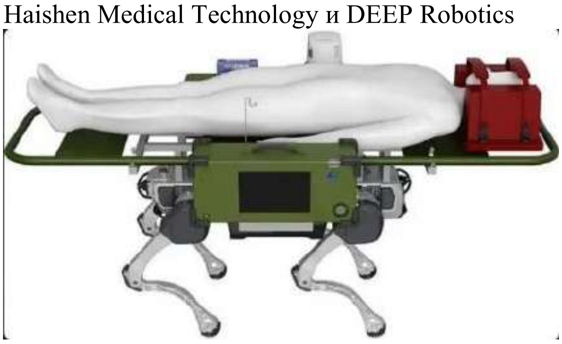
Because of the reduced time between the detection of the first signs of a heart attack and defibrillation by a flying robot, the efficiency of cardiac care can increase from 8% to 80%.

Thus, there is a large number of developed technical solutions for the use of robotic devices in various spheres, which can be successfully applied in search and rescue operations in emergency zones. For this purpose, it is necessary to analyse the existing robotic devices, various auxiliary and service equipment and justify the possibility of their joint use in search and rescue operations in emergency zones.

On 26 March 2025 in Beijing, *CSSC Haishen Medical Technology* (Figure 3, b) and *DEEP Robotics* (Figure 3, c) unveiled the world's first first aid rescue robot and casualty transport robot. Both robots are equipped with three modes of locomotion: on legs, wheels and crawler belts. They are capable of performing various functions including walking, running, climbing stairs, climbing hills, descending, avoiding and overcoming obstacles. The robots can operate stably at temperatures ranging from -20°C to 55°C, making them versatile and suitable for a wide range of applications: disaster rescue, emergency rescue, battlefield first aid, hospital mobility and more.

a – SAVER casualty transport robot

b – first aid robot for first aid treatment CSSC Haishen Medical Technology и DEEP Robotics



c – casualty transport robot CSSC Haishen Medical Technology и DEEP Robotics

Figure 3: Medical aid and casualty evacuation facilities.

In conditions of time deficit that accompanies the process of rescue operations, it is advisable to use flying robotic devices (Sherstnev, Bodin, Bezborodova, 2019). It should be noted that in accordance with the current legislation of the Russian Federation, priority in the use of airspace is given to flying robotic devices used in emergency response (Bezborodova, Sherstnev, Vinogradov, Vinogradova, 2018). However, the currently existing flying robotic devices are designed to perform only some specific rescue operations.

Thus, some flying robotic devices are used to evacuate victims. In particular, Israel has developed such a device for human evacuation *Cormorant* (Figure 4), capable of carrying up to 350 kg of payload to a maximum range of 32 km at a speed of over 160 km/h.

In the USA, the possibility of evacuating the wounded from the battlefield by means of flying robotic devices *DP-14 Hawk* (Figure 5) is being considered. This vehicle is a twin-rotor aircraft of vertical takeoff and landing, inside which one person can lie down.

Nevertheless, these flying robotic devices are not equipped with systems of life support and maintenance of vital functions of the human body, which is a significant disadvantage: a seriously

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injured victim may need resuscitation measures directly during evacuation, i.e. in flight.

Figure 4: Flying robotic device DP-14 Hawk.

Figure 5: Israeli flying robotic evacuation flying device «*Cormorant*».

During search and rescue operations, using the results of the forecast corrected on the basis of data transmitted from a flying robotic device equipped with measuring devices and sensors, rescuers receive reliable information about the possibility of access to different parts of the emergency zone.

In emergency conditions, flying robotic devices can provide emergency medical aid to victims (Soldatov, Kulnev, Shvets, Bigunets, 2010) by stopping the impact on victims of shock factors that aggravate their condition or lead to death (provision of personal respiratory protection equipment, isolation capes, etc.).

The content of emergency medical care depends on the striking factors and the nature of injuries sustained by the victims.

Based on the analysis of the injuries of victims from the acting striking factors, a flying robotic device providing emergency medical aid in an emergency should be equipped with a medical manipulator.

To stop bleeding, a medical manipulator can be equipped with an *Xstat* applicator designed to stop bleeding and be able to inject it into the wound of the victim. Inside the applicator there are special haemostatic capsules.

To isolate chemical, thermal and radiation burns as well as wounds, the medical handler must be able to apply an isolation dressing. Plasters for isolating burns are made of special impregnated material. In contact with the damaged skin, it acts in two ways: it absorbs the dying tissue and at the same time creates a soft gel layer that provides the skin cells with the necessary moisture for rapid regeneration.

To protect the victim from chemical impurities in the air, the flying robotic device provides the victim with an insulating gas mask.

One regenerating cartridge is sufficient for 70 minutes for medium physical exertion, and 45 minutes for heavy exertion. In any case, during this time the victim will be taken to a medical facility. The emergency cape will help the casualty to protect for a short period of time from temperature fluctuations, moisture, chemical vapours and to a lesser extent from penetrating radiation at a weight of 50 grams.

Once the victims are found, their main goal is to hold on until the evacuation measures start. And a flying robotic device equipped with a medical manipulator is capable of performing the described functions, which will increase the efficiency of emergency medical care several times.

The prerequisites for the creation of flying robotic devices for evacuation were difficult terrain conditions in the emergency zone, high concentration of impact factors, the desire to preserve human reserves (Figure 6).

Figure 6: Model of a flying robotic evacuation device manufactured in Israel.

Thus, the considered main characteristics of robotic means provide evacuation of victims from the

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emergency zone.

3 RESULTS AND DISCUSSION

A properly equipped flying robotic device can effectively assist victims in an emergency. It should be orientated to search, assist and evacuate victims from the emergency zone. A single flying robotic device often cannot perform all these functions; therefore, it is necessary to create and equip specialised flying robotic devices equipped to solve a specific task: search for victims in the emergency zone, provide them with special devices to assess the condition of victims, medicines and rescue equipment, communication and evacuation means.

Figure 7 shows an algorithm for organising assistance to victims in the emergency zone. It starts with the search for victims in the emergency zone. This operation is performed by flying robotic devices equipped with photo and video equipment and microcomputers with special software to identify victims against the background of natural or man-made landscape. Once the victim is identified, his coordinates are transmitted to a specially equipped drone carrying devices to determine heart rate (pulse) and blood loss. Colour photo and video data is used to determine blood loss. Special software determines approximate blood loss of the victim by the change of colour of the face, clothes, surrounding space. Heart rate is determined by ultra-wideband radar. Experimental works have shown that signals of ultra-wideband radar are well reflected and received from a human body (living). Moreover, the forms of reflected signals depend on the pulse rate and respiration rate.

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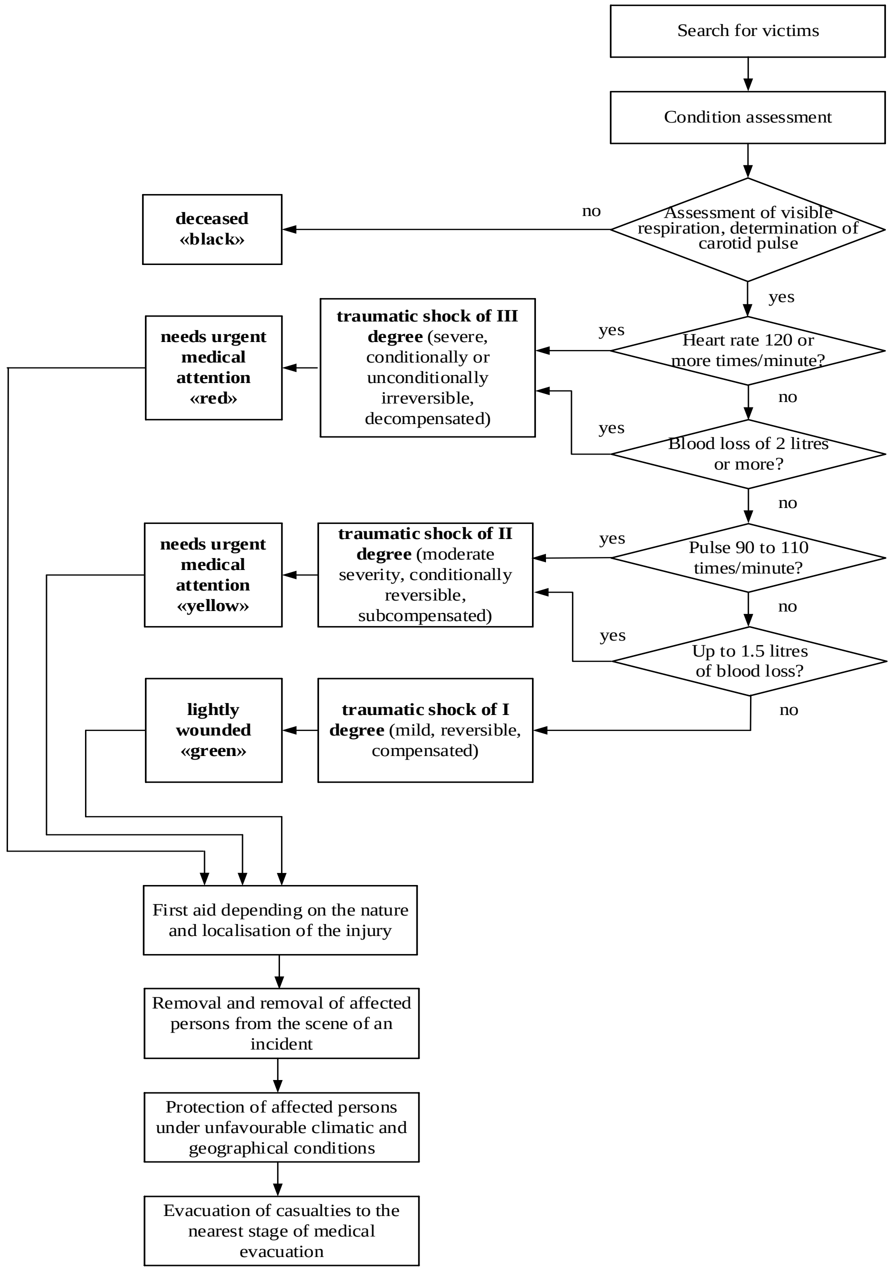

Figure 7: Algorithm of organising assistance to victims in the emergency zone.

Having thus determined the presence and quantitative data of these parameters and analysing them according to the algorithm shown in Figure 7, medical triage and marking of victims in the emergency zone without the direct participation of a doctor or with his remote control of the process is carried out.

Based on the medical triage and labelling data for each group of casualties, the necessary set of actions is performed to ensure and maintain their life activity until they are delivered to the hospital.

Lightly wounded "green" victims, following the instructions of the operator of the flying robotic device given through a loudspeaker, leave the emergency zone on their own.

Rescue doctors are sent to the "yellow" and "red" victims, having the coordinates, using navigators to provide first aid and organize evacuation. To provide first aid, flying robotic devices deliver medical devices and manipulators to the victim, reducing the physical load on the rescue doctor and allowing him to be more effective in providing medical assistance to the victims.

Special robotic devices for evacuation purposes, on the ground or by air, carry "yellow" and "red" victims out of the emergency zone, maintaining the vital functions of the evacuee during the evacuation process.

Based on the above, the developed algorithm for the organization of assistance to victims in the emergency zone provides timely evacuation of priority victims and increases the effectiveness of medical care.

4 CONCLUSIONS

The constant growth in the number and scale of negative consequences of various anthropogenic and natural disasters, recorded as emergencies, makes it necessary to improve existing methods and means to minimise damage from emergencies. The developed algorithm of triage and evacuation of victims in emergencies on the basis of robotic mechanisms provides timely evacuation of priority victims and increases the efficiency of medical care.

REFERENCES

Muravyev, M. Yu., 2007. Problems of first aid in emergency rescue work and ways of their solution. *Civil security technologies.* V. 4, № 1 (13). P. 41–45.

Kaznacheev, M. V., 2016. Improvement of medical triage of the wounded at the advanced stages of medical evacuation : Dissertation for the degree of Candidate of Medical Sciences : 14.01.17 – Surgery.

Baranova, N. N., 2022. Medical evacuation of victims in emergency situations. Volume I : dissertation for the degree of Doctor of Medicine. 05.26.02 – Safety in emergencies. Medical Sciences. 14.02.03 – Public health and health care.

PwC Report on the commercial use of drones globally, May 2016. – URL: www.dronepoweredsolutions.com (circulation date: 10.01.2025)

The Truth About Drones website – URL: https://thetruthaboutdrones.com/2014/10/29/ambulance-drone-prototype-unveiled-in-holland/ (circulation date: 10.01.2025)

Zhenmin zhibao online website. – URL: http://russian.people.com.cn/n3/2025/0328/c31517-20295439.html (circulation date: 10.05.2025).

Sherstnev, V. V., Bodin, O. N., Bezborodova, O. E., 2019. Criteria and principles of effective application of unmanned aircraft in emergency situations. Actual problems of science : collection of scientific articles of XV International Scientific and Practical Conference. P. 218–224.

Bezborodova, O. E., Sherstnev, V. V., Vinogradov, O. S., Vinogradova, N. A., 2018. Economic and legal issues of using unmanned aircraft to ensure technosphere security. Fortus: Economic and political studies. № 2.

In Israel, drone evacuation of the wounded has been tested. – URL: https://news.rambler.ru/weapon/39972706-v-izraile-protestirovali-evakuatsiyuranenyh-bespilotnikom/ (circulation date: 10.01.2025).

DP-14 Hawk unmanned aerial vehicles for casualty evacuation. – URL: http://zonwar.ru/news5/news_875_DP14_Hawk.html?ysclid=le6o6vls96658766661 (circulation date: 10.01.2025).

Soldatov, E. A., Kulnev, S. V. V., Shvets, V. A., Bigunets, V. D., 2010. Prospects for the use of unmanned aerial vehicles in the interests of medical service in the course of liquidation of consequences of emergency situations. Medico-biological and socio-psychological problems of safety in emergency situations. № 2. З. 50 – 55.

Ilyasov, F. Sh., 2009. Radars for detection of people behind optically opaque barriers. *Civil Security Technologies.* V. 7, № 3–4 (21-22). P. 86–90.