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Aerial medical platform for soldiers and civils evacuation – Concept, implementation plan and assessment of adaptation possibility of existing technologies

Krzysztof Puchała[1], Grzegorz Moneta[2], Daniel Lichoń[3], Rafał Grzejda[4*], Arkadiusz Bednarz[3], Witold Mielniczek[5], Marian Łopatka[1], Elżbieta Szymczyk[1], Sergii Ignatovych[6], Roman Mykhailyshyn[7,8,9]

[1] Faculty of Mechanical Engineering, Military University of Technology, ul. Gen. Sylwestra Kaliskiego 2., 00-908 Warsaw, Poland
[2] Łukasiewicz Research Network, Institute of Aviation, Al. Krakowska 110/114., 02-256 Warsaw, Poland
[3] Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, ul. Powstancow Warszawy 12., 35-959 Rzeszow, Poland
[4] Faculty of Mechanical Engineering and Mechatronics, West Pomeranian University of Technology in Szczecin, ul. Piastów 19., 70-310 Szczecin, Poland
[5] B-Technology Sp. z o.o., Jasionka 954E, 36-002 Jasionka, Poland
[6] Aerospace Faculty, National Aviation University, 1 Liubomyra Huzara Ave., 03058 Kyiv, Ukraine
[7] Walker Department of Mechanical Engineering, Cockrell School of Engineering, The University of Texas at Austin, Austin, TX 78712, USA
[8] Graduate School of Engineering Science, Osaka University, Osaka 560-8531, Japan
[9] EPAM School of Digital Technologies, American University Kyiv, 02000 Kyiv, Ukraine
* Corresponding author's e-mail: rafal.grzejda@zut.edu.pl

ABSTRACT

The presented paper proposes a some concept of an evacuation drone that could pick up the wounded from the battlefield and transport them to their final destination for adequate medical care. The existing state of the art of drones and their equipment is described, as well as the possibility of using current technology to build a new drone. This paper presents a vision of the 'future/ideal drone' and the 'technically/reasonably achievable drone today', and consequently the levels of its development. The main rationale for choosing a drone configuration, including the basic characteristic sizes, is discussed. In view of the purpose of the drone, i.e. need to perform basic medical activities, current robots used in remote surgery were analysed. Due to the fact that the final version of the drone is to take up the wounded without the participation of a third party, design aspects related to this are presented and examples of solutions are proposed.

Keywords: evacuation, drone, medical, robotics, MEDEVAC, CASEVAC, military operations, civil emergencies.

INTRODUCTION

Increasingly destructive and deadly war machines and devices make it necessary to develop adequate defence measures. Recent years have seen a significant increase in the use of unmanned vehicles, particularly unmanned aerial vehicles (drones). Staying on the subject of war, it should be mentioned that Ukrainian forces are currently using a large number of drones of various types to repel a bestial and frenzied assault launched by the group currently in power in Russia. This year was expected to be a significant change for Ukrainian drone aviation. The government has allocated a record 40 billion hryvnias (more than $ 1 billion) to support local manufacturers. Currently, around 200 companies in Ukraine are involved in the production of unmanned systems, of which about 50 have already completed the necessary authorisation procedures and are actively supplying their products to the military [1]. From a military point of view, drones are currently used mainly for reconnaissance and destructive missions. This is done without any direct threat to the operator and at a much lower cost due not only to the avoidance of losing a trained person, but also to the significantly smaller size and cost of the machine itself and thus its operation. These factors are the reason for the equally large expansion of drones in civilian applications.

Industries using drones include the wider construction industry along with infrastructure, meteorology, agriculture, or finally law enforcement and life-saving services: police, border guards, firefighters, rescue and medicine. Activities performed by drones in construction and infrastructure include inspection of hard-to-reach objects [2, 3], mapping of construction sites or inspection of construction progress [4]. A thorough literature analysis of drone use in this sector can be found in [5]. The application of drones to predict weather for traffic is presented by Sziroczak et al. [6]. Balaji et al. [7] and Kim et al. [8] discuss the use of drones in agriculture. Law enforcement agencies mainly use drones for surveillance and search of large areas and contaminated or difficult to access areas [9]. Drones are also used for rescue and medical purposes. At this point, it is only worth mentioning that the medical drone market is forecast to grow from $ 1.25 billion in 2023 to $ 3.62 billion by 2030 [10].

A point of commonality between the civilian sector and the needs of the military is saving the lives and health of the injured. The paper presents a proposal for a drone to pick up and transport an injured person from a place where his or her life is in danger to a place that provides proper medical care. The drone is intended to pick up the injured person without the involvement of a third party and be able to perform first aid rescue operations. Based on a review of the literature, no proposal for this type of vehicle was found. The first concept and preliminary design of the drone in question is presented in [11].

The concept of air evacuation has been around for a long time. An example of an early air ambulance is shown in Figure 1. The idea of transporting injured people by aircraft originally met with much criticism and opposition, which was overcome after such flights were made despite objections. A similar situation currently exists in relation to the transport of the injured by unmanned aerial vehicles.

Survival rates among wounded soldiers in recent conflicts have improved significantly compared to the Second World War [13], after which air evacuation began to be used on a larger scale, primarily by helicopters such as the Bell H-13 Sioux (Figure 2). This is mainly due to the increasing use of air evacuation and refined procedures, including the application of the so-called 'golden hour' rule. It should be noted, however, that the conclusions presented are based on US data (referring to conflicts in which the United States was involved). These were asymmetric conflicts with a significant technological and force advantage on the US side, especially in terms of air forces which allowed such evacuation to be implemented with relative ease. In a situation of aligned air forces or foreign forces superiority, evacuation by helicopters may be difficult or impossible. The gap created will be able to be filled by evacuation drones, thus sustaining a high survival rate.

Despite the realisation that the introduction of evacuation drones will bring many tangible

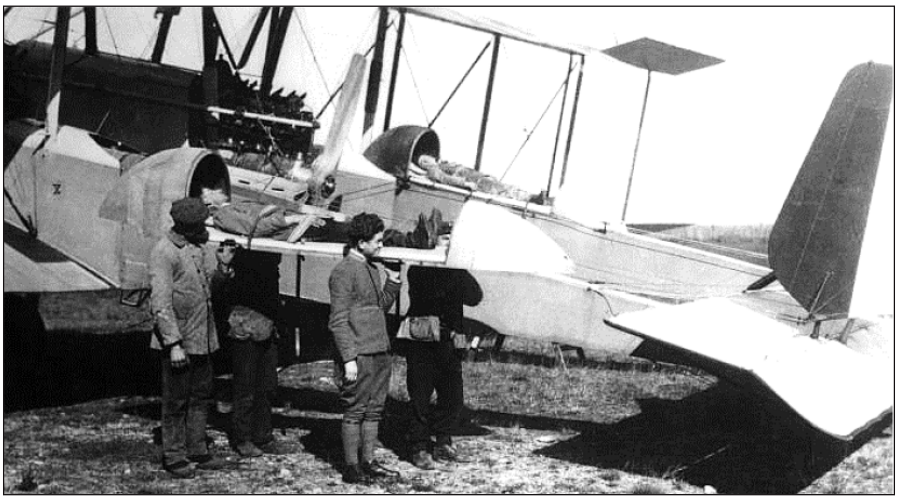

Figure 1. Early air ambulance – Caproni Ca 50 [12]

Figure 2. Bell H-13 Sioux [14]

benefits, and despite steps taken in this direction by many institutions of the US government since about 2009, there is no such drone placed into service to date. Factors that may contribute to this state of affairs are:

- lack of confidence in such a means of transport (no direct contact with the doctor, need to confine the injured person in a 'small black box');
- lack of confidence in artificial intelligence, which is almost always mentioned as the technology that will be involved in such a drone;
- the fact that companies developing similar projects see greater profit in the growing vertical take-off air cab/taxi sector, with fewer issues that will need to be resolved (ethical, legal and medical);
- such projects have to be largely funded by government institutions, which have their limited resources and have to address medical, ethical and legal issues.

In a situation where a wounded battle comrade has to rescued, all other issues begin to seem unimportant. Good evidence of this is the fact that, despite the lack of procedures and recommendations, the first evacuation of a wounded person from the front line was carried out in 2023. This took place in Ukraine using a high-capacity transport drone [15].

It is not a requirement or a necessity for a rescue drone to make significant use of artificial intelligence. As proven and validated skills should be used, it is likely that in the future all the activities of such a drone could be controlled by artificial intelligence if it reaches an appropriate level of development. In the first instance, however, it is assumed that the drone will be controlled by a team of suitably qualified specialists. The response to this situation is the Ambular Project, an open non-commercial air ambulance development programme [16] (Figure 3).

Figure 3. Air ambulance model by the Ambular Project [17]

EXISTING DRONES SOLUTIONS FOR MEDICAL/RESCUE PURPOSES

Drones leverage advanced technologies to support various medical and emergency response applications. Some of the cutting-edge drone solutions for medical and rescue purposes include: Automated External Defibrillator (AED) Delivery, Medical Supply Delivery, Emergency Response, Telemedicine, Organ Transplant Transportation, Water Rescue, Disaster Assessment (Figure 4).

AED delivery drones are designed to rapidly carry and deliver AEDs to the site of a cardiac arrest. These drones can be dispatched in response to emergency calls and provide lifesaving assistance prior to the arrival of emergency medical teams [18–20].

Medical Supply Delivery Drones equipped with temperature-controlled cargo compartments are used to deliver medical supplies, vaccines, and essential medicines to remote or inaccessible areas. They play a critical role in enhancing healthcare access in underserved regions [21–23].

Emergency Response Drones are used by emergency response teams to assess disaster-stricken areas, search for missing persons and identify potential hazards. These drones are equipped with thermal imaging cameras and other sensors to locate people in difficult terrain [24–26].

Some drones are equipped with video conferencing capabilities to enable remote communication between healthcare professionals and patients in hard-to-reach areas. These telemedicine drones can provide medical consultation and emergency support when traditional medical access is limited [27–29].

Drones have also been used to transport organs for transplantation quickly and efficiently. They can significantly reduce transportation time and extend the viability of organs for transplantation [30–33].

Disaster Assessment Drones are used after natural disasters or accidents. They are equipped with high-resolution cameras to survey and assess the damage. These aerial assessments provide valuable data for disaster response and relief efforts [34–36].

Water Rescue Drones are drones with buoyancy capabilities used in water rescue operations. They can drop lifebuoys or floatation devices on people in distress and assist lifeguards during water-based emergencies [37–39].

Drones for patients/wounded transport are not mentioned in Figure 4 because such drones for use in active medical service have not yet been developed. Not even the military industry can boast of such, even though it often proves to be a driving force for the introduction of new technologies. Naturally, the idea of using such vehicles is not new, and military institutions have been considering the use of unmanned systems for some time, as reflected in the report [40]. It lists requirements and directions for development and characterises the legislative process for such vehicles. It mentions vehicles that, as existing designs or those under development, could act as an ambulance. Examples of these are shown in Figure 5.

Most of the designs shown in Figure 5 are simply helicopters equipped with remote or preprogrammed control systems. This entails high production and operating costs. In Poland, despite a strong tradition of helicopter design and production, there is currently no factory with 100% Polish ownership, which may prove crucial in the development of new concepts. It should be noted that the AgustaWestland RUAV helicopter shown in Figure 5d is a modernised design of the Polish PZL SW-4 helicopter developed at Wytwórnia Sprzętu Komunikacyjnego 'PZL-Świdnik' SA, of which AgustaWestland currently owns 87.62% of the shares. Due to its different design from the previous ones and the resulting compact size, AirMule (Figure 5f) may be the best platform for NATO to develop. It should be noted, however, that the AirMule's 2-fan design with vector blade control is not inexpensive. The fact that such

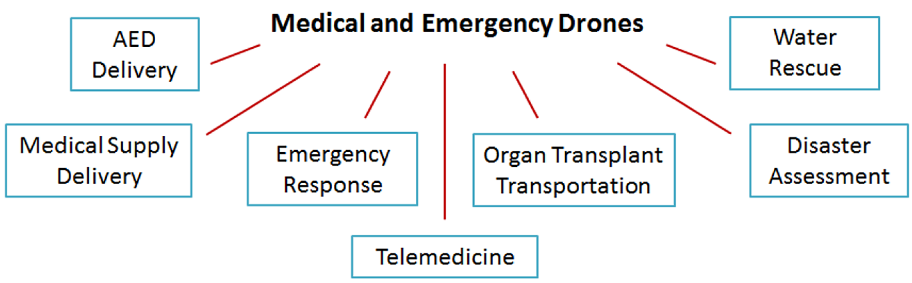

Figure 4. Tasks for which medical and emergency drones are used

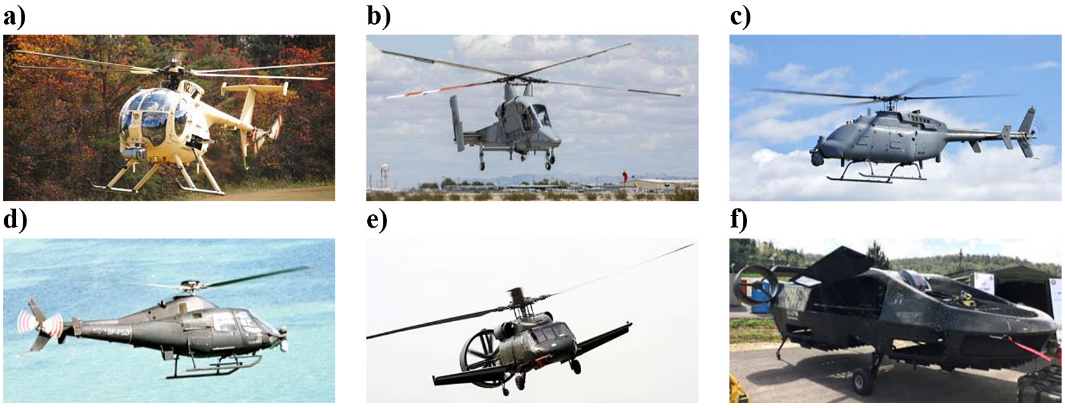

Figure 5. Potential drone ambulance platforms: a) Boeing Unmanned Little Bird [41]; b) Kaman KMAX [42]; c) Northrop Grumman FIRE-X [43]; d) AgustaWestland RUAV [44]; e) Piasecki Aircraft X-49A [45]; f) Urban Aeronautics AirMule [46]

solutions have not yet been used for purposes other than vertical take-off may indicate the difficulty of achieving stable flight in windy weather.

The report cited previously [40] also shows conceptual designs and those in the early stages of development. Figure 6 illustrates designs of this type. The first is inspired by 'standard' multi-rotor drones (Figure 6a), while the second is a miniature helicopter with tandem rotors (Figure 6b). The combination of these two proposals is the drone concept discussed further in the paper. It is the design with a multi-rotor system, which has an independent drive and at the same time provides a control system by changing the rotation of the individual rotors, that seems to be the simplest to implement.

Most of the vertical take-off vehicles currently proposed to be air cabs/taxi or recreational vehicles are based on such a system (Figure 7).

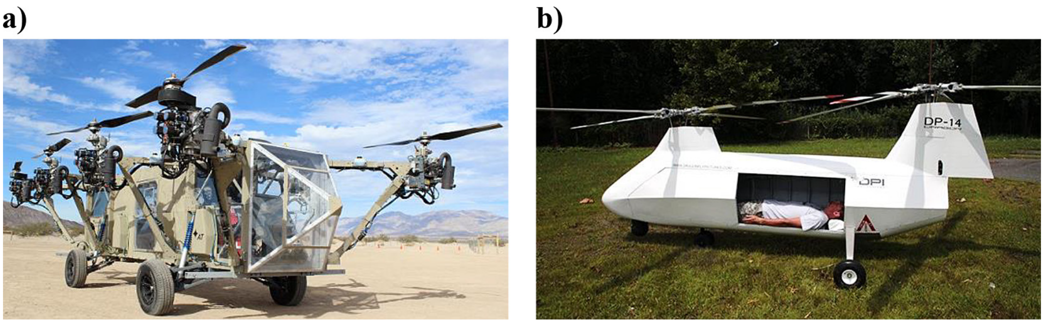

Figure 6. Potential conceptual/early stage drone ambulance platforms: a) Advanced Tactics Black Knight [47]; b) DPI DP-14 [48]

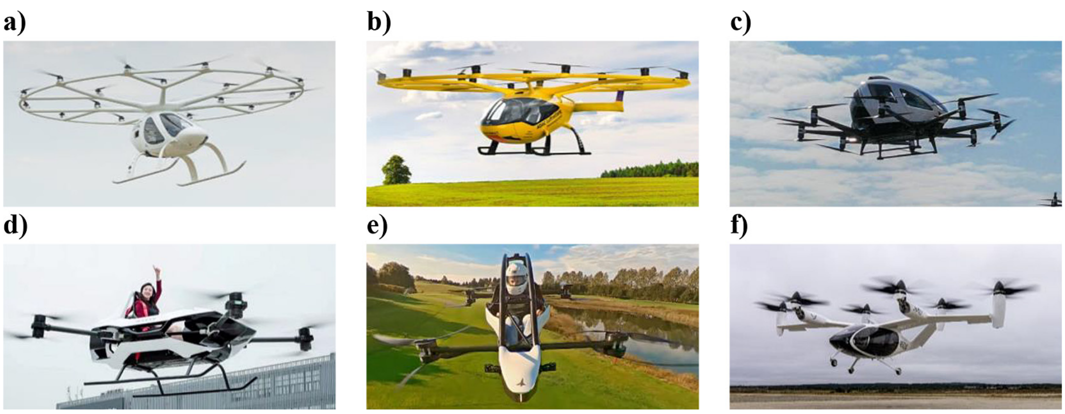

Figure 7. Air cabs/taxi or recreational vehicles drone platforms: a) Volocopter [49]; b) ADAC Luftrettung Volocopter [50]; c) Ehang 216 [51]; d) XPeng AeroHT Voyager X1 [52]; e) Jetson ONE [53]; f) Joby Aviation S4 [54]

These designs are already in use and some have versions as ambulance-type vehicles, and all indications are that this will be one of these proposals that will be the first rescue drone put into service.

Another interesting proposal is the Beccarii concept. Is is a Polish design that provides the performance of a helicopter and tracked vehicle in one (Figure 8). The Beccarii is an innovation in search and rescue, setting new standards for versatility, capability and adaptability in challenging environments. Unlike traditional rescue vehicles, it combines advanced locomotion abilities – flying, tracked driving, swimming and vertical take-off and landing (VTOL) – with a unique ability to operate on and take-off from water. This allows the Beccarii to quickly reach and navigate any terrain, making it a lifesaver in a variety of scenarios.

Figure 8. Working model of Beccarii

FUTURE/IDEAL DRONE FOR ASSUMED TASKS AND ACHIEVABLE DESIGNS, LEVELS OF DEVELOPMENT

As demonstrated in earlier sections, there are many examples of the flying ambulance of the future in the literature. At the concept development stage, its creator is only limited by his or her own imagination. In order for a concept to become a reality, it must be justifiable and feasible and additionally meet various requirements. These requirements stem from the following issues: technical and technological related to economic, medical, legal and ethical. Dominant among these are technical and economic issues. The drone is to be manufactured in Poland or jointly with Ukraine. Both of these countries have long aviation traditions, but the current state of the aviation industry in these countries is not conducive to the development of similar concepts. The concept under discussion must therefore be sound and the implementation plan well thought out. The implementation plan related to technical and technological issues is shown in Figure 9. The drone will consist of various components that can be developed independently (platform, wounded loading system, medical robot), but its core component will be the platform together with the propulsion and control system.

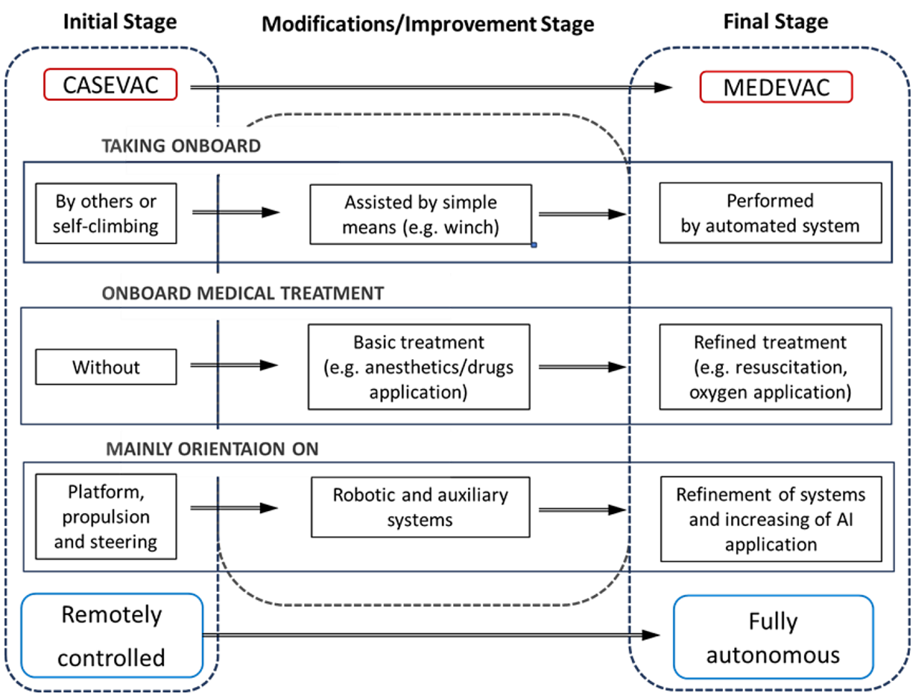

Figure 9. Stages of development of the proposed drone

Since there is no structure that could be used as a base and subjected to modifications at this point, the drone has to be developed from scratch. This results in the need to develop as simple and inexpensive a design as possible in the first stage. At this stage, the main effort will be on development of the platform, propulsion system and control system. The final structure will probably be made of components that need to be joined. It is worth noting that the one of the most common methods of joining is still through multi-bolted connections [55–59]. The first prototype is likely to be a casualty evacuation vehicle (CASEVAC) meaning that the injured will be loaded on board by other people or will be boarded themselves and transported without medical assistance.

The first version of the drone will certainly be controlled remotely (without the use of artificial intelligence systems). The design thus developed will then be modified and improved in the design development stage. This will allow for the gradual acquisition of experience, further technological development and judicious disposal of resources. The main efforts will then be directed towards drone robotisation and gradual adaptation of artificial intelligence [60–63]. This assumes primary medical care via remote systems. In the final stage of development will see the automation of as many activities as possible, through navigation and flight control or loading of the wounded using artificial intelligence systems with operator supervision. After this stage, the final medical evacuation vehicle (MEDEVAC) will be created. As mentioned, the drone will consist of various components developed largely independently. Thus, it may turn out that some systems will be developed earlier than anticipated and/or may be used in other projects regardless of whether or not the drone is built. As far as medical issues are concerned, it does not seem, given the state of the art of existing designs of this type in terms of flight stability, noise and vibrations, that the transport of the wounded will be in any way inferior to helicopter transport. In fact, it can be assumed with a high degree of certainty that it will even be more advantageous. Furthermore, in a critical situation it is better to attempt to evacuate the injured person than to leave him to die. As far as legal issues are concerned, these are the responsibility of governments, and the development of such a drone can provide evidence of the validity of its implementation and thus the basis for a positive attitude towards it and consideration of the law associated with it. Previous failures in the deployment of such drones indicate that the designs assumed so far have posed too many technological problems and/or are too costly. Hence the choice of the drone concept more broadly discussed in Section 4.

The modelling of various aspects related to drones has received a lot of attention recently. For modelling drone structures, computer-aided design (CAD) systems are most commonly used [64–66]. Together with finite element method (FEM) systems, it allows fast and efficient design, reducing the number of costly experimental tests. Novel software greatly reduces design cost.

OVERALL CONCEPT OF PROPOSED RESCUE/MEDICAL DRONE

The proposed concept is based on a tandem-rotorcraft helicopter system. The Cornu 1907 machine (Figure 10a) is recognised to be the first attempt to build such a type of helicopter, probably capable of taking to the air after only a few seconds. The first successful design (capable of controlled flight) of this type is considered to be Nicolas Florine's machine (Figure 10b).

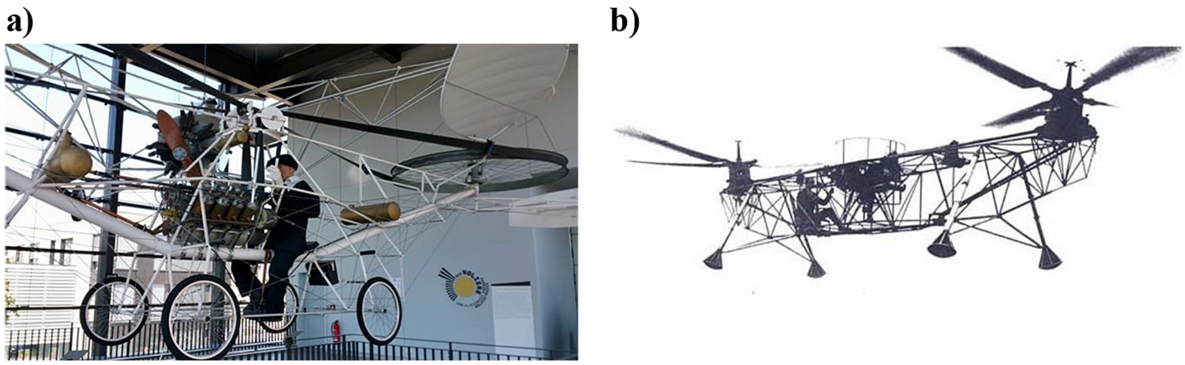

Figure 10. Existing examples of a tandem-rotorcraft helicopter system: a) Replica of the Cornu Helicopter [67]; b) Nicolas Florine's machine [68]

The first helicopter of this type to enter production and use was the Piasecki HRP-1 (Figure 11a). It should be noted that this model was developed for military rescue purposes. Another design from the early history of tandem-rotorcraft models is the McCulloch MC-4 (Figure 11b).

The Boeing H-47 Chinook (Figure 12), which is still in production and in use today, is manufactured by Boeing Helicopters, a company derived from Piasecki Helicopter, which produced the HRP-1.

The advantages of the chosen configuration are:

- increased range of centre of gravity,
- increased longitudinal stability,
- increased lifting capacity,
- reduced propeller size by using a pair of rotors.

The disadvantage of this configuration is the complicated power transmission system. However, this applies to the traditional drive system, where there is one motor and power is transmitted to the other motor via a shaft and gearbox. When each rotor is driven by its own independent motor with gearbox, this problem does not occur.

Introducing additional side rotors relieves the load on the main rotor, while providing a simple means of control by varying the speed of the individual rotors.

Taking into account the horizontal position in which the wounded person is transported, all the advantages of the tandem-rotorcraft with the possibility of eliminating its disadvantage, and, in addition, the possibility of using a simple control system, this drone configuration was chosen, an example visualisation of which is shown in Figure 13.

The results of preliminary calculations of the drone are presented in [11]. They concern the case in which the drone is completely electrically powered. The calculations were based on available data for similar designs such as the McCulloch MC-4 (Figure 11b) and DP-14 (Figure 6b) and with assumptions on the cruising speed and masses of individual components.

Figure 12. Boeing H-47 Chinook [71]

The main features of the drone after preliminary calculations (and assumptions) are as follows:

- weight equal to 1690.5 kg (of which 1177.5 kg is the weight of the battery and associated components),
- payload capacity of approximately 160 kg – data taken from NATO requirements for one person with his 'luggage',
- cruising speed of 120 km/h,
- continuous power of individual motors:
  a) 90 kW for the longitudinal rotor,
  b) 40 kW for the side rotor,
- range of 35 km (70 km round trip),
- additional 20 minutes for various task-related aerial manoeuvres.

The dimensions of the drone must correspond to the cargo spaces of NATO transport aircrafts. For example, they are: 12 m × 2.7 m × 3 m for the Lockheed Martin Hercules C-130 and 9.14 × 1.98 × 2.53 m for the Boeing H-47 [72, 73].

An electrically powered drone reduces the possibility of detection due to the acoustic and heat signature. However, this is not a necessity. The structure should have the ability to be converted to a hybrid-powered system or can be designed from the outset as hybrid or combustion engine powered. The usage of composite

Figure 11. Production versions of tandem-rotorcraft helicopters: a) Piasecki HRP-1 [69]; b) McCulloch MC-4 [70]

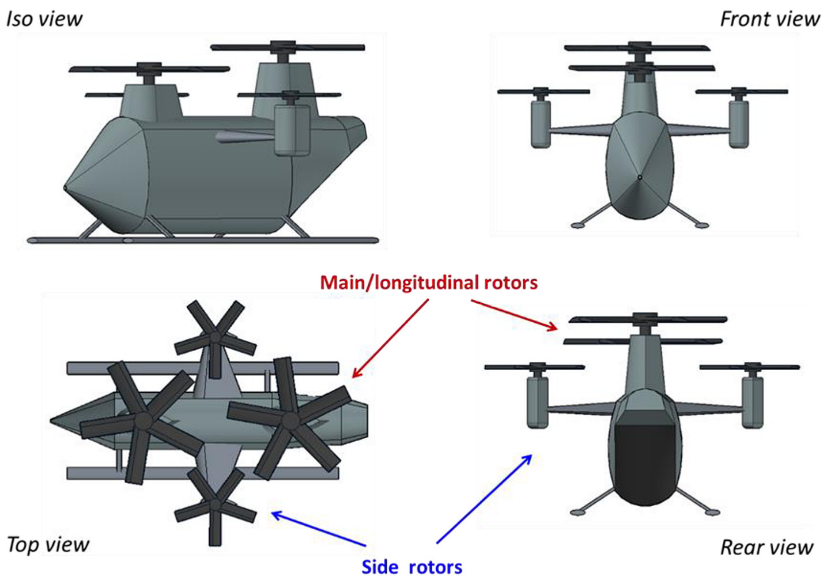

Figure 13. Overall concept of a drone with rotors arrangement

materials increases the efficiency of structures and improves their functional properties [74, 75], despite some implementation problems [76, 77].

MISSION PROFILE

Taking into consideration both the calculated performance of the conceptual rescue/medical drone and the assumed main task, i.e. evacuation of wounded from the battlefield, a specific mission profile was derived (Figure 14).

The initially calculated range of 35 km indicates that the drone will operate close to the front line, but out of range of most enemy weapons (artillery, mortars, suicide drones). Furthermore, this range can be extended by using a different type of propulsion system (hybrid or combustion engines), increasing the safety of evacuation operations [11]. The drone ground operator will remain in communication with combat forces. Upon receiving the evacuation message, the drone will take-off and perform a semi-autonomous cruise flight at up to 100 m above ground level, which is similar to current U-space drone operations in a civilian environment. The location of wounded soldier will be achieved within 20 minutes, which include the take-off, flight and landing phases. The landing on the battlefield will be followed by the placement of the wounded soldier in the cabin. The time spent on the ground to prepare the evacuation should be the shortest,

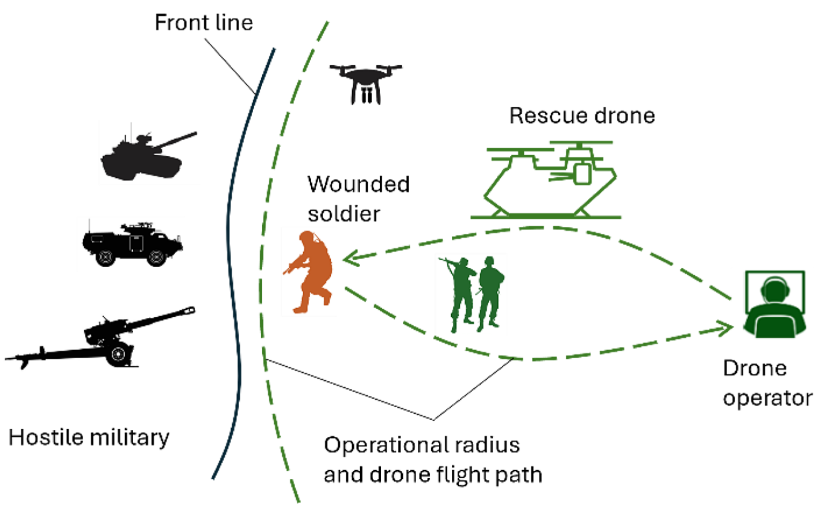

Figure 14. Mission profile - evacuation of a wounded soldier

but this parameter depends on the current tactical situation and the extent of the medical injury. The drone will then perform a return flight to the launch site, where ground medical services will continue to provide medical assistance. Finally, the drone will be prepared for the next flight by technical inspection and battery replacing/recharging. Taking into account the length of the front line, the operational stations of the rescue drones should be placed at regular distances of about 20 km, complementing each other.

It should be noted that the presented drone concept differs in terms of the weight, payload, speed and range compared to classical helicopter designs. Therefore, a detailed study of the flight performance depending on the design parameters should be carried out, for example similarly to studies related to light fixed-wing unmanned aircrafts [78, 79].

The presented mission profile fits into the current trend in civilian aviation, i.e. the urban air mobility (UAM) concept (Figure 15). This concept aims to introduce VTOL vehicles to transport people and goods in the urban areas. UAM is supposed to be managed with the support of automation. This distinguishes UAM from classical air traffic management, which uses pre-described flight routes and departure and arrival procedures [80, 81]. This creates an opportunity to use the proposed concept also in a civilian environment to support medical interventions in urban areas. Potentially, this application can reduce critical rescue times compared to ground ambulances or even ambulance helicopters, given traffic and limited urban space. Moreover, civilian application will reduce the life-cycle costs of the structure relative to operational capabilities.

SURGEON ROBOTICS

Medical robots can be divided into four groups [82, 83]:
- passive systems that provide information to the surgeon,
- active systems that perform a planned procedure under human supervision,
- interactive systems used as mechanical guides (semi-active or synergistic systems),
- teleoperative systems that are controlled remotely by the surgeon.

Passive systems consist of an articulated arm that holds an instrument that is moved manually by the surgeon, with the position of the instrument being recognised by the navigation system [84]. They are not directly involved in the performance of the procedure, which remains under the complete control of the surgeon. With this in mind, medical passive systems cannot be used in the design of a military drone intended for rescue and medical missions.

Active systems use preoperative and intraoperative planning data to autonomously perform multifaceted surgical manipulations (without the surgeon's involvement). An example of such a system is the TSolution-One used in robot-assisted orthopaedic surgery (Figure 16). The fact that medical active systems are programmable makes their adaptation in a medical-rescue drone project probable.

Interactive systems require an interaction between the robot and the surgeon, who mechanically constrains the robot. Within this group, two types of solutions can be distinguished: semi-active and synergistic systems. In semi-active systems, this mechanical constraint is realized with no feedback to the surgeon. In synergistic

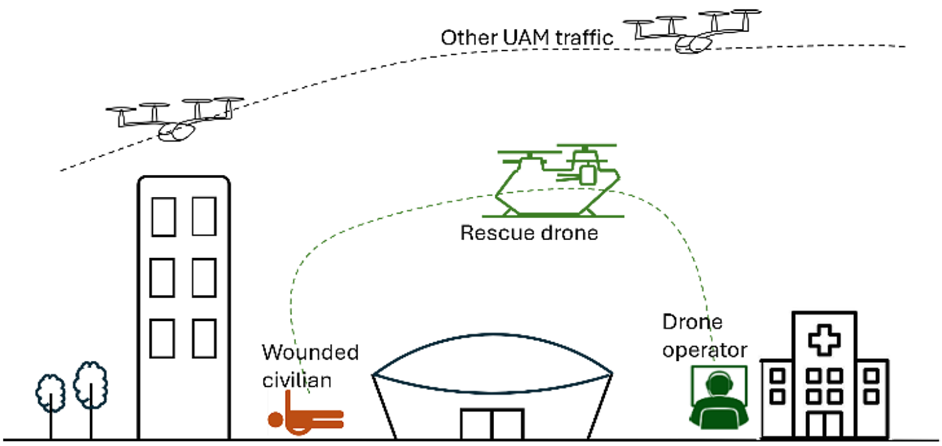

Figure 15. Mission profile – transportation of a wounded civilian in urban area

Figure 16. TSolution-One [85]

systems, on the other hand, mechanical constraints are programmable. This means that these systems are based on the principle of haptic models (i.e. information feedback). Examples of the latest semi-active systems are the CORI Surgical System [86] (Figure 17), and the MAKO Robotic Arm Interactive Orthopaedic System [87] used in total knee arthroplasty. A study of an example synergistic system for robotic surgery is described in [88]. The characteristics of the medical interactive systems indicate that they cannot be implemented in the case of the medical-rescue drone planned for development.

Teleoperative systems consist of two physically separated subsystems called 'surgeon-side' and 'patient-side', which is why these systems are often referred to as master-slave systems [90]. In this type of system, the operator uses a master interface that sends commands to the slave robotic arms, which interact directly with the patient. An example of a master-slave system is the Da Vinci Surgical System [91], which is now by far the most widely used medical robotics system in the world [92]. Another example of this type of system is the Robin Heart robotic system [93, 94] (Figure 18). The construction of the Da Vinci Surgical System and the Robin Heart robotic system are similar, both of them having spherical kinematics with the center of the sphere located outside of the mechanism. However, master manipulators and robot control approaches are different for these robots.

There are also other master-slave systems used in preclinical studies. Marinho et al. [96] developed a versatile master-slave system called SmartArm, composed of two industrial-type manipulator arms. Faulkner et al. [97] used the Versius robotic system, which has a modular design and smaller footprint compared to the Da Vinci Surgical System. This allows the instrument arms to be placed closer together and operate at

Figure 17. CORI Surgical System [89]

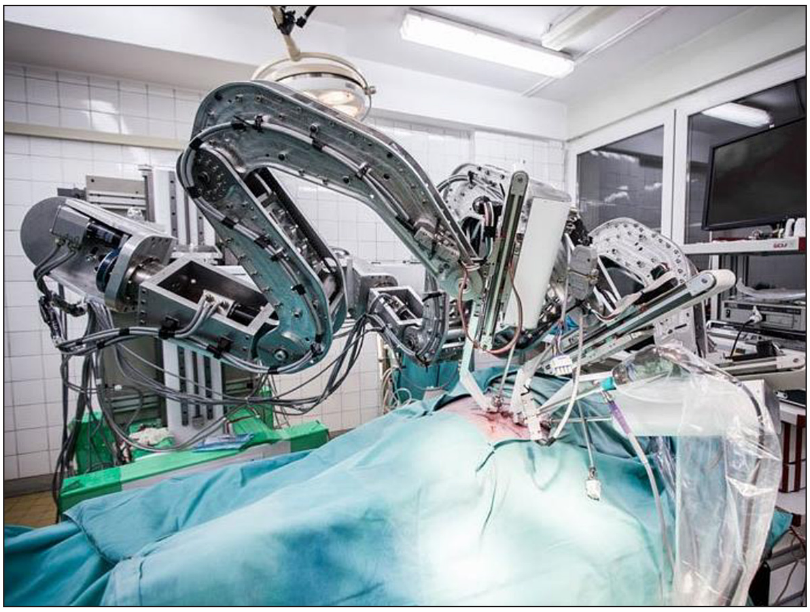

Figure 18. Robin Heart robotic system [95]

smaller triangulation angles and distances without proximal collisions. Hagn et al. [98] presented a comprehensive system for endoscopic telesurgery called DLR MiroSurge, which is in the testing phase. Master-slave systems are also being developed at other research centres [99].

The idea of teleoperation systems used in surgery could be implemented in the case of the medical-rescue drone planned for development. Additional analysis would then be needed to select the number of slave robotic arms, configure them accordingly, equip them with anthropomorphic grips (for example, as in [100]) and develop a control system.

CHOICE AND DESIGN OF RESCUE ROBOTIC SYSTEMS FOR GRASPING AND MANIPULATING OF THE WOUNDED

Many factors need to be taken into account when evacuating the wounded from the battlefield Thus, the proposed robotic system should carry out the following actions during evacuation:

- recognition (determining the position and orientation of the wounded relative to the drone),
- positioning/orientation (changing the position and orientation of the wounded to ensure safe manipulation),
- safely grasping the wounded,
- manipulation (transporting the wounded inside the drone),
- immobilisation of the wounded inside the drone,
- emergency assistance.

Each of these actions has its own characteristics, so each is presented separately below.

Recognition

To begin with, the robotic system needs to determine the position and orientation of the wounded in relation to the drone. This is due to the fact that there are many uncertain conditions during rescue operations and the wounded may be positioned close to the landing site or accidentally on the battlefield. The information obtained will influence further algorithms for the grasping and manipulation of the wounded. Modern vision systems are increasingly being used in drones of various types (Figure 19a). Research is also being conducted in the localisation and recognition of wounded people using different perception systems (Figure 19b).

There are a number of possible placement options and algorithms for using the recognition system for a rescue drone:

- the system is placed on the bottom of the drone, which performs recognition and localisation of the wounded, after which the best position for the drone to land is selected from the point of view of the possibility of landing and the optimal path for dragging the wounded to the drone,
- the system is placed along the perimeter of the drone and is put into operation during and after the landing, allowing not only to determine

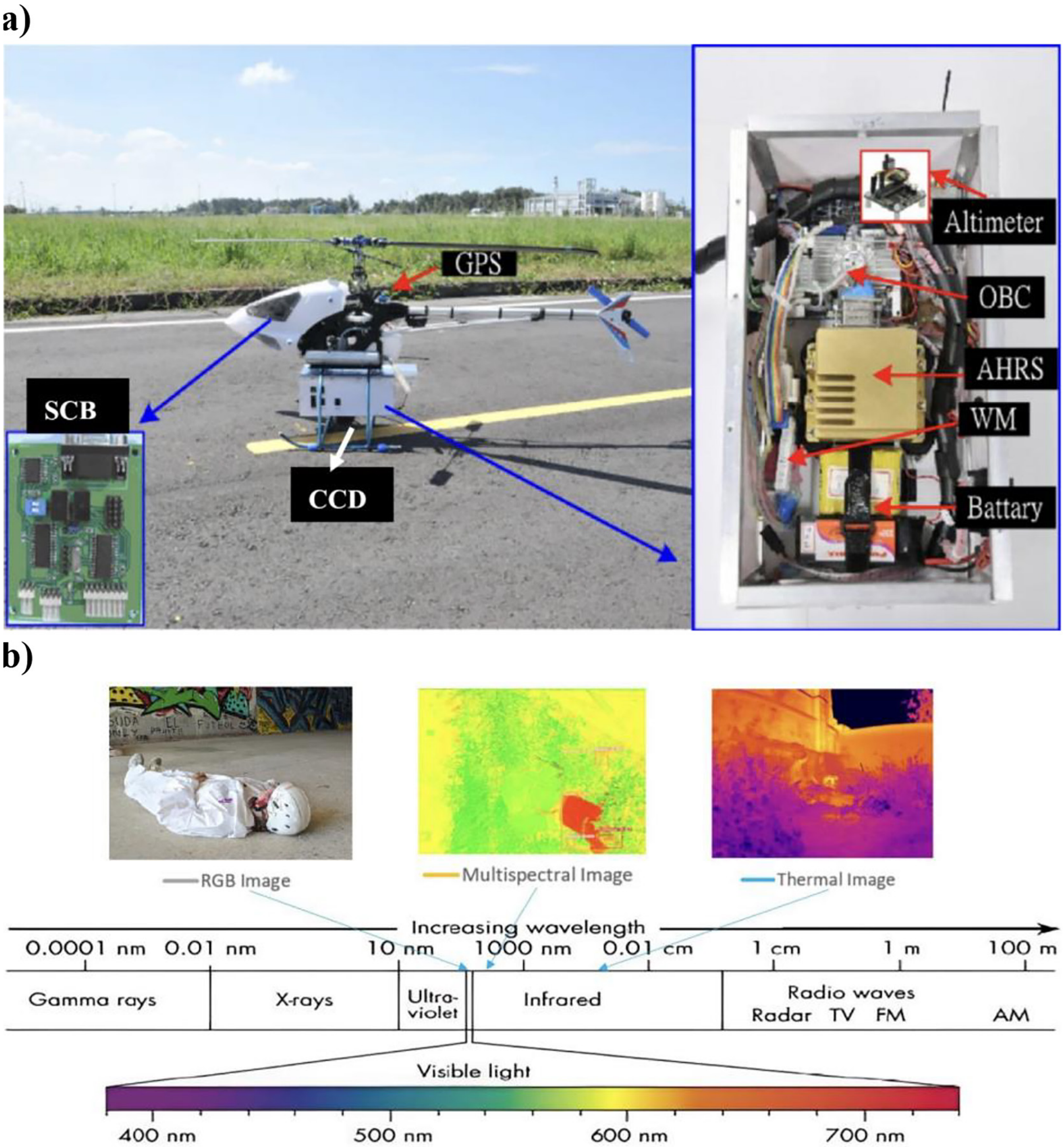

Figure 19. Vision and recognition systems of modern robotic systems: (a) vision system on a helicopter-type drone [101]; (b) multi-vision sensing system for recognising wounded people in a real environment [102]

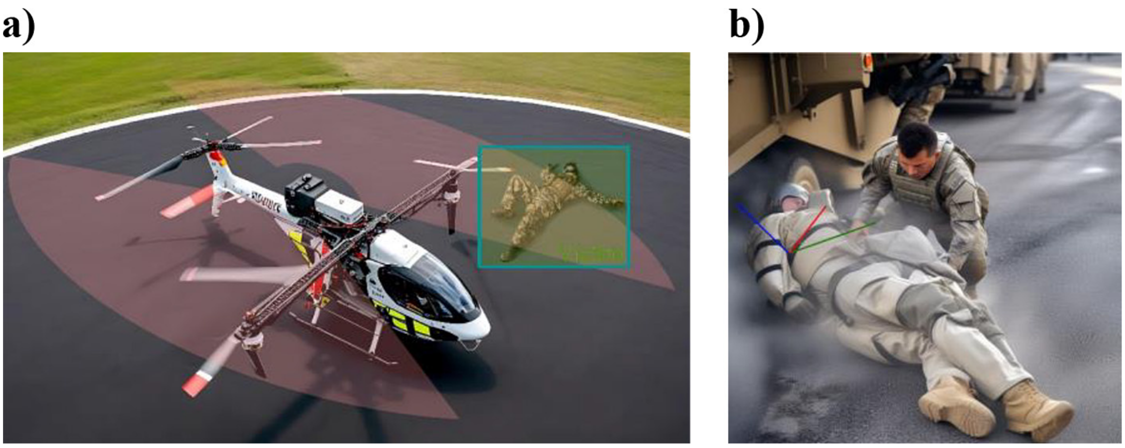

Figure 20. Recognition of the wounded: (a) side vision for identifying the wounded; (b) detection and determination of position and orientation in space

the optimal position of the drone, but also to control the process of manipulation the wounded and his or her immobilisation in the drone (Figure 20).

Positioning/orientation, grasping and manipulation

The repositioning, grasping and manipulation of the wounded person should be considered together as one device is used to perform these tasks. Known designs of rescue mobile robots that perform similar functions include [103]: RoboCue (Figure 21a), Battlefield Extraction Assist Robot (BEAR) (Figure 21b), Robotic Safety Crawler, Valkyrie, REX and others.

Such robots generally have a significant mass to enable lifting, reorienting and transport of wounded people. This is due to the use of electro-mechanical drives to ensure the necessary payload, which requires the use of larger motors (for example, an industrial robot with a payload of 60 kg, the ABB IRB 4600-60, has a mass of 445 kg). In order to provide a lower robot mass and sufficient payload, industrial robots as well as some rescue robots (such as the BEAR shown in Figure 21b) use hydraulic drives. However, the mass of such robots is still quite large, so that they cannot be placed in a drone to evacuate a wounded person. For example, the mass of the BEAR is 227 kg.

With this in mind, the development of a lightweight mobile robot that can perform body positioning/orientation and grasping is extremely relevant for use with drones. Usually, a drone cannot land directly in the shelter or co-linearly to the wounded, so there will always be some distance between the drone and the body that needs to be covered and grasped.

A common practice on the battlefield is for another soldier to drag the wounded on his or her back, so that the body is not lifted completely

a) b)

Figure 21. Mobile rescue robots: (a) RoboCue [104]; (b) Battlefield Extraction Assist Robot [105]

a) b)

Figure 22. Dragging the wounded on the battlefield: (a) by one soldier; (b) by two soldiers

(Figure 22). Zhao et al. [106] propose to carry out manipulation by dragging the wounded by the arm and manipulation by pulling him or her to the ground. Such a decision is only effective for a wounded who is unconscious, as it is important to maintain balance and prevent the wounded from falling over during such pulling.

Therefore, it is proposed to use a cable driving mechanism to perform the drag and not require heavy manipulators. In addition, the following two mobile robot mechanism concepts are proposed to perform the other tasks such as reorienting the body backwards, securing the cable connection to the body and lifting (fixing) the head to ensure safe dragging of the body:
- mobile robot with pneumatic actuators,
- bio-inspired snake robot.

Mobile robot with pneumatic actuators

The concept of a mobile robot with pneumatic actuators is to use soft pneumatic actuators to rotate the body (Figure 23a) and to fix the head while dragging the body (Figure 23b). Additionally, the robot must be equipped with a mechanical gripping device directly connected to the cable to minimise the load on the mechanics of the mobile robot.

The robot's operating algorithm is as follows:
1. The position and orientation of the body is determined by the recognition system. If the body is in the correct orientation (on its back with the head towards the drone), proceed to step 3, otherwise continue with the algorithm.
2. Positioning and orientation of the body is carried out according to the requirements shown in Figure 23a (in a lying position on the back with the head towards the drone) tracking the position with the help of cameras.
3. The head and arms are lifted using soft actuators and the wounded is gripped by a bulletproof vest.
4. The cable is pulled and the wounded head is secured using soft actuators.
5. The body is pulled inside the drone (Figure 23b).

Bio-inspired snake robot

Many researchers are engaged in the development of bio-inspired cable-powered robots [107], with some also focusing on rescue applications [108–110]. Compared to the previous concept, the bio-inspired snake robot has much more flexibility in terms of grasping and manipulation. By equipping the snake with sensor systems [111], the robot can conduct human-robot interactions and interact with unpredictable environments [112]. However, the main drawback of such a system is its complex kinematic and dynamic control. The concept of the bio-inspired snake robot is to use the end effector as a gripper for body armour and subsequent transport (Figure 24a) or

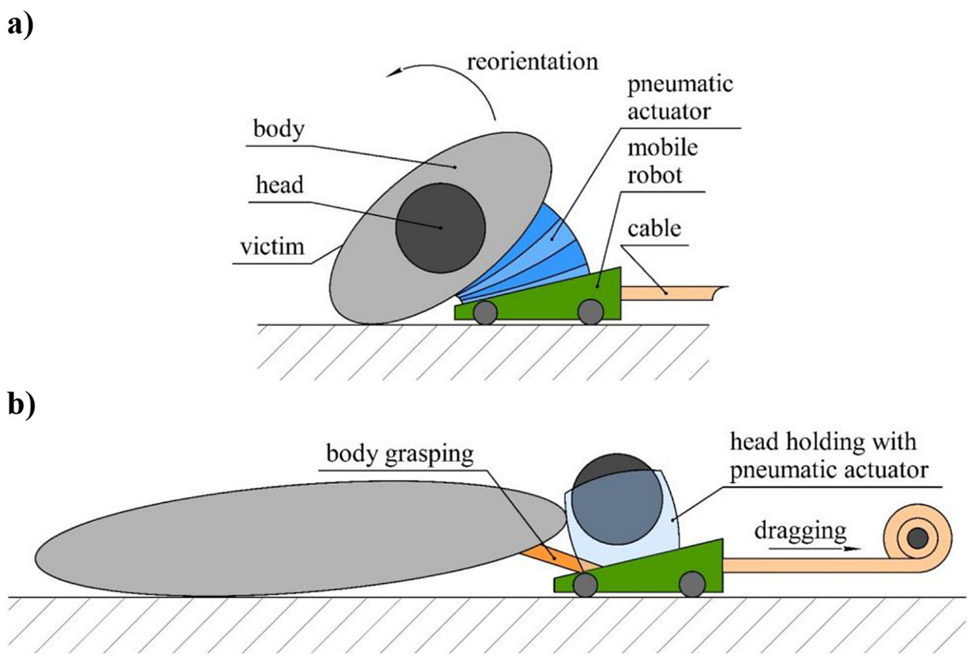

Figure 23. Concept of operation of a mobile robot with pneumatic actuators: (a) body reorientation; (b) grasping and dragging the body into the drone

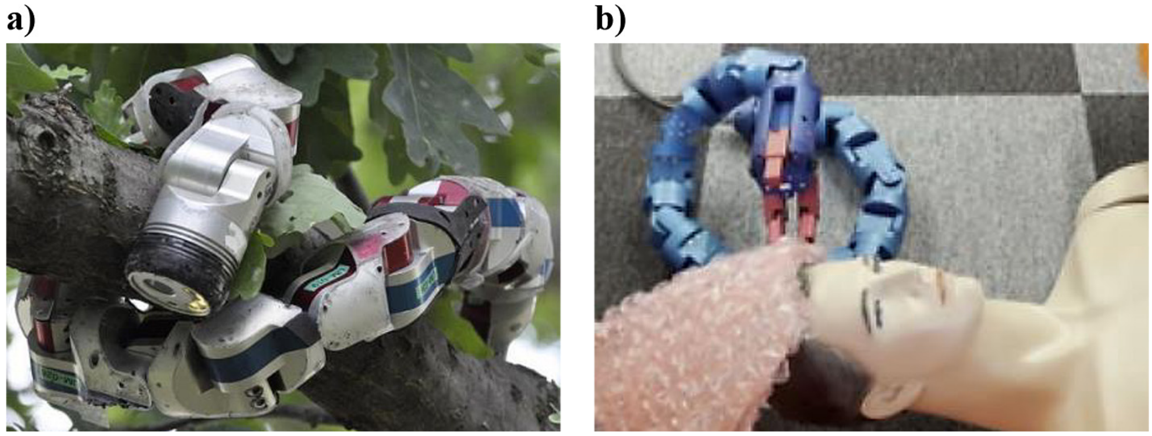

Figure 24. Snake robots: (a) classic design with powerful connections [107]; (b) rescue operation experiments with a gripper module [108]

to use the entire robot body as a holder for the wounded body (Figure 24b). The robot's operating algorithm in this case is as follows:
1. The position and orientation of the body is determined using the recognition system. If the body is in the correct orientation (on its back with the head towards the drone), proceed to steep 3, otherwise continue with the algorithm.
2. Positioning and orientation of the body is carried out according to the requirements (in a lying position on the back with the head towards the drone), tracking the position with the help of cameras.
3. The bulletproof vest is captured and the head is immobilised (Figure 25a) or the body is wrapped (Figure 25b).
4. The body is pulled inside the drone, in the case of wrapping the body (Figure 25b) the head and arms are raised due to the tension of the cable.

After analysing both concepts of a robotic system for positioning/orientation, grasping and manipulation of the wounded, it can be noted that grasping bulletproof vests are required in both cases. However, the current US standards [114, 115] do not specify and implement a grasping system for the wounded. The same situation exists with NATO and other countries standards, where there are only standards for the level of protection, but not for the ergonomic parts. In particular, it should be pointed out that the grasping systems are in desirable locations

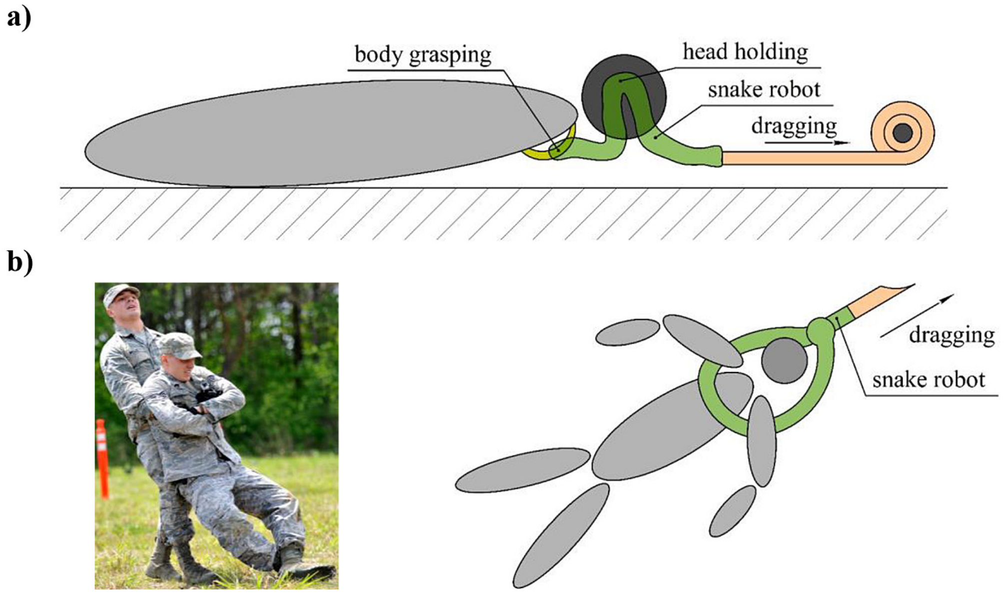

Figure 25. Working concept of a bio-inspired snake mobile robot: (a) grasping behind a bulletproof vest; (b) dragging an wounded person during training [113] and a snake robot imitating grasping under the arms

Figure 26. Different types of bulletproof vests: (a) USA FAS Full Armor System [116]; (b) Ukrainian bulletproof vest [117]; (c) NATO Armor Model 77 vest [118]

on some bulletproof vests (marked in red in Figures 26a and 26b), but not all manufacturers offer them (Figure 26c). This is due to the fact that there is no single standard for all countries, and there are only general recommendations from the National Institute of Justice for the production of bulletproof vests [115]. Therefore, further deployment of robotic rescue systems will require some standards to facilitate the grasping and manipulation of wounded people. However, if such standards are not possible, a more flexible bio-inspired snake robot concept, which will allow a wounded person to be grasped either through a customised bulletproof vest or if other equipment is used, will make sense.

Immobilisation and emergency assistance

As immobilisation and emergency assistance are already carried out on board the drone, the use of this only requires additional equipment. Safety belts are usually used to immobilise the body, and various injections and other tools are used to provide first aid. Therefore, based on the above, it is necessary to place one or two cooperating robot arms inside the drone to interact with the human body. At the same time, the arms should be able to move along the wounded person's body due to linear guides, providing an extension of the robot's working area (Figure 27). Furthermore, in order to ensure the efficiency of the various applications, it is necessary to place an end-effector change system to increase the efficiency of performing the assigned tasks.

Task such as securing the body with safety belts can be executed automatically using the cameras located inside the drone. However, other decisions regarding medical conditions and necessary medical intervention cannot currently be executed automatically, so by providing a general overview of camera-1 and the camera fixed on the robot arm (camera-2), the operator will be able to perform teleoperative applications depending on the situation. Considering the equipment of the robot arm such as the tool, camera, force/torque sensor and automated tool changing system (weighing up to 2 kg), the payload of a single robot arm should be in the range of 3 to 5 kg to ensure the ability to perform all necessary operations.

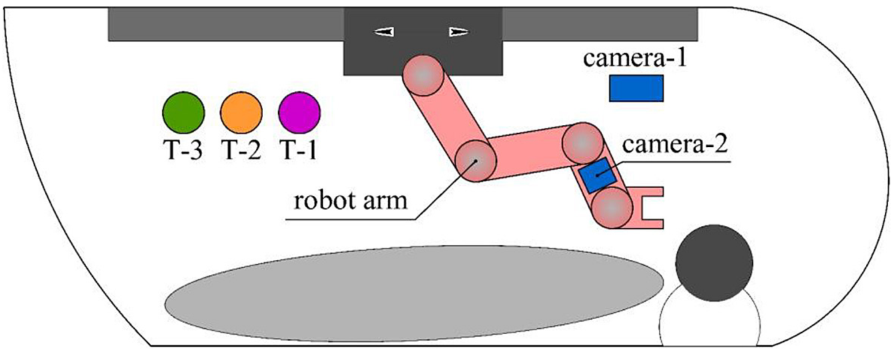

Figure 27. Layout of equipment inside the drone (T1, T2, T3 – tools)

CONCLUSIONS

The fundamental objective of the review presented in this paper was to describe a certain aspects of a drone concept for wounded transport. The knowledge gathered is to be used to put the proposed drone into service in the near future.

With reference to the medical drone concept described above and summarising the review of the state of the art carried out, the following conclusions can be drawn:

1. The review identifies drones as a feasible solution for medical evacuation in challenging conditions, particularly where traditional helicopter evacuation may face limitations due to enemy air superiority or other threats. The smaller size of drones and their unmanned operation potentially reduce both risk and costs.
2. Although technical and medical issues are priorities, the successful implementation of a drone for medical transport also requires addressing legal, ethical and medical standards. Balancing these interdisciplinary challenges will be crucial to the operationalisation the drone.
3. Current UAVs based on helicopter designs are associated with high costs, both in terms of construction and operation. Additionally, alternative designs, such as ventilator-based drones, have difficulties with stability in windy conditions, indicating that these options may not be suitable for reliable medical transport.
4. Concepts such as the Beccarii model, which integrates the capabilities of flying, driving, swimming and vertical take-off and landing, offer promising opportunities for versatile emergency response solutions. Some of the technological elements from such designs, like the tracked chassis, could be adapted to enhance rescue drones.
5. The proposed drone utilises a tandem-rotorcraft helicopter layout with side rotors to enable stable horizontal positioning of the wounded. This layout also allows for simplified power transmission, independent rotor control and enhanced stability – all key to safe medical evacuation.
6. The drone concept includes modular components, such as a patient loading system and an on-board medical robot, which can be developed independently. This modularity allows flexibility, upgrades and integration of new technologies over time, streamlining both development and implementation.
7. The drone design is in line with the broader concept of VTOL vehicles for transporting people and goods in urban environments. This overlap suggests a possible dual use of the drone outside of a military or emergency contexts, contributing to both humanitarian and commercial applications.
8. Of the robots used in medicine, only active and teleoperative systems could have a potential application in the rescue drone concept. However, given the mass of existing robotic systems, there is no concrete model that can be directly implemented.
9. Various positioning and algorithmic options can be used to utilise the recognition system in a rescue drone. At the same time, the ability to simultaneously reposition, grasp and manipulate victims is essential. The use of a cable driving mechanism to drag victims on their backs, modelled on the current technique of dragging a wounded soldier by another soldier, will eliminate the need for heavy manipulators. To realise the reorientation of the body, the safe connection of the cable and the lifting of the wounded person's head to ensure safe dragging, a mobile robot with pneumatic actuators and bio-inspired snake robot can be proposed.
10. The implementation of robotic rescue systems requires the introduction of specific bulletproof vest standards to facilitate the grasping and manipulation of victims.
11. The addition of a cooperative robotic arm is required for onboarding and emergency assistance on the drone. Positioned in the middle of the drone, the arm should be capable of interacting with the human body through, for example, linear guides to allow movement along the victim's body. Automatic body restraint using safety belts can be performed by on-board cameras, but decisions regarding the victim's condition will require operator intervention.
12. The required payload of the cooperative robotic arm should be set at 3 to 5 kg, which is sufficient for all applications, even if the combined weight of the tool, camera, force/torque sensor and automated tool changing system reaches 2 kg.

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