SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 215

DRONE SWARMS – AS AN INNOVATIVE TOOL TO CARRY OUT IRREGULAR WARFARE

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Purpose: The main purpose of the article is to analyze the possibilities of using drone swarms as an innovative battlefield tool.
Design/methodology/approach: The research includes simulation methods by using computer simulation methods based on the so-called random walk – Brownian motion and Brownian bridge.
Findings: The research shows that the innovative use of drone swarms will further increase the possibility of using them in an asymmetrical conflict. Particularly important is the cheapness of the presented solution, the possibility of using it after only a short training and the option to perform an earlier simulation of the effects of the drone swarms application by people with an average level of IT knowledge.
Research limitations/implications: The study focused on analyzing the possibilities of using simulation methods to manage innovative drone swarms exclusively for military purposes and the possibilities of using such solutions. According to the authors, the research should be carried out in other areas of social life.
Practical implications: In the era of Industry 4.0, which is based on digitization and robotization, it will be possible to increasingly use solutions that make use of artificial intelligence (AI) on the battlefield, such as the application of innovative drone swarms.
Originality/value: The presented solution is based on innovations in various areas, it can be stated that this type of drone application is an open innovation and can be developed by both military and civilian companies.
Keywords: open innovation; national security; drones; Industry 4.0; warfare; Brownian motions.
Category of the paper: Research paper.

1. Introduction

Currently, new innovative solutions in military technology are increasingly appearing, the use of which may lead to the improvement of the functioning of an army on the modern battlefield. One of such modern innovative solutions is the use of drones for military applications (Li et al., 2022; Rozmirez-Montoya et al., 2022). The issue of innovation is important for the development of the contemporary military industry because as a result of the use of innovations, including open innovations, the effectiveness of technical solutions used in the military can be significantly improved (Sloane, 2011; Gajdzik, Wolniak, 2021, 2022; Lee et al., 2018, Bober et al., 2017). Such solutions are in line with the contemporary trends in the implementation of the so-called Industry 4.0 concept, which is based, inter alia, on digitization, robotization and application of artificial intelligence (Olkiewicz et al., 2019; Drozd, Wolniak, 2021). The innovative use of drones presented in this publication is an example of this. In the literature, there are currently three parallel terms related to the subject of drones: (UE, 2019) unmanned aerial vehicle (UAV) (Tice, 2009), unmanned aerial system (UAS) and the most popular – drone. All of these terms refer to an aircraft that does not require a flight crew on board and is not able to board passengers (Fowler, 2014). The aircraft is remotely piloted (guided by a pilot that does not have to see the drone) or performs the flight autonomously (by itself, using the autopilot or other system on-board). In addition, the term unmanned aerial system refers to a system comprising several components. The components include a drone, a control system, a telecommunication link to pilot the drone and the drone's equipment (Aroosa, 2021; Fairehead, 2021).

Soon, wars could be fought without the participation of humans. Intelligent drones will start to appear on the battlefields, and other autonomous machines will join them (Johnson, 2019; Hallaq et al., 2017). Such innovations in the military constitute a revolution on the modern battlefield, changing many aspects of the warfare, especially in the case of asymmetric conflicts, where one of the sides is weaker in terms of conventional military (Bousquet, 2017; Boyle, 2015; Mack, 1975; Jacob, 2017; Yun, Liu, 2019). The issue of asymmetric wars is important because contemporary armed conflicts are usually of this nature (Cianciara, 2021).

The ongoing war in Ukraine and the previous conflicts of recent years have proven that drones are becoming increasingly used equipment on the battlefield (Byman, 2013). They have been an effective weapon against military units armed with Russian equipment in the past. They got a lot of publicity during the clashes over the Nagorno-Karabakh region between the armed forces of Azerbaijan and Armenia in the fall of 2020 (Rauch, 2021). It needs to be emphasized that the former one was largely modernized by Turkey in an ongoing process since the 1990s. This cooperation has intensified over the next years. Drones, in particular, achieve good results in asymmetric warfare, where one side has a major military advantage (Wolfendale, 2021; Jeangène, 2023).

Drones have also been used by guerrilla groups in recent years. It was probably the Syrian guerrilla who was behind the spectacular attack on Russian military bases in that country (Baggiarini, Rupka, 2020; Malaviya, 2020). The operation was carried out by a swarm of drones, which were programmed with specific targets along with the GPS data, thus they were autonomous. Some of the drones attacked a Russian support vessel. The attack was mostly prevented. The Saudis, however, failed to prevent the attack of 10-25 drones carried out by the Yemen rebels aimed at one of Saudi's largest oil refineries (Johnson, 2020; Behnke, 2020). The anti-aircraft defence system was ineffective due to the low flight path and numerous angles of attack. The operation resulted in a massive fire at this oil installation (Ruschi, 2020; Gusterson, 2019).

Drones are capable of destroying ground targets no worse than bombers. At the same time, being much more precise. Contemporary combat drones are becoming an increasingly important component of weaponry (Bauer et al, 2022).

In order not to waste the potential of the purchased combat drones and the taxpayers' money, the army has to combine innovative technology and new tactics. The drone swarms tactic, in particular, has great potential in terms of innovation (Bergen, Sims, 2021).

The analysis of the respected literature (Fowler, 2014; Aroosa, 2021; Fairehead, 2021; Borg, 2021; Antebi, 2016; Dekel et al., 2017; Benjamin, 2013; Kostenko et al., 2022; Schilling, 2022; Ragab et al., 2022; Soria et al., 2022; Iacovelli, Grieco, 2021) indicates a research gap concerning the use of drones on the contemporary battlefield, in particular regarding the so-called drone swarms. There are publications on drone swarms and drone swarms management, but there are no detailed publications on the military use of this innovation. Swarms of drones can be used in search operations, transport networks or monitoring. The point is for the swarm to not only control its surroundings but also itself and should not need an operator (Kostenko et al., 2022; Schilling, 2022; Ragab et al., 2022; Soria et al., 2022; Iacovelli, Grieco, 2021). It is also possible to use them for military purposes. From the military standpoint, a swarm is an autonomous, interconnected group of small unmanned aerial systems that are working together to achieve a shared objective with the operator on or in the loop. Coordination and responsiveness are what distinguish between a real swarm and the employment of the drones en masse. The latter occurs when a large number of drones are used against a single target, mainly to incapacitate it by overpowering its defences (Gagaridis, 2022).

In particular, no studies focusing on the analysis of the possibility of using simulation methods to manage innovative drone swarms for military purposes were found. This publication tries to fill in this gap by examining the options of employing such innovative solutions in the armed forces.

The objective of this publication is to analyse the possibilities of using drone swarms as an innovative battlefield tool.

The research includes simulation methods by using computer simulation methods based on the so-called random walk – Brownian motion and Brownian bridge. A detailed description of this method can be found in the methodological part of this publication.

2. Literature Review

Until recently, the military had a monopoly on drones and was using them in military operations. They were employed for surveillance, reconnaissance and precision attacks. Drones have become one of the symbols of the fight against global terrorism (Vanžura, 2021; Norris, 2020).

Currently, drones are used by civilians for both professional/commercial purposes (i.e. monitoring places with difficult access, filming important events) and private ones (i.e. bought for children for their first communion and used as toys) (Rahmani, 2020; Gregory, 2020).

Drones are getting smaller in size and cheaper without losing their basic features, which are used by the military (see tables 1-5) (Schulte, 2019; Jones et al., 2019; Gray, 2018). The most important features of modern drones include a live view and a "return to home" option where the default location of the return of the machine can be activated after giving it an appropriate command, mapping the route by using GPS point positioning (Davis, 2022; Gordon et al., 2021).

Table 1.
NATO UAVs Classification 2009

Class	Application
Class I weight: < 150 kg;	Employment: a tactical support unit at a team, platoon or company level; flight time: up to 6h
Class II weight: 150-600 kg;	Employment: a tactical support unit at a battalion or brigade level; flight time: up to 24h
Class III weight: > 600 kg;	Employment: an operational and strategic unit; flight time: up to 40h; important information: high operating altitude (>3000m)

Source: based on: https://pl.wikipedia.org/wiki/Bezzałogowy_statek_powietrzny, 21.03.2024.

Table 2.
UAVs Classification based on the weight

Designation	Weight	Example of UAV
Super heavy	>2000 kg	RQ-4 Global Hawk
Heavy	200-2000 kg	A-160
Medium	50-200 kg	Raven
Light	5-50 kg	RPO Midget
Micro	<5 kg	Dragon Eye

Source: based on: https://pl.wikipedia.org/wiki/Bezzałogowy_statek_powietrzny, 21.03.2024.

Table 3.
UAVs Classification based on the maximum altitude above the sea level

Category	Maximum altitude above the sea level	Example of UAV
Low	< 1000 m	Pointer
Medium	1000-10000 m	Finder
High	> 10000 m	Darkstar

Source: based on https://pl.wikipedia.org/wiki/Bezzałogowy_statek_powietrzny, 21.03.2024.

Table 4.
UAVs Classification based on the application

Category	Application (main objectives)	System name and type
Objective and decoy	Air targer simulation for artillery and rocket shooting	Cele Voodoo, Banshee (firmy Meggitt Defense Systems)
Reconnaissance	Performing reonnaissance on the battlefield	RQ-1 Predator
Combat	Used to attack selected targets	Schiebel S-100 Camcopter, MQ-9 Reaper (Predator B)
Logistic	Used for load handling and other battlefield protection purposes	AirMule (Urban Aeronautics)
Research	Testing new aerodynamics and electronic technologies and solutions	Altair UAV (General Atomics Aeronautical Systems)
Civil and commercial	Performing civil and commercial tasks (monitoring stadiums, boarders, streets)	Eagle Eye (Bell) – US boarder guard, Fulmar (Aerovision) – search for tuna schools

Source: based on Burdziakowski, 2011, pp. 15-20.

Table 5.
UAVs Classification based on UVSI (Unmanned Vehicle Systems International)

Class	Radius	Flight time	Altitude
Nano	1 km	10 min	100 m
Micro	10 km	60 min	150 m
Mini	10 km	120 min	300 m
Close range	30 km	4 h	3000 m
Short range	70 km	6 h	3000 m
Medium range	200 km	10 h	5000 m
Medium altitude long endurance (Male)	>500 km	24 h	13 km
High altitudelong endurance (Hale)	2000 km	>24 h	20 km

Source: based on Borkowski, Łach, Zwierzyna, 2018, pp. 115-130.

In Poland, the latest document regulating the movement of drones is the Notice of the Minister of Infrastructure of July 3, 2009, on the publication of a uniform text of the Regulation of the Minister of Transport, Construction and Maritime Economy on the exclusion of the application of certain provisions of the Act – Aviation Law to certain types of aircraft and determining the conditions and requirements for the use of such aircraft[1]. In addition, the notice of the Marshal of the Sejm of the Republic of Poland on July 19, 2019, on the publication of the uniform text of the Act is also in force – Aviation Law[2]. Moreover, Poland, as an EU member, respects and has implemented EU regulations containing new rules for the use of drones in the EU (UE, 2019/497; UE, 2019/495; UE, 2019/947; UE, 2020/639). Initially, these provisions were to apply throughout the EU from July 1, 2020, but due to the global pandemic the date was postponed to December 31, 2020 (UE, 2020/1058; UE, 2020/746). The European Aviation Safety Agency (EASA) has developed common European rules to ensure the free movement of drones and a level playing field for all operators of the unmanned aerial vehicle systems within the EU. They will allow the UAV operators (the operator of the UAV is any legal or natural person using or intending to use one or more UAVs) to perform drone operations across the EU without any difficulties. These rules rely on the assessment of the risk of

[1] http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190001497, 21.03.2024.
[2] http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190001580, 21.03.2024.

operating drones and ensure a balance between the obligations of the drone manufacturers and operators in terms of safety, respect for privacy, the environment, and protection against noise and safety. In Polish and European law, there is no longer a division into drone flights "for recreational and sports purposes" and "for purposes other than recreational and sports". Therefore, there is no distinction between "commercial" flights and other "recreational and sports" flights. In Polish law, there is a division into operations performed with the use of UAVs in the visual line of sight (VLOS), beyond the visual line of sight (BVLOS) and in the first-person view (FPV). Of course, the EU law does not resign from the above-mentioned distinction performed by the UAV pilots, however, the main division is related to the risks posed by flights in each category for people on the ground and other airspace users (UE, 2019/945). This division distinguishes three categories:

1. Open Category (also includes three additional flight subcategories: A1, A2, and A3) – the VLOS operations do not require an approval/authorization, the drone mass has to be less than 25 kg and the drones cannot be operated above 120 m (or an obstacle taller than 120 m), where the risk to a third party is close to zero.
2. Specific Category – the VLOS/BVLOS operations have to be performed with a declaration to comply with the standard scenarios or apply for an operational authorization due to the higher risk for third parties in comparison with the Open Category.
3. Certified Category – includes VLOS/BVLOS operations that require UAS certification under Delegated Regulation (EU) 2019/945 and operator certification.

In addition to the division into the types of operations in terms of risk and the sufficient distance from people, the European Commission also introduced a division of drones into classes from C0 to C4 based on the following criteria:

1. C0 (C0 drones can fly in all subcategories of the Open Category) – drones under 250 g and a maximum flight speed of less than 19 m/s with a flight altitude limited to a maximum of 120 m.
2. C1 (C0 drones can fly in all subcategories of the Open Category – A1, A2, A3) – drones under 900 g or ones that generate kinetic energy below 80 J on impact with a human, with a maximum flight speed of less than 19 m/s and a flight altitude limited to a maximum of 120 m.
3. C2 (C2 drones can fly in the subcategories A2 (close to people, minimum 5 m to 30 m) and A3 (no flight over uninvolved people) of the Open Category) – drones under 4 kg that has a free flight mode activated from the apparatus and a limited speed to 3 m/s horizontally, with the flight altitude limited to a maximum of 120 m.
4. C3 (C3 drones are limited to the A3 subcategory (no flight over uninvolved people) of the Open Category – drones under 25 kg that can fly in various automatic modes and have a flight altitude limited to 120 m.

5. C4 (C4 drones are limited only to the A3 subcategory (no flight over uninvolved people) of the Open Category – drones under 25 kg that have no automatic modes apart from the standard flight stabilization.

Europe-wide Standard Scenarios (STS) have been developed for the specific category that allows VLOS and BVLOS flights over a controlled ground area in a populated environment at a maximum altitude of 120 m. For this category, the division into the C5 (VLOS flights, STS- 01 scenario) and C6 class identification labels (BVLOS flights, STS-02 scenario) has also been introduced. In addition, in Poland, the operator can declare to perform operations according to the National Standard Scenario (NSTS – declaration to the NSTS can be submitted until December 2, 2023, and the declaration is valid for 2 years), which has been described in the Guidelines of the President of the Civil Aviation Authority No15-23 (NSTS-01 – NSTA-09).

The Polish legislation precisely regulates the issues related to the civil use of UAVs, and the Civil Aviation Authority is responsible for governing the process of obtaining appropriate qualifications. The registration of operators should be made at the following web address: https://drony.ulc.gov.pl/. Every person operating a drone should register. The registration does not apply only to people who own drones under 250 g with no camera (or other data recording equipment) or toy drones under the EU Directive 2009/48/W.

In addition, every drone operator should coordinate the flight with the Polish Air Navigation Services Agency (PANSA) before performing a flight (PANASA, 2019) and know the Flight Information Region in which the flight is to be performed (Aspoland, 2024).

Therefore, it is time-consuming, expensive and requires extensive knowledge from the operator to obtain the appropriate qualifications. The big question is whether such knowledge and skills supported by appropriate qualifications and certificates are necessary when executing offensive actions during a hybrid war? (Nikitha et al., 2022; Rawat et al., 2021).

The four terrorist attacks of September 11, 2001, proved that in such activities only effectiveness is important and that knowledge and qualifications confirmed by certificates are redundant (Yan, 2020; Li et al., 2019).

3. Methodology

Methods based on simulation techniques, in particular, a random walk (Brownian motion, Brownian bridge) were used to analyze the data on the innovative use of drones on the battlefield in the form of a drone field.

A random walk is a mathematical and physical concept. It determines the random movement of a "particle", wherein successive movements of time the "particle" moves from its current position to another, randomly chosen one. A random walk is therefore an example of a simple stochastic process, and Brownian motion is an example of it (Delsaulx, 2018; Xie, He, 2022; Bernstein et al., 2022). They directly relate to the chaotic movements of particles in a fluid – all particles move at the same time in different directions and different speeds. A mathematical model of the physical phenomenon of Brownian motion is the Wiener process, which was used to model and simulate one of the stages of the movement of a drone swarm (Xu, Cheng, 2022; Lu, Zhou, 2022).

Definition of the process (Karatsas, Shreve, 1997; Papoulis, 1991):

We call the Wiener process (Brownian motion) a stochastic process
$W = (W_t)_{t \geq 0}$ such that
$W_0 = 0$ almost certainly;
W has independent increments, i.e. for all $0 \leq t_1 \leq t_2 \leq \cdots \leq t_k$ the random variables $W_{t_1}, W_{t_2} - W_{t_1}, W_{t_3} - W_{t_2}, \cdots, W_{t_k} - W_{t_{k-1}}$ are independent;
the variable $W_t - W_s$ is normally distributed $\mathcal{N}(0, \sqrt{t-s})$ for all $0 \leq s \leq t$;
the trajectories W are continuous with probability 1.

The Wiener process in the innovative modelling of a swarm took place in a three-dimensional space. This means that each of the drones included in the swarm will move randomly on an XYZ axis. The reflection principle for the Wiener process was applied in the middle phase of the swarm's flight (in stochastic analysis, the assertion that if the path of a Wiener process f(t) reaches a value f(s) = a, then 2a – f(t) (t) > a) is also a path of a certain implementation of a Wiener process; the reflection principle can be derived from the strong Markov property of the Wiener process), which allowed determining a "safe corridor" of the swarm's passage (variable Z). In the corridor, the drones continued to change their position randomly and without any restrictions in relation to the XY coordinates.

In the last stage of the innovative method of drone traffic modelling, it was assumed that the drones have to ultimately reach the target, meaning to reach the appropriate point in the airspace while keeping a random walk until the end. The so-called Brownian bridge (Latała, 2011; Franke et al., 2022; Es-Sebaiy et al., 2021) was used for this purpose. The Brownian bridge, like the Wiener process, is a Gaussian process.

Definition of the process:

For each finite set of indicates $t_1, t_2, \cdots, t_n \in T$ the random variable $(X_{t_1}, X_{t_2}, \cdots, W_{t_n})$ has a normal distribution.

The Brownian bridge is a Gaussian process {X_t }_(t∈|0,1|) with continuous trajectories such that EX_t=0 and Cov(X_(t_1),X_(t_2))=t_1 (1-t_2) for t_1≤t_2. This means that it is enough to condition the Wiener process at t=1-W1=0. Then the two extreme points of time in the process become the "pillars of the bridge" to which the Wiener process is attached to.

In order to make calculations enabling the innovative use of drone swarms on a battlefield, the following assumptions were made in the field of simulation and the modelling process.

1. The simulation – initial conditions:
   - Take-off of 100 drones from the same point – central point (X, Y, Z) = (0; 0; 0).
   - Use of light drones – maximum working load 0,5 kg.
   - Simulation area – 2,8 km2 (the 1st and 4th quadrants of the coordinate system – 1.4 km^2).
   - Simulation time T = 200*t, t = 10 s [t = 2000 s ≈ 34 min].
   - Implementation of the stochastic process – Brownian motion and Brownian Bridge.
   - Drones move autonomously.
   - Drones do not know their targets at the time of take-off.
   - Drones are randomly organized into subgroups.
   - Target – two objects of strategic importance for the aggressor.
2. The simulation: phase one – "wandering" of the swarm:
   - Phase duration: ti ∊ [1;100].
   - Dispersion of the swarm by using a random walk – Brownian motion.
   - Evaluation of the dynamics of the swarm's movement – determining the direction and force of the swarm's dispersion (coordinates: X [m] and Y [m]).
   - Evaluation of the dynamics of reaching a safe corridor by the swarm movement (coordinate Z [m]).
   - Evaluation of a safe corridor for a swarm movement at the height of Z ∊ (80; 100) m.
3. Recognition of two phases of achieving the appropriate height of the swarm:
   - A rapid increase of the swarm's height – Brownian motion.
   - Keeping the swarm in a safe corridor – Brownian motion, the reflection principle for the Wiener process.
   - The simulation: phase two – attack.
   - Phase duration: ti ∊.
   - The drones are randomly divided into two groups.
4. All the drones belonging to a given group have a common end point:
   - group 1: (X, Y, Z) = (940; 460; 0),
   - group 2: (X, Y, Z) = (20; -500; 0).
   - Drones are to reach the designated target by using a random walk – Brownian bridge.
   - The drones are in a safe corridor until ti = 190, then there is a rapid and controlled loss of altitude to the point Z (200) = 0 - the proper phase of the attack.

4. Results

According to the provisions adopted in the research methodology, appropriate calculations were made to analyse the behaviour of innovative drone swarms on the battlefield.

Figures 1-5 comprehensively present the two phases of the attack. The first phase is a stage of the "swarm's wandering". The second phase shows the "random swarm division" and a random walk of the swarm toward the target points. The whole action lasted for about 34 minutes under the simulation assumptions (2000 seconds). There was no contact between the drones and the operator/base at any stage of the simulation.

In the second phase, it is seen that the swarm divides into two groups after it receives information about its targets. The first group consisted of 52 drones and maintained its flight direction. The second group of 48 drones had to make a significant correction of the flight direction to reach their objective.

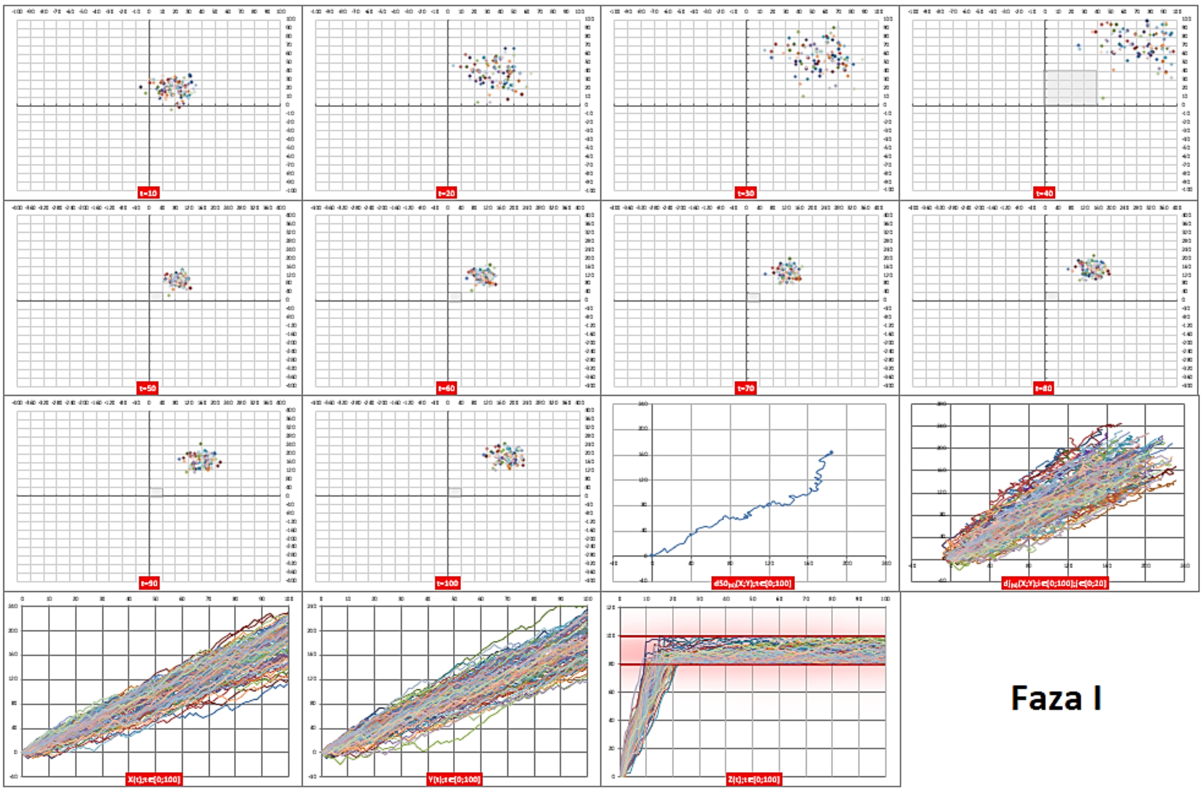

Figure 1. The summary of phase I.

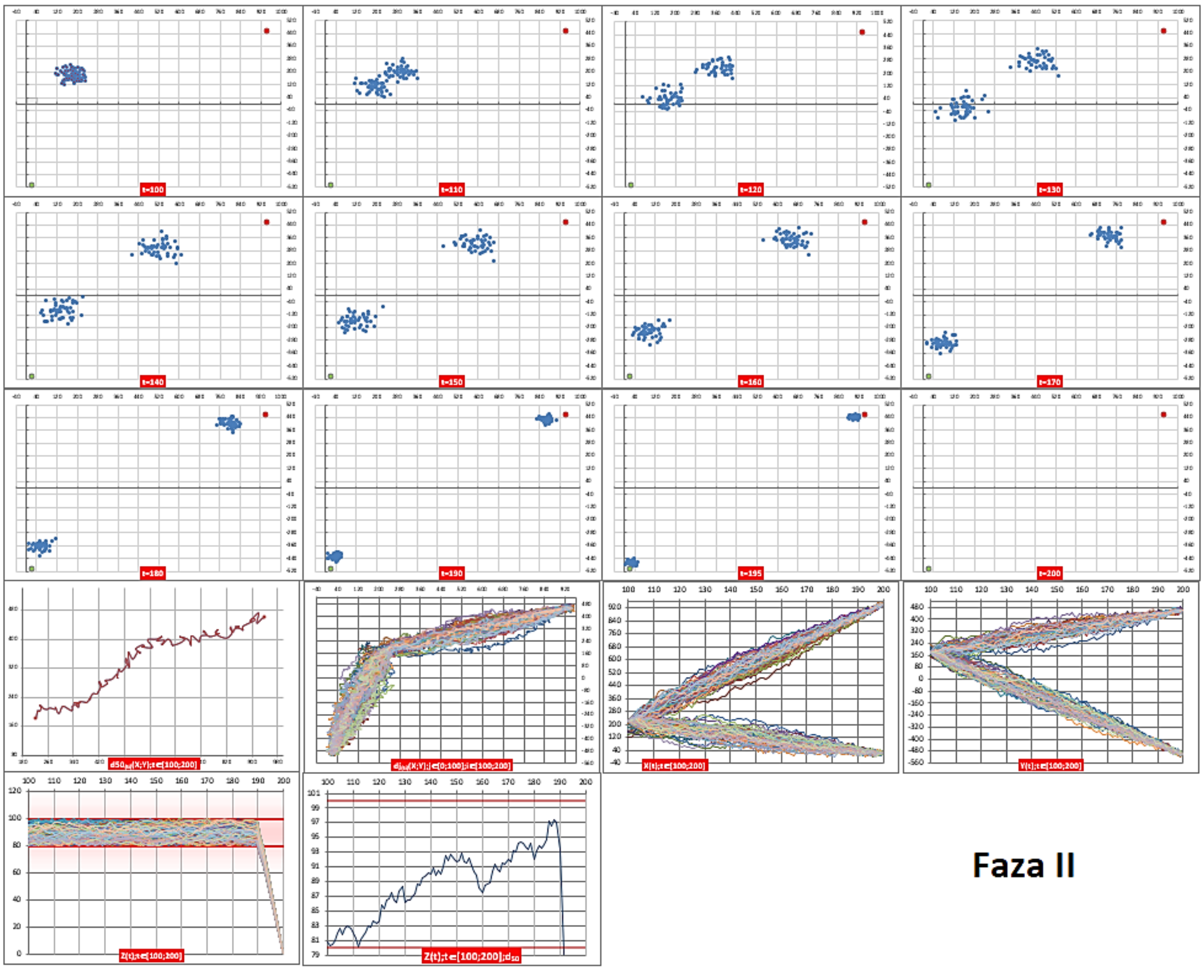

Figure 2. The summary of phase II - a comprehensive coverage.

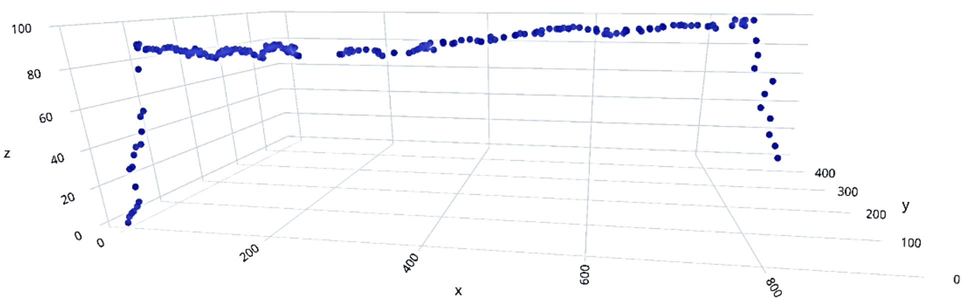

Figure 3. The complete path of a drone showing the movement from take-off to reaching the target - drone no 50.

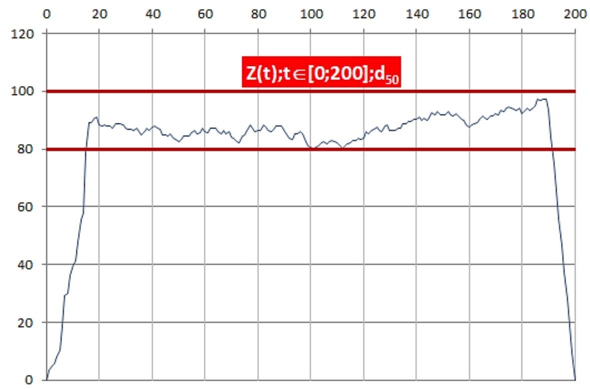

Figure 4. The complete path of a drone showing its movement from take-off to reaching the target with the visualization of a random walk in a safe corridor.

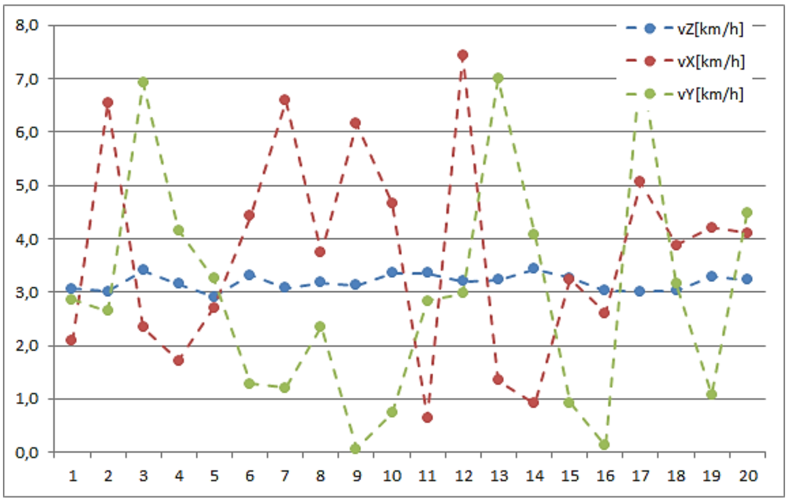

Figure 5. Drones speeds at different levels in the final phase of the attack.

5. Discussion

The innovative capabilities of employing drones operating in a swarm confirm the current results of the use of single drones on the battlefield. Starting from the early research of Benjamin (Benjamin, 2013) to the new research on drones of Antebi (Antebi, 2017) and Borg (Borg, 2021), attention was drawn to the particular use of UAVs in the case of the so-called asymmetrical battlefield. The research discussed in this publication shows that the innovative use of drone swarms will further increase the possibility of employing them in asymmetrical conflict. The innovative solution complies with the requirements of the modern asymmetric battlefield presented by Mack (Mack, 2021), Jacob (Jacob, 2017) and Ciancia (Ciancia, 2012).

It is particularly important to combine the cheapness of the presented solution with the possibility of using it after undergoing a short training and performing an earlier simulation of the effects of the employment of a drone swarm by people having average IT knowledge.

Due to the fact of combining innovations from various areas within the proposed solution, it can be stated that this kind of drone use can be considered an open innovation and can be developed by both the military and civil companies (Ingrassia et al., 2022; Yun, Liu, 2019; Es-Sebaiy et al., 2021; Cooke et al., 2022).

The open innovation character of this solution is evident by the possibility of improving it by the use of the free R software (Alam Khan et al., 2022; Valdez-Juárez et al., 2022).

Currently, you do not have to be an advanced programmer or a mathematician to be able to program. Many ready-made solutions to mathematical problems can be found on the internet, which considers the diversity of programming languages. All it takes is to choose the best solution and adapt it to one's own needs if necessary. Two solutions based on the R language, which was used for modelling and creating the simulation, are presented below. It is possible to improve the proposed solutions thanks to their open innovation character (Naqshbandi, Jasimuddin, 2022).

An example of a function in the R language responsible for the Brownian motion (RDRR)

```
BM <- function(x=0, t0=0, T=1, N=100){
 if(T<= t0) stop("wrong times")
 dt <- (T-t0)/N
 t <- seq(t0,T, length=N+1)
 X <- ts(cumsum(c(x,rnorm(N)*sqrt(dt))),start=t0, deltat=dt)
 return(invisible(X))
}
```

An example of a function in the R language – Brownian bridge (RDRR)

```
BBridge <- function(x=0, y=0, t0=0, T=1, N=100){
 if(T<= t0) stop("wrong times")
 dt <- (T-t0)/N
 t <- seq(t0, T, length=N+1)
 X <- c(0,cumsum( rnorm(N)*sqrt(dt)))
 BB <- x + X - (t-t0)/(T-t0)*(X[N+1]-y+x)
 X <- ts(BB, start=t0,deltat=dt)
 return(invisible(X))
}
```

Currently, the employment of drones does not require a GPS and the physical presence of an operator in the area of operation. All of these characteristics make it possible to destroy or damage more than just military infrastructure. Such activities may focus on logistics, communication, command, critical infrastructure, weapons and military equipment (Baggiarini, Rupka, 2020; Malaviya, 2020; Ruschi, 2020).

According to the authors of this publication, the fact that the innovative solution presented in the simulation is based on a random phenomenon makes this form of attack resistant to drone detection and neutralization (Gao et al., 2022; Mei, Shao, 2016). The possibility of carrying out various attack simulations by using commonly available tools makes this solution an open innovation (Dixit et al., 2022; Ibarra et al., 2017; Amabile, 1996; Lekan et al., 2021).

The innovativeness of the presented solutions and their open character make it possible to use them in a variety of ways with high efficiency (Hizam-Hanafiah, Soomro, 2021; Orzeł, Wolniak, 2022; Olkiewicz et al., 2021).

The popularization, miniaturization, ease of use, and advanced technology of drones are not ignored by the military. At the end of 2017, the Royal Australian Air Force (RAAF) clearly identified in a report the threat resulting from the use of small UAVs – experts are mainly concerned about the development of unmanned micro-devices that can operate without the GPS and find and destroy small targets (Matsatsinis, Marinakis, 2021; Kumari et al., 2020; Krakowski, 2020; Agwu, 2017; Miranda et al., 2020; Zaidi et al., 2022; Saebi, Foss, 2015; Patrucco et al., 2022)[3].

6. Conclusions

Based on the simulation of the innovative use of a drone swarm, the following conclusions were obtained:

1. The size of a swarm depends on the "budget".
2. Each drone operates independently from the rest.
3. The drone does not have to be in contact with an operator (uploading a complete program to the drone's memory).
4. The "swarm" can be divided into any number of subgroups – each subgroup can carry out different tasks or objectives.
5. Acceptability of a high percentage of failures (shooting UAV by appropriate detection and defence systems).
6. Lack of detectability of the attack (employment of small drones and the randomness of their movement makes it impossible to predict the trajectory of the target).
7. The unpredictability of the drone's movements (the next position of the drone is not conditioned by its previous position).
8. Resistance of the "swarm" to interference (no channel of communication between the drones themselves and the drones and the operator).

[3] https://www.aspistrategist.org.au/39608-2/, 21.03.2024); https://pl.sputniknews.com/20180531/ Sputnik-bezpieczenstwo-swiat -technologie-drony-8074395.html, 21.03.2024.

The obtained results prove the existence of substantial possibilities for using innovative swarms of drones on the modern battlefield. The presented solution is very innovative in a way it combines a relatively low cost and ease of use with innovative effects that are impossible to achieve in any other way.

The simulation clearly showed that the innovative use of small UAVs for irregular operations can serve as an alternative to conventional kinetic operations on the battlefield. The innovative effects of the solution result from two main reasons:

- First: the attack can be carried out by pre-trained personnel.
- Second: the costs of the attack are relatively low compared to other traditional measures.

The reasons presented above prove that the proposed solution is highly innovated in comparison to the traditional employment of single drones on the battlefield. Particularly, a lower level of trained personnel is an advantage compared to the classic solution, which increases the possibility of using it in asymmetric conflicts.

The innovative solutions presented in this publication may find a wide application on the battlefield in the future, in particular in asymmetric warfare. This is because the gadgets discussed in the publication can be bought in large quantities and with a small budget.

Thanks to the use of innovations, it is possible to carry out attacks that bypass anti-aircraft defence and destroy expensive equipment and logistics infrastructure at a relatively low cost, which is crucial on the modern battlefield. Currently, in the era of Industry 4.0, which is based on digitization and robotization, it will be possible to increasingly use solutions with the utilisation of artificial intelligence on the battlefield. One of such solutions is the use of innovative drone swarms presented in this publication.

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