SECURITY & DEFENCE QUARTERLY
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Analysis of the power of drones and limitations of the anti-drone solutions on the Russian-Ukrainian battlefield

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Abstract

The recent and rapid growth of low-cost, sophisticated drones, along with the associated technological challenges, is a notable feature of warfare tactics. As the Russians and Ukrainians become more dependent on these cost-effective yet crude drones, they establish a new battlefield characterised by high efficacy and low cost. Both Russian and Ukrainian forces launch drones to target each other. Drones locate their targets, perhaps with low efficacy, but they can cause significant destruction. Drones can destroy and carbonise tanks, which cost about $4 million each. However, the unit price of drones does not exceed $1,000. The limitations and ineffectiveness of most anti-drone devices currently on the market, including lasers, high-power microwaves, and radio frequency jammers, are evident in the increasing ubiquity of drones. This case study suggests that current counter-drone technologies are unable to neutralise kamikaze and weaponised drones on both sides. As a result of these failures, Russian and Ukrainian forces employ new technologies, such as metal grids and nylon net barriers, which are effective in destroying and stopping drones to some extent. This article presents a case study involving the reliance on drones by both warring sides, who have also been utilising anti-drone tactics since February 2022. The work investigates the solutions currently available to both adversaries for reducing the impact of weaponised drones on the battlefield. This study evaluates them and demonstrates how their inherent drawbacks could motivate the development of new strategies and countermeasures against armed drones.

Keywords:

first person view, drone, geopolitics and international security, countermeasure drone, Russo-Ukraine conflict, defence and security

Article info
Received: 9 April 2025
Revised: 12 July 2025
Accepted: 16 July 2025
Available online: 29 September 2025

Citation: Chaari, M.Z. (2025) 'Analysis of the power of drones and limitations of the anti-drone solutions on the Russian-Ukrainian battlefield', *Security and Defence Quarterly*, 51(3). doi: 10.35467/sdq/208347.

http://doi.org/10.35467/sdq/208347

Introduction

This article presents a case study on how drones have revolutionised warfare tactics on the battlefield and in war zones, with a particular focus on the conflict in Eastern Europe. It also highlights the limitations and weaknesses of electronic counter-drone systems in disrupting illegal drones, which has led to drones' significant advantage in air superiority.

Recently, drones have become available to anyone interested worldwide. Beyond its entertainment value, this technology presents numerous possibilities. Many companies, such as DJI, Parrot, Skydio, and XAG, recently have started producing drones for hobbyist applications (Portuese, 2024). Unfortunately, these entertainment drones are frequently misused. Perhaps this increased accessibility has prompted renewed efforts by malicious actors, such as terrorist groups, drug dealers, and criminal organisations, to exploit drones for malicious purposes (Guven, 2024). A drone can carry a high-resolution gimbal camera and fly over strategic areas to gather sensitive and private data as well as perform surveillance and reconnaissance. Drones are used for information collection, surveillance, reconnaissance, combat, and mine detection. It is perhaps not surprising that the primary focus of current concerns regarding low-cost and modified drones is their potential to function as a supply system for explosive devices.

Since the start of the conflict, Ukrainian and Russian forces have engaged in drone-centric warfare, utilising these cost-effective and easily assembled devices to conduct precise attacks and defend against assaults. Several drone attacks have targeted critical infrastructure in recent months (Resendiz, 2025). While it appears to be an innocuous little object, it is, in fact, a lethal weapon that is quite challenging to defend against.

Remotely piloted drones, or first-person view (FPV) drones, worth about $5000 each, have disabled hundreds of vehicles and military equipment on both sides in the Eastern European conflict (Amran, 2024; Korshak, 2025). Incidents at airports and other public facilities highlight the necessity of a new technology that would safeguard against the threat posed by drones (Gong *et al.*, 2024). Drones carrying a few pounds of explosives pose a significant threat to tanks, strategic areas, and other combat vehicles, especially as they become less expensive (Mogelson, 2024). FPV drones can carry mortar bombs or rocket-propelled grenade (RPG) projectiles, while smaller models can transport small amounts of TNT wrapped in duct tape (George-Ion, 2024). They are typically detonated with a couple of rigid wires that connect on impact. Drone performance relies on guidance systems; some models heavily depend on advanced Global Positioning System (GPS) technology, while others integrate inertial navigation systems (INS) with optical and infrared (IR) sensors for enhanced targeting capabilities. Due to their huge potential in warfare, many military manufacturing facilities have shifted their focus to the production of drones that enable remote warfare, a concept not new in itself.

The benefits of drones are highlighted by the following points: fewer soldier casualties, a lower financial burden of conflict, and reduced depletion of tanks, vehicles, and military assets (Galynska and Bilous, 2022). Drones represent the most advanced evolution of this era, combining powerful monitoring capabilities with offensive mechanisms. This evolution highlights the advancement from earlier remote weaponry systems to the contemporary standards in modern warfare. Drones have acted as transformative agents in modern warfare for decades, significantly altering the mechanics of conflict. As these essential tools evolved into more sophisticated systems, they introduced new risks and significant implications for modern warfare (Modebadze, 2021). In this context, one of the key advances in drone technology is the emergence of kamikaze drones, or loitering munitions, which have revealed significant ethical and legal deficiencies in the current international humanitarian law (Kunertova, 2023).

The comparison of missiles and drones reveals valuable lessons. Both missiles and kamikaze drones deliver precise, explosive payloads using advanced guidance systems. According to various sources and reports, the estimated cost of the Geran-2, or Shahed-136, drone ranges from approximately $20,000 to $30,000 (Silva, 2023). It is easy to manufacture or buy from Iran. Using African workers and Chinese components, Russia increased its domestic Shahed-136 drone production. According to information and reports from the frontline, the Shahed-136 has a very low hit rate. The average number of hits is approximately 20%. Alternatively, cruise missiles cost roughly $900,000–$1,000,000 each. The cost of the missile is about 30 times that of a Shahed drone.

Precision-guided missiles and other advanced weapon systems employ improved methods, enabling more accurate attacks. Missiles require extensive infrastructure and specialised knowledge to operate, which makes them more challenging for most states to obtain. Also, their use is more controlled. However, drones are not heavily technology-dependent and can be utilised by any military force. In this regard, kamikaze drones have gained more attention worldwide than traditional remote warfare systems, such as missiles. Because they are cheaper, easier to use, and more prevalent, they are more likely to be deployed against people in a new context war. Kamikaze drones offer distinct advantages. They have numerous unique features that draw great attention to them.

The rapid and effortless detection and neutralisation of drones presents a challenge for many radar systems and anti-drone measures. Even the most expensive Patriot anti-missile batteries, owned by powerful nations, are not explicitly designed to destroy the drones used in recent attacks. These small drones are incredibly manoeuvrable and can torment a soldier until his brutal demise. The most domestically available options are small quadcopters made from inexpensive, readily available Chinese parts and mostly controlled via FPV goggles. Employing missiles against them, such as man-portable air defence systems (MANPADS), is ineffective. These drones are tiny and have almost no IR signature for a missile to lock onto.

This article is structured as follows: Section 1 is the Introduction. Section 2 discusses the importance of the drone in the Russo-Ukrainian conflict. Section 3 presents the limitations of the existing countermeasures in destroying drones. Section 4 introduces new anti-drone solutions present in the conflict. Section 5 highlights the study's findings, demonstrating both advantages and disadvantages of the new countermeasures and innovative approaches. Finally, we end with a Conclusion in Section 6.

The importance of drone in the Russo-Ukrainian conflict

In the Russo-Ukrainian conflict, kamikaze drones come in all shapes and sizes and have relatively small battery capacities. Unlike advanced unmanned aerial vehicles (UAVs) equipped with extensive sensors and communication systems, drones are designed to stay airborne for extended periods, identify targets with high precision, and then crash into their targets, sacrificing the drone itself. The investigation report from the conflict area mentions that the most popular drone utilised is a commercial FPV drone (Locher *et al.*, 2025). The FPV drone utilises a technique that enables the pilot to operate it via an

http://doi.org/10.35467/sdq/208347

onboard video camera, which feeds real-time visual data to the pilot, allowing the drone to be navigated beyond the pilot's line of sight (Agarwal, 2024). Binding is the process of establishing a strong and lasting connection between a sender and a recipient. The receiver accepts commands exclusively from a particular sender, disregarding all others. The receiver is said to be effectively "bound" to the sender. For example, if a device is bound to a particular transmitter, it will only respond to instructions from that transmitter, even if other transmitters are close. In this regard, binding a drone to its remote controller will ensure that the drone only responds to commands from its designated controller, preventing interference from other devices. The use of inexpensive commercial drones in warfare for intelligence, surveillance, reconnaissance, combat, artillery targeting, and information and psychological operations highlights that genuine capability does not necessarily derive from costly bureaucratic defence procurement processes. Drones provide solutions in the conflict between Ukraine and Russia. Ukraine's production objective for 2025 is 4.5 million FPV drones, up from 20,000 per month last year. Russia is ramping up production equally. Figure 1 presents the components of an FPV drone. Figure 1a shows the control of FPV with fire retardant (FR) goggles, and Figure 1b shows the FPV drone control with radio frequency (RF) remote control.

In the conflict, both adversaries are extensively using drones on the frontline. As shown in Figure 2, four groups of drones are utilised in the conflict. Micro-drones are used for intelligence, surveillance, and reconnaissance (ISR) and can carry a tiny camera. Mini drones used for kamikaze operations can carry ammunition. Medium drones can transport payloads of more than 50 kg and operate for up to 15 hours in ISR applications, thereby supporting troops. Heavy drones, including those used for combat and ISR, are often employed as rockets.

Figure 2 shows how consumer drones are deployed in the Ukrainian conflict as suicide drones, bombers, reconnaissance aircraft, surveillance aircraft, and relay aircraft. Both adversaries have used the so-called kamikaze drones in the Russo-Ukrainian war (Oleksenko *et al.*, 2024; Seo *et al.*, 2023). Figure 3 exposes several proposed missions of an FPV drone in the Russo-Ukrainian conflict.

Since February 2022, FPV drones have been employed in implementing various tactical methodologies in the Russo-Ukrainian battlefield (Ibrahim, 2024; Zafra *et al.*, 2024). Each adversary is continually planning its next move. On 1 June 2025, Ukrainian drones struck more than forty Russian aircraft, including A-50, Tu-95, and Tu-22 M3, according to sources from the Security Service of Ukraine (SBU). The report indicates that Russian strategic bombers are facing significant losses within Russia. The SBU carried a large-scale

Figure 1. Components of a domestic drone.

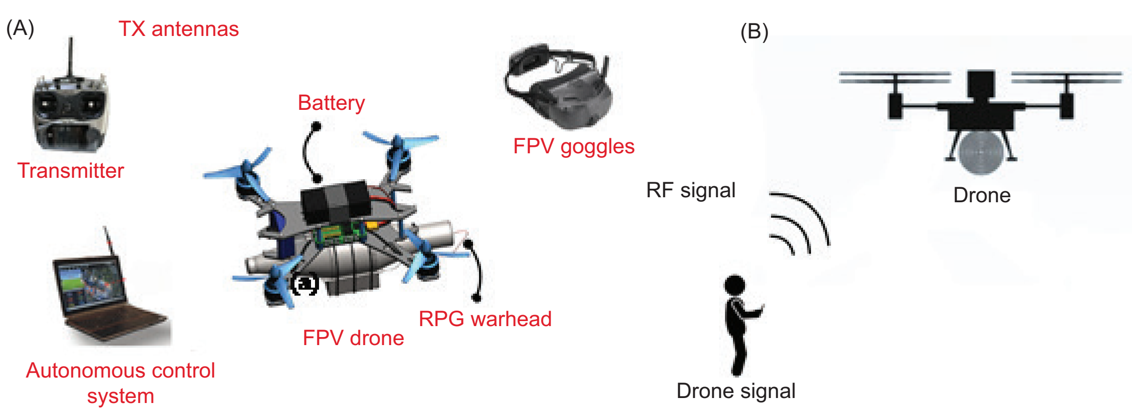
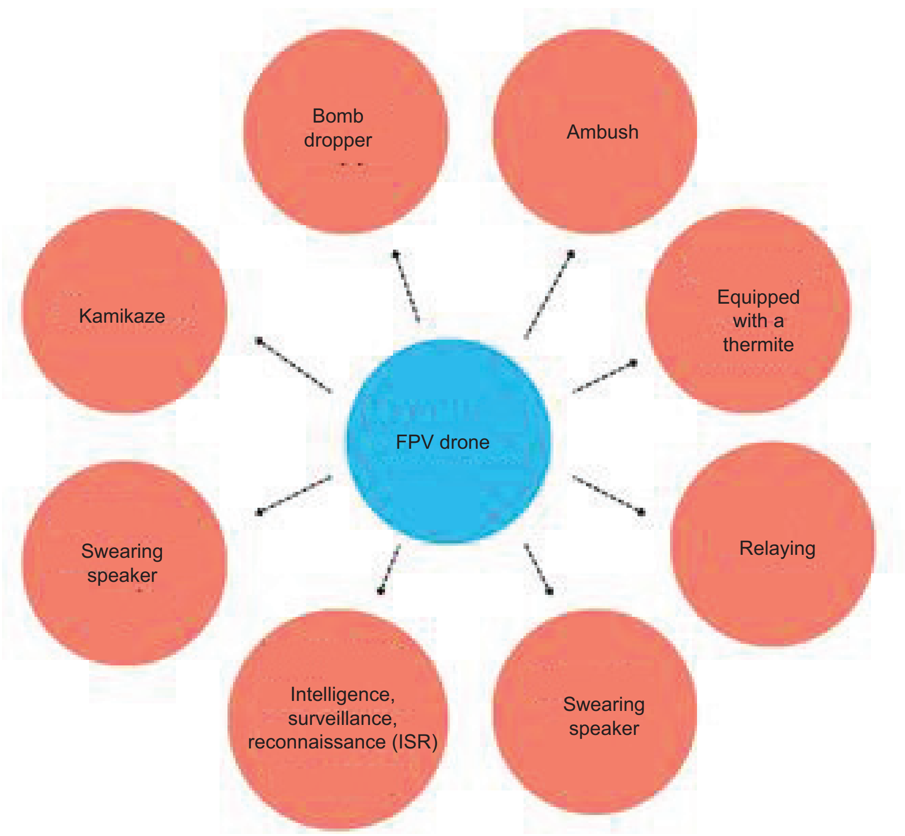


Figure 2. Four different groups of drones have been utilised in the Russo-Ukrainian conflict.

Figure 3. Various missions of FPV drone in the Russo-Ukrainian conflict.



special operation to eliminate enemy bombers deep within Russia (Fenbert, 2025). The SBU drones targeted aircraft that bomb Ukrainian cities every night. This special operation was called Spiderweb, but some referred to it as Russia's Pearl Harbour. An FPV drone-based operation by Ukraine was executed approximately 1,700 km from Ukrainian territory (Adams and Lukiv, 2025). This is likely the largest and most significant drone-based sabotage operation in history. Russia's losses have already exceeded $7 billion. On 30 May 2025, Ukrainian soldiers from the "Birds of the Magyar" drone unit eliminated another high-value target: a BM-21 Grad multiple-launch rocket system (Kozatskyi, 2025). A precise hit neutralised both launcher and its payload. The BM-21 Grad, once a symbol of concentrated artillery fire, is now increasingly vulnerable to $1,000 drones equipped with inexpensive cameras.

Table 1 exposes some tactical methodologies employing FPV drones in the frontline of the Russo-Ukrainian conflict.

Table 1 illustrates various tactics employing FPV drones in the battlefield, including those with fibre-optic connections; they were employed for structural analysis, leaflet dropping, and as FPV dragons, among others. Both adversaries acquired commercial and laboratory drones to address their deficiencies. All the components of these drones are readily available in the market, and permission is not required to obtain and use them. Table 2 outlines the advantages and disadvantages of consumer drones within the context of the Russo-Ukrainian conflict (Chaari, 2024; Wackwitz, 2024).

Table 1. Tactics employing FPV drones in the Russo-Ukrainian conflict.

FPV tactical missions	**Specifications**
Free hunting (Hambling, 2024b)	FPV drone strikes pre-identified targets and locations.
Swarm (Bisht, 2024)	The FPV drone group targets specific objects.
Escorting the attack of the assault group	Fire support for the advancing units' actions.
Ambush	Landing and waiting, preparing for a surprise attack on the target.
Combination strike	FPV strikes target, releasing munitions from a "bomber" drone.
Double impact	Utilising two or more FPV drones with varying charges to penetrate a shelter and eliminate personnel.
Trap (variants)	Applying highly hazardous compounds with skin-blistering effects on the FPV drone body.
Carry mines	Delivering and installing anti-personnel and anti-tank mines.
Sapper	Deploying munitions or affixing explosives to mines.
Reset	Dumping ammo on the target.
Dragon (Kabachynskyi, 2024; Lendon *et al.*, 2024)	FPV putting an explosive substance at hostile places.
FPV-PVO	Countering UAVs and hexacopters using FPV drones is possible if radio-technical methods detect UAVs.
Saboteur	It is recommended that sabotage devices be concealed and affixed to objects not visible from the drone's rear. The devices should be activated remotely using pre-programmed positions.
FPV-motherships (Dean, 2023)	UAVs act as "motherships" for fixed-wing and rotorcraft drones, transmitting signals to other drones and enabling FPV drones to operate in a broader range of locations.
FPV with fibre-optic connections (Nikolov, 2024)	Troops use UAVs equipped with fibre-optic connections to maintain control of FPV drones, even in the presence of electronic warfare (EW) systems, which allows them to engage targets up to 10 km away.
Examination of structures (McNabb, 2024)	Their purpose is to locate enemies and navigate building interiors. Also known as "tiny whoops."
FPV with a speaker	FPV drones fitted with speakers are used at locations to weaken the troops' morale and force them to surrender.
Drop leaflets	Using an FPV drone to drop leaflets on enemy territory.

Table 2. The advantages and disadvantages of FPV drones.

Advantages	Disadvantages
• Ready-made technology • Ease of use • Handle explosives • Mobility • Small size and restricted visibility • There are no losses • Possibility of finalisation	• Difficulty of repair • The video camera cannot be changed; some models must be purchased separately • Increased acoustic noise level • Vulnerability in the sky • Subject to alteration • Meteorological dependence • Drones have a range of just a few miles

As nations such as Iran, Israel, the United States, Russia, Ukraine, North Korea, Turkey, and China develop several types of drones tailored to their strategic objectives, it is essential to recognise the inherent diversity of these systems (Henriksen and Bronk, 2025). Although all are classified as kamikaze drones, they show significant differences in technology, guidance system, and operational effectiveness. It is vital to understand the distinctions and categorisations of drones, as they lead to markedly different consequences on the battlefield. These distinctions need to be considered when overseeing and regulating the use of drones. Table 3 outlines the various types of drones used in the conflict in Eastern Europe, highlighting unique technological approaches, such as specifications and categories, and their implications in modern warfare.

As shown in Table 3, six guidance systems are implemented in the drones used in the conflict. This section presents and discusses each of the guidance systems.

- **Global Navigation Satellite System (GNSS):** This method enables precise positioning and navigation by utilising satellite signals to determine the drone's location and path. The intricacy of GNSS systems can vary significantly: sophisticated drones employ multi-frequency, multi-constellation GNSS receivers to enhance accuracy and reliability in adverse environments. Conversely, simpler models may rely on single-frequency receivers with limited capabilities.

- **Global Positioning System:** This system facilitates accurate navigation to designated predetermined coordinates. The sophistication of GPS systems varies: advanced drones utilise highly accurate GPS technology, whereas simpler models rely on less precise yet economical alternatives.

- **Inertial Navigation System:** This system monitors movement and orientation using accelerometers and gyroscopes independent of external signals. The precision of INS systems varies: sophisticated models offer better reliability, whereas basic versions may experience drift over time.

- **Infrared sensors:** These identify thermal signatures, making them advantageous for nocturnal activities or conditions of reduced visibility. The sophistication of IR sensors differs, with more modern models often offering superior resolution and enhanced sensitivity.

- **Radar homing:** It locks onto radar emissions from targets, making it effective against radar systems and electronic emitters. Variations in sensitivity, range, and signal processing complexity impact the cost and operational effectiveness of these systems.

Table 3. List and specifications of the most commonly used drones in the Russo-Ukrainian conflict.

	Drone name	Country of origin	Drone specifications	Drone categories and types	Guiding system
Drones used by Ukraine	Switchblade 300 (Manuel, 2025) Switchblade 600 (ISR & Combat)	US	Loitering missile system. Operational range: 40 km. Tiny visual, thermal, and acoustic signatures	• Highly sophisticated • Military	Cursor-on-target GPS, real-time video
	BAYRAKTAR-TB-2 (ISR & Combat) (Axe, 2023)	Turkey	Drone capable of reconnaissance, surveillance, and combat. operational range: 4,000 km. Endurance: 72 hours	• Highly sophisticated • Military	Tracking moving targets. In-flight mission abort; initiate emergency self-destruction. Camera with 10× optical zoom
	FlyEye (ISR & Combat) (Manuel, 2024)	Poland	FlyEye has a top speed of 120 km per hour, a service ceiling of 3,000 m, and can operate for over 2.5 hours. It is propelled by a silent electric engine based on lithium polymer technology	• Highly sophisticated • Military	GPS, real-time video
	Defend Tex drone 155 (ISR & Combat) (South, 2021)	Australia	Expendable/reusable, economical, ISR payload capability, swarming technology, tube-launched, and autonomous flight	• Highly sophisticated • Military	GPS, real-time video
	Autel EVO (ISR & Combat) (Hambling, 2022)	US	The CW-30E and CW-40 offer an endurance of 8 hours, a payload capacity of 6 kg, and a maximum control range of 200 km. These drones are suitable for high-precision operations over extensive areas	• Highly sophisticated • Military	GPS, real-time video
	Quantix Recon UAS (ISR) (Oliver, 2022)	US	Gather information	• Highly sophisticated • Military	Target identification and tracking
	Atlas Aerospace (ISR) (Valpolini, 2022)	Latvia	Its communications are secure and encrypted, enabling nearly 10 miles beyond visual line of sight (BVLOS) operations. The AtlasPRO features a battery life of 32 minutes and a setup time of just 3 minutes, making it suitable for a variety of missions	• Highly sophisticated • Military	Target identification and tracking
	Weaponised DJI drone (ISR and light Combat)		DJI Matrice 300 DJI Mavic Series (approximate cost $400 to $4,000) DJI MAVIG Series (approximate cost $40,000)	• Low-sophistication • Commercial	Civilian-class GPS

(*continues*)

Table 3. Continued.

	Drone name	**Country of origin**	**Drone specifications**	**Drone categories and types**	**Guiding system**
Drones used by Russia	Shahed 131 (Combat) (Bouks, 2023)	Iran	The Shahed-131 is a long-range weapon capable of striking deep into hostile territory. Its estimated range is approximately 900 km	Low-sophistication Military	Civilian-class GPS
	Shahed-136 (Combat) (Denysyuk *et al.*, 2024)	Iran	The Shahed-136 possesses an estimated range of almost 2,500 km, rendering it a long-range weapon capable of penetrating deep into enemy territory. It employs a basic GPS navigation system for guidance	Low-sophistication Military	GPS, GNSS
	Orlan-10 (Kharuk, 2024) (ISR & Combat)	Russia	Utilised for reconnaissance and surveillance	Highly sophisticated Military	Primarily used for reconnaissance and targeting, reports of indirect civilian impact through targeting assistance, rather than direct strikes
	Orlan-30 (Novichkov, 2024) (ISR & Combat)	Russia	With a wingspan of 3.9 m, it can achieve a maximum flight duration of 8 hours, a maximum altitude of 4 km, and an airspeed of 90–150 km/h. The take-off weight is 40 kg, allowing for a maximum payload of 6 kg, and it can operate at wind speeds ranging from 10 to 20 m/s	Highly sophisticated Military	Primarily used for reconnaissance and targeting, reports of indirect civilian impact through targeting assistance, rather than direct strikes. Western manufacturers manufacture the majority of drone components. (Daly, 2024)
	Lancet (Faragasso, 2023) (Loitering munition)	Russia	Cost per unit: domestic cost: $20,000; export cost: $35,000maximum velocity: 110 km/h in cruising mode; 300 km/h in diving mode	Highly sophisticated Military	Target identification and tracking
	Aileron (ISR & combat) (Battlefield Bytes, n.d.)	Russia	The Aileron-3 SV is a ground-operated, uncrewed aerial vehicle designed for battlefield surveillance and intelligence gathering	Highly sophisticated Military	Target identification and tracking

(*continues*)

Table 3. Continued.

	Drone name	Country of origin	Drone specifications	Drone categories and types	Guiding system
	Griffin-12 (ISR & Combat)	Russia	Griffin-12 multifunctional drone. Maximum take-off weight: 5.5 kg; cruising flight speed: 80 km/h; maximum flying speed: 120 km/h; maximum flight distance: 90 km	Highly sophisticated Military	Target identification and tracking
	Lastochka-M (ISR & Combat) (Kirill, 2022)	Russia	The drone weighs approximately 7 kg and has a range of around 30 km. Depending on the mission profile, its maximum endurance is 2 hours. During an assault on the target, it can achieve up to 120 km/h speed	Highly sophisticated Military	Target identification and tracking
	Weaponised consumer drone (ISR & light combat)	Russia	Consumer drones with payload mechanisms are designed to deploy small grenades and explosives	Low-sophistication Commercial	GPS, GNSS

Table 4. Drone classification in the Russo-Ukrainian conflict.

Drone classification	Description
High sophistication	Drones in this category use advanced guidance systems, which include GPS, inertial navigation systems (INS), optical sensors, and radar-homing capabilities. This combination delivers exceptional precision and adaptability, allowing these drones to locate and engage targets effectively in various environments. However, their heightened complexity presents significant challenges. The advanced technology and high cost of these drones pose a low risk of unforeseen consequences.
Moderate sophistication	They frequently use a combination of GPS and INS, ensuring reliable performance for precise hits at a lower cost than advanced models. Although small drones have effective targeting capabilities, they often lack the advanced features and versatility of more sophisticated systems. Their shortcomings may lead to inaccurate targeting, particularly in complex or volatile environments.
Basic sophistication	This category includes drones that utilise basic guidance technologies, such as fundamental GPS and limited optical sensors like cameras. Although they are cost-effective and have the potential for broad application, their technological simplicity presents significant challenges, particularly in striking the goal precisely.

- **Optical sensors:** These utilise cameras and visual sensors for immediate imaging and precise targeting. The complexity of optical sensors varies from simple cameras to sophisticated multi-spectral imaging systems, offering enhanced resolution and targeting precision.

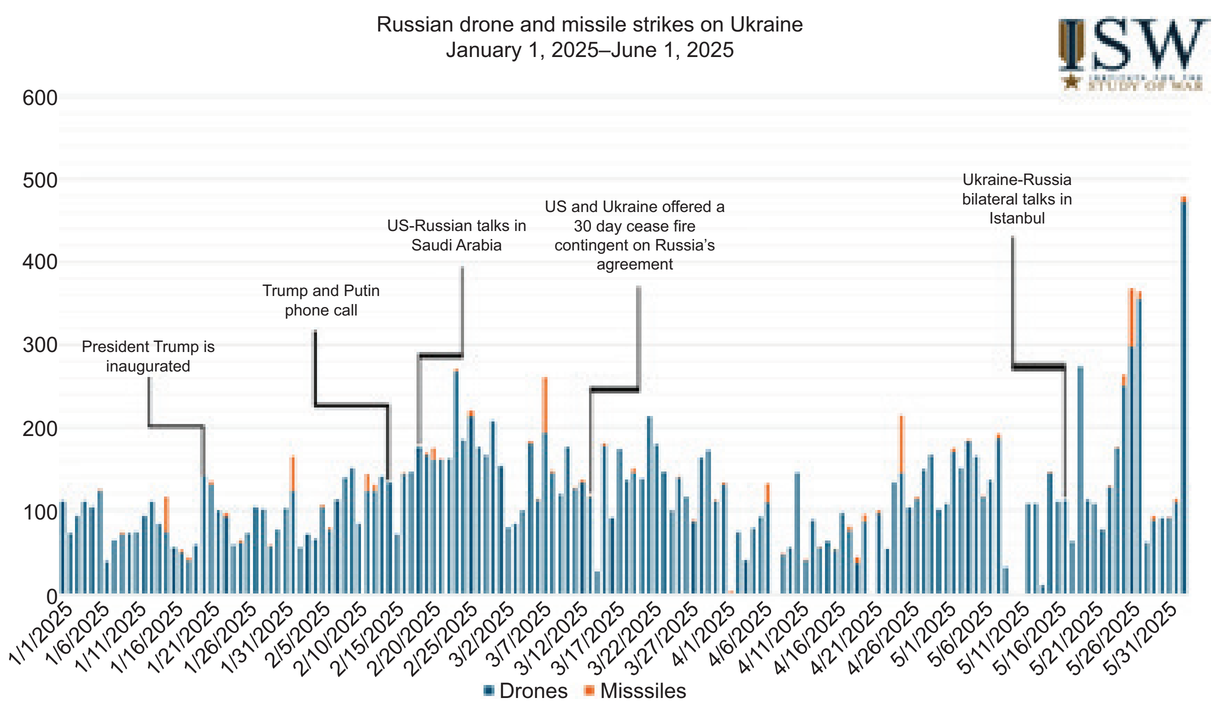
Based on the six guidance systems presented above, Table 4 categorises drones into three types: high sophistication, moderate sophistication, and basic sophistication. This classification relies on their guidance technologies and control systems. According to Table 4, European and the US countries utilise highly sophisticated drones, whereas Iran employs less advanced ones due to limited access to technology. Variations in guidance systems, particularly in terms of accuracy and effectiveness, create distinct strategic roles for kamikaze drones.

Ineffectiveness of the current anti-drone and electronic warfare (EW) technologies in the conflict

Figure 4 shows Russian drone strikes on Ukraine from January 2025 until June 2025. According to this chart reference, the number of strikes increased significantly in March 2025. The increase presents a significant limitation for counter-drone and EW systems, as the number of attacks is extremely high.

The rising frequency of assaults by FPV drones highlights the inadequacies of current technologies, including RF jammers, handheld gun jammers, lasers, high-power microwaves, and trained eagles, in thwarting and neutralising illegal drones. There are various technologies for countering drones worldwide, each with different capabilities, as shown in Figure 5. Experts have determined that the demand for anti-UAV devices in the market is increasing rapidly. The jammer device can disrupt radiofrequency communication with drones; nevertheless, it cannot halt autopilot-programmed or autonomous drones. Anti-drone systems, trained eagles, and capture systems have limitations, including a limited range for intercepting swift and nimble drones. Current anti-drone technologies are well-established in their inability to disable drones entirely. With over 75% of the drone market share, DJI drones are the most popular consumer drones on the market. Many experts recommend two primary methods of defending against these drones in the conflict in Eastern Europe: an anti-drone jammer gun and a system called DJI AeroScope. DJI, the same company that manufactures DJI drones, also produces DJI AeroScope,

Figure 4. Russian drone strikes on Ukraine from January to June 2025 (Gibson *et al.*, 2025).



which is referred to as an anti-DJI drone. The DJI AeroScope can reveal the locations of drone operators and neutralise drones, but this applies only to DJI drones manufactured after 2014.

The increasing number of attacks by modified and programmed drones demonstrates the limitations of current countermeasures against drones. We assess the effectiveness of each technology in neutralising drones at various distances and under different weather conditions. Table 5 presents various anti-drone technologies, outlining their advantages, disadvantages, and approximate costs.

Table 5 lists most of the technologies and methodologies used to neutralise and eliminate drones. Regarding anti-drone measures, popular devices are not widely available, require significant knowledge, are expensive, and sometimes exhibit low performance efficiency. The table also highlights the drawbacks of these technologies. As previously mentioned, drones have become a symbol of the conflict in Ukraine, with both sides using them extensively for reconnaissance and munitions delivery. Faced with the weaknesses of the technologies described in Table 5, both sides sought to build effective defences against the drone threat, employing various methods, including fishing nets, anti-drone weapons, mechanical cages, and advanced EW jamming devices, to disrupt drone frequencies over large areas. The following section presents counter-drone solutions within the context of the Russo-Ukrainian conflict. Two innovative technologies, semi-autonomous drones with terminal guidance and fibre-optic-guided drones, can potentially render RF jammer counter-drone systems obsolete. Both operate wholly beyond the scope of jammers. This implies that the anti-drone system is currently ineffective.

Figure 5. The most popular technology to detect and destroy weaponised drones.

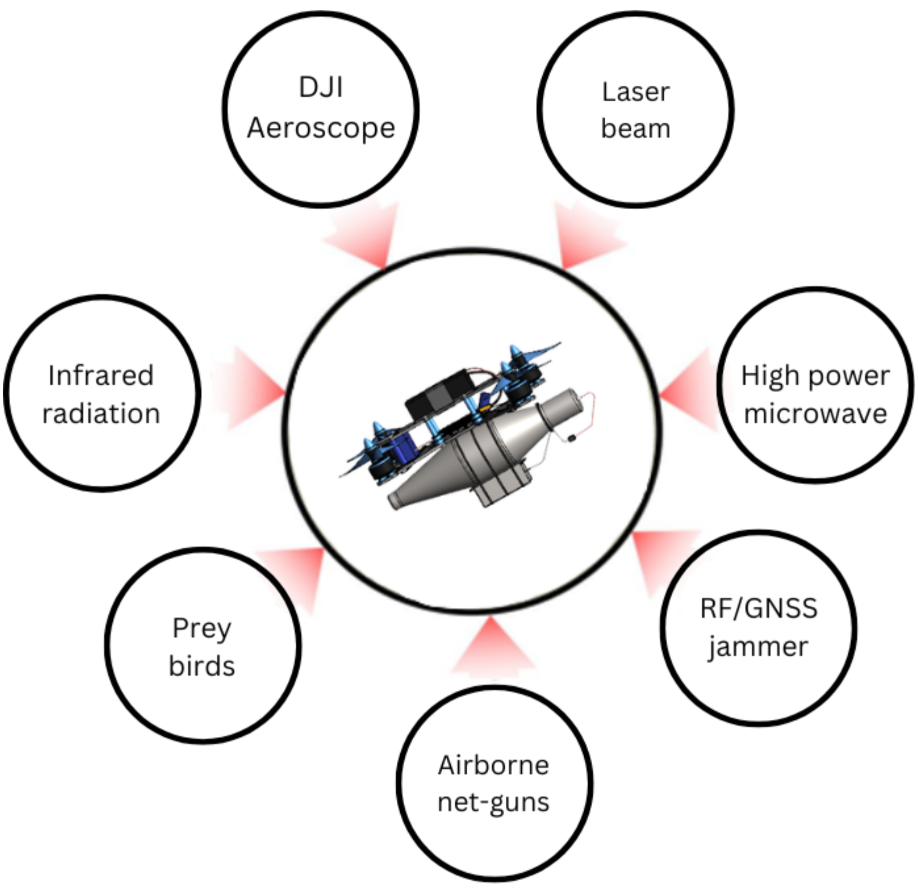


Table 5. The most popular anti-drone technologies.

Technology name	Type	Drawback	Benefit	Approximate cost	References
RF/GNSS jammer	Destroy	Ineffective against autonomous UAVs Ineffective against drones that use inertial navigation systems/sensors Inadequate against UAVs employing encrypted communication The jamming has the potential to interfere with other sensitive apparatus	Could simultaneously neutralise grouped targets, degrading their reception. Signal-to-noise ratio The directivity diagram of the jamming signal can be oriented and directed as needed	\$20,000–\$100,000	Spanghero *et al.*, 2025
Interceptors as air-to-air missiles.	Destroy	Same mechanical limitation	Air-to-air drone destroy	\$10,000–\$15,000	Jenkins and Wang, 2024
Handheld gun jammer	Destroy	Effective only for short distances	GNSS frequencies and bands are well recognised and comparatively straightforward to interfere	\$12,000–\$15,000	Bunker and Begert, 2023
Laser anti-drone	Destroy	• Climate sensitive • Accurate measurement of the objective position is indispensable • Lasers with high-power output may cause interference with other systems	• When the operation is conducted at low power, the UAV cameras may be blinded, or the target may be burned or destroyed • An objective that is easily monitored • Less costly and safer than projectiles or other physical countermeasures	Not available	Chaari and Al-Maadeed, 2020; Wang *et al.*, 2024
High-power microwave (HPM) anti-drone	Destroy	HPM has high-temperature propagation, presenting an IR signature that a rocket can latch onto and destroy it quickly	High-power microwave systems produce a magnetic field, eliminating errant and suicidal drones. This can damage the drone's motherboard or any sensors	Not available	Chaari, 2021; Dobija, 2023
Anti-drone airborne net-guns	Destroy	It cannot destroy or capture high-speed, large-sized drones	A portable anti-drone system can detect and neutralise drones	Not available	Sagar, 2021; Zhang *et al.*, 2024
GPS, GNSS spoofing	Destroy	Spectrum sensing systems are beneficial	Could exploit the vulnerabilities of various UAV systems	Not available	Sathaye *et al.*, 2022
Prey birds	Destroy	• Applicable only to slower and smaller UAVs • Could harm falcons	• Does not require complex technology • Fewer humans are required	\$2,000	Kanu *et al.*, 2024; Ki et al., 2023
DJI AeroScope	Detection and destruction	Challenges in identifying drones manufactured before 2014	Geofence	\$30,000	Jolly, 2023; Wallace *et al.*, 2024

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http://doi.org/10.35467/sdq/208347

Table 5. Continued.

Technology name	Type	Drawback	Benefit	Approximate cost	References
Optical system	Detection	The weather has a significant impact. At risk of encountering challenges. Low-end	Low cost and fewer regulatory limitations. Miniaturised identification	\$20,000–\$30,000	Elsayed *et al.*, 2021; Popescu, 2021
Tx/Rx antenna	Detection	The system uses the radar signature of tiny, unmanned aircraft (low RCS) to detect their presence. If the drone is stationary or flies at a low speed, it is impossible to differentiate it from obstacles. Degradation results from interference.	Long range. Determines the UAV's shape, distance, speed, and direction. 2D (PESA) and 3D (AESA) modes. Constant observability	\$10,000	Flak, 2021; Solaiman et al., 2023; Yamani and Yoon, 2022
Acoustic receiver	Detection	Limited range. Sensitive to surrounding noise. Susceptible to decoys. Low accuracy. High signal detection complexity	Covers the frequency range of 20 Hz–20 kHz. An acoustic signature library can be easily updated from one flight to another. Lightweight and easily compatible with other types of sensors Compatible with RF-based sensors.	\$100,000	Busset *et al.*, 2015; Frid *et al.*, 2024; Shi *et al.*, 2020
RF receiver	Detection	• Understanding UAV communication specifications, encompassing frequency bands and modulation types, is necessary. • Accurately determining the angle of attack is challenging. • Challenging to use in urban areas because of fading and multipath effects. • Vulnerable to malicious or unauthorised modifications of RF that exceed receiver capabilities. Unable to detect autonomous flight	• Records the communication spectrum and signals between the operators and the UAV. • Easy to implement and low in complexity • Capable of functioning in any weather and at any time of day or night • Prospect of pilot localisation	\$10,000	Flak, 2021
Infrared radiation camera	Detection	• Provides two-dimensional (2D) images • The atmospheric conditions and the ambient temperature can result in limited performance • Reliant on geo-referenced data • Line of Sight (LoS) is essential • Reduced precision	• Covers the entire visible and infrared spectrum (3 MHz–300 GHz) • IR cameras can operate in cloudy weather, both during the day and at night. • Could be assisted by computer-vision technologies	\$10,000	Kim *et al.*, 2018; Sommer and Schumann, 2020

New anti-drone solutions present in the Ukrainian-Russian conflict

As numerous solutions and techniques have been available since the first day of the fighting between Ukraine and Russia, this section presents several efficient solutions capable of destroying any drone in the Russo-Ukrainian conflict, as illustrated in Figure 6. Some solutions are active, while others are passive.

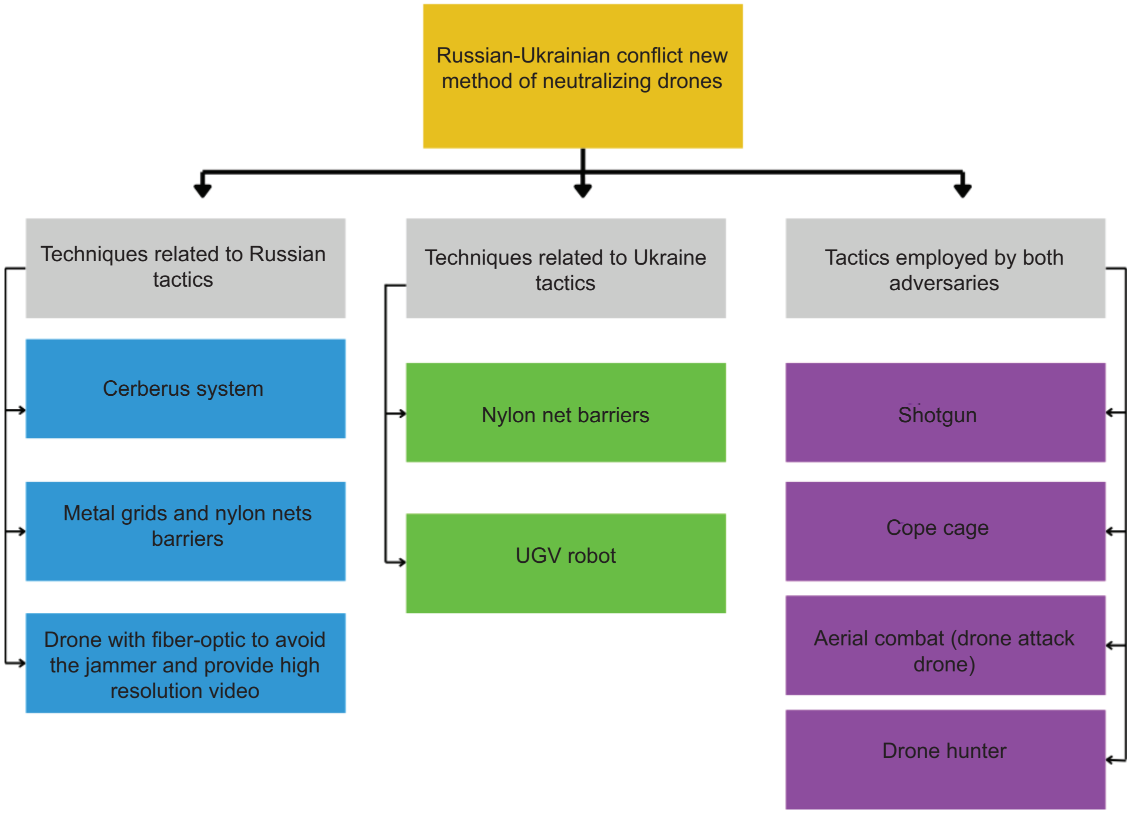
Russia's solution to the Ukrainian drones

This section outlines the Russian strategies and innovative methods used to neutralise or eliminate Ukrainian drones, thereby countering practical advancements in Ukrainian EW.

Russian armoured vehicle completely covered with anti-drone mesh, also known as cope cages

The problem for frontline tanks is that they cannot afford to trade away too much mobility, not even for drone protection. These tanks must move fast, in and out of cover, to support combined-arms assaults on enemy positions. They also need to be able to turn their turrets 360 degrees. Russian tanks (T-90) cost $4 million but can be destroyed and carbonised by drones, whose price does not exceed $1,000. Drones have knocked out hundreds of cars and armed vehicles on both sides. As on 22 March 2025, Russia had

Figure 6. Novel anti-drone solutions in the context of the Russo-Ukrainian conflict.



lost more than 10,000 tanks; a significant number of them were neutralised by kamikaze drone strikes (Nikolov, 2023). That makes them top killers of tanks in assault echelons fighting at the line of contact between Russian and Ukrainian troops. As the conflict continues, improvised solutions to various dangers to armour have emerged, and cope cages have become a more standard feature of armoured vehicles, as presented at the Russian defence exhibition, shown in Figure 7.

Neutralise the Ukrainian drone with shotgun fire

The option to shoot at the drone while it is airborne is a tactical solution, but it has low effectiveness. The shot must be highly accurate, especially since the drone is hundreds of metres above the ground and relatively small. The Russians tested a grenade launcher attachment that fires shotgun shells at FPVs (Pike, 2025). The company INGRA has developed a new, unparalleled device, Rosyanka, designed to destroy quadcopters, as illustrated in Figure 8. The testing stage has been completed. Rosyanka changes the calibre of the under-barrel grenade launcher, enabling it to fire a 12-gauge hunting cartridge with an effective range of 15–30 metres (Kirill, 2024). It appears to be much more effective than the net pistol with a short barrel.

A Russian counter UAV system equipped with a novel turret is undergoing testing. It features three PKM 7.62×54-mm calibre machine guns to engage Ukrainian drones, especially fixed-wing drones. These are shown in Figure 9. This technique has low efficiency and cannot be used at night because the heavy machine gun lacks a thermal camera. The installation's advantage lies in the number of machine guns and its ability to focus fire on a designated target at a single location.

Numerous individuals assert that this strategy is quite effective and remarkable; many indicate that the Russian military employs a bicycle, scooter, or car outfitted with three PKMs to neutralise drones. In a Russian counter-drone system, four AK-74 assault rifles are equipped with thermal imaging technology to combat Ukrainian drones during nighttime operations, as shown in Figure 10. This technique is considered highly efficient. It can be utilised both day and night, as the heavy machine gun has thermal camera capabilities.

Figure 7. Cope cage.

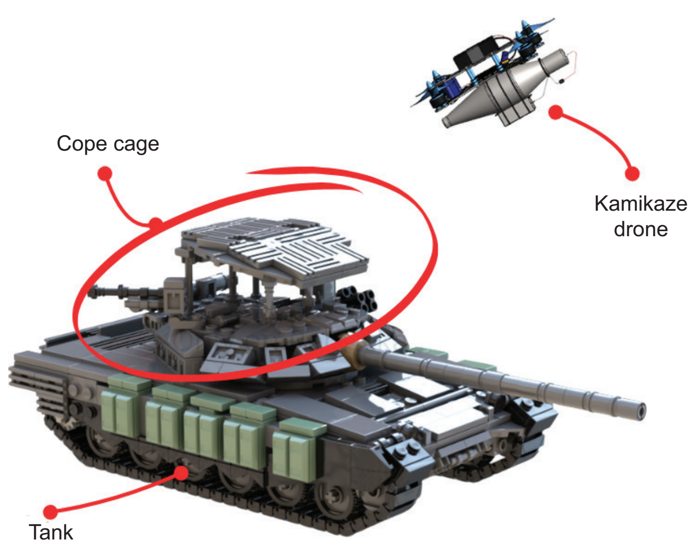


Figure 8. Russian anti-drone GP25 adaptor. Available at:
https://armourersbench.com/2024/05/19/russian-anti-drone-gp25-adaptor/

Figure 9. Combining three PKM 7.62×54-mm calibre machine guns without thermal cameras. Available at:
https://vpk.name/en/982399_with-a-long-range-view-how-small-air-defense-installations-are-created-in-the-svo-zone.html

Figure 10. Four AK-74 assault rifles with thermal cameras. Available at:
https://www1.ru/news/2025/02/16/rossiiskie-umelcy-skrestili-cetyre-ak-74m-dlia-borby-s-bpla.html

Cerberus system

Russian inventors are designing a Cerberus control and charging system for a swarm of fibre-optic drones; the system comprises a platform with six or twelve hangars for these drones. The complete system deploys from a truck and releases the drones, which operate as a swarm via artificial intelligence (AI) technology, as shown in Figure 11. This allows it to act as an "energy cluster," creating a new type of "military energy geography" based on numerous independent, mobile energy clusters that support an "electrified military force," which is extensively deployed over a hyperextended area. In addition to its direct combat applications, the system has broader potential applications. It can be employed for intelligence collection, accurate targeting of additional military assets, and defensive functions. It can deploy heat decoys to confuse enemy missiles or synchronise with air defence systems to enhance the defensive network.

http://doi.org/10.35467/sdq/208347

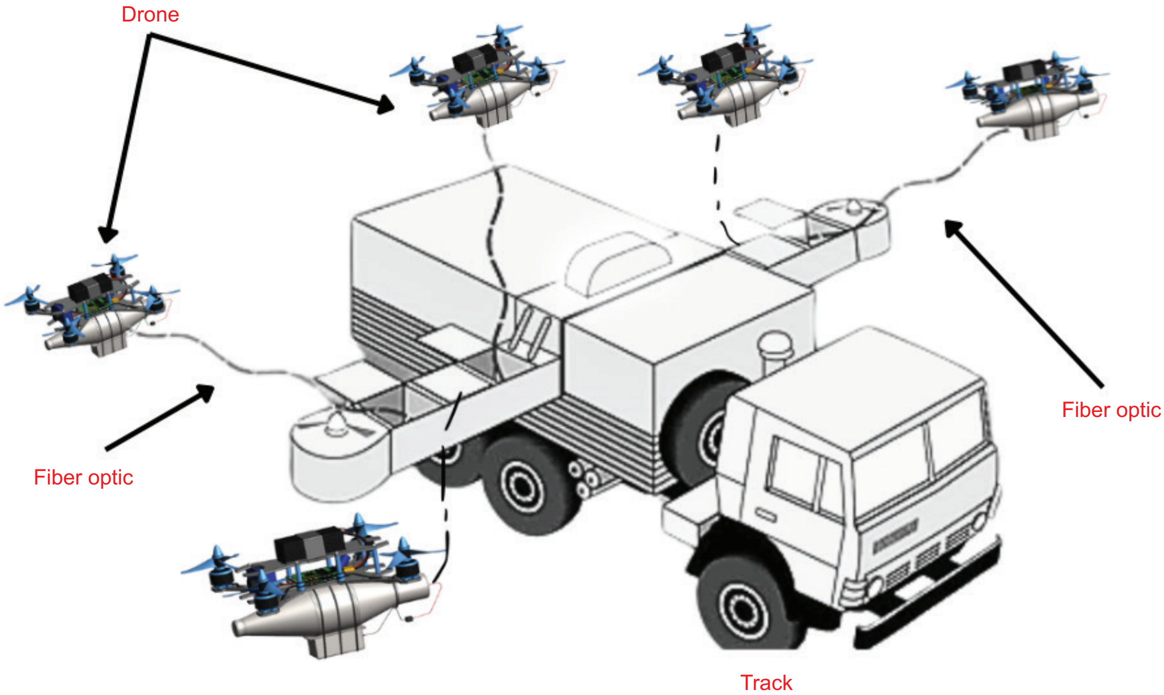


Figure 11. Russia is developing the Cerberus system to oversee fibre-optic drone.

The Cerberus system represents a significant development in military technology. This innovative technique utilises fibre-optic communication to control drone swarms, enhancing accuracy and resilience against electronic disruptions. In contrast to conventional drones, which are susceptible to jamming, the Cerberus system guarantees continuous control and real-time data transfer, even under adverse conditions.

Physical barriers

Two types of barriers are utilised in the conflict, namely nylon net and steel net.

Nylon net to protect the military convoy road

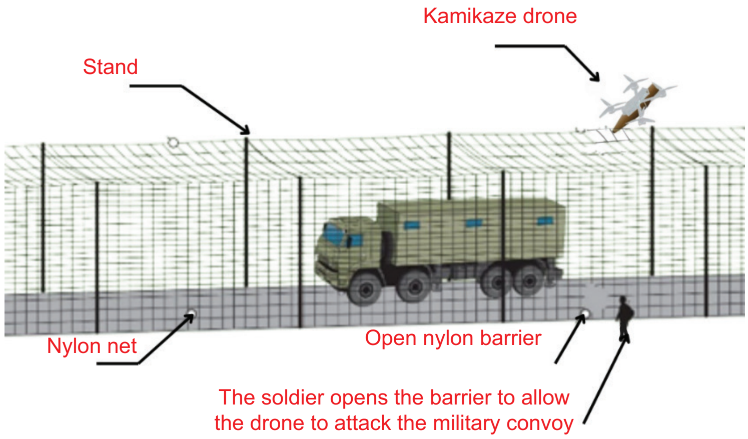
The threat presented by small drones is significant and is likely to persist. To safeguard roads from FPV drone attacks, the Russian military employs a fishing net. They either capture the drones and prevent them from detonating or force them to detonate at a location far away from the target. However, nets are only effective in established positions. Anti-drone nets hang over some streets and passages, as shown in Figure 12.

Nylon net barriers must be substantial and well-made, as a skilled FPV drone pilot can manoeuvre the deadly weapon through a random hole or entrance. Currently, the use of nets has proved to be quite effective in preventing drone attacks.

Steel net to protect the strategy area from the threat of drones (military bases)

It has been nearly 2 years since the start of Ukraine's innovative use of long-range drone operations against Russian military bases. The Russian defence industry is promoting

Figure 12. A fishing net to protect the military road from FPV.

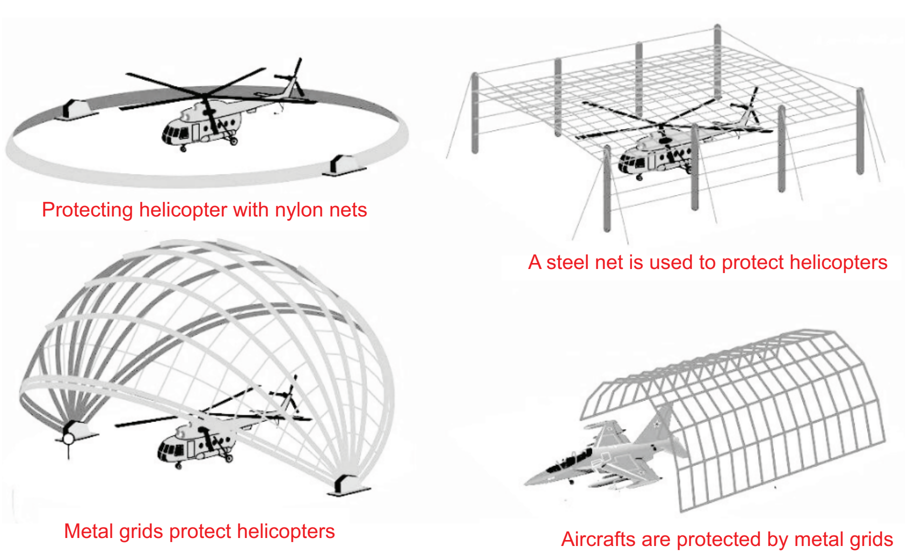


portable counter-drone steel netting and mesh as a potential defence solution. These advancements aim to protect combat aircraft from drone attacks, demonstrating a significant adjustment in response to the evolving threats of modern warfare, as shown in Figure 13. Although these countermeasures may provide theoretical protection, concerns regarding their practicality, deployment speed, and effectiveness against increasingly sophisticated drone technologies are growing. However, at the moment, the most effective method of safeguarding military equipment from drone attacks is the use of steel nets. This technique is particularly employed for protecting aircraft, especially after Ukrainian drones struck over forty aircraft, including the A-50, Tu-95, and Tu-22 M3 on 2 June 2025. Many reports indicate that Russian strategic bombers are suffering significant losses. Russia's total losses have already surpassed $7 billion.

Net to Protect Russian Oil Station

In response to escalating Ukrainian long-range drone strikes and loitering munitions, Russia has implemented anti-drone defences at critical sites, such as oil depots. They are

Figure 13. A steel net used to protect military equipment.



using nets and metal grids around oil storage facilities to minimise damage. A Ukrainian drone attack on an oil station in Stavropol Krai demonstrates the effectiveness of these passive countermeasures. The protective netting surrounding the plant prevented the drone from inflicting significant damage or starting a fire, even though the drone's high-explosive bomb detonated upon impact, as shown in Figure 14. A new statute in Russia imposes criminal liability on facility owners who fail to implement anti-terrorist security measures, prompting various private efforts to protect these facilities. The absence of a centralised strategy leads to significant variability in security measures across locations. In contrast to the effective defence at Stavropol, a prior drone strike in Belgorod breached netting barriers, resulting in damage to petroleum storage facilities. A different approach implemented at Moscow's oil refinery utilises metal cables configured in the form of a grid over essential infrastructure, intended to intercept heavy, rapidly flying drones and reduce the likelihood of direct impacts.

Notwithstanding these defensive adjustments, Ukraine's drone operation has demonstrated resilience and extensive reach, striking many facilities, including oil depots, distilleries, and ammunition storage sites, such as the Kombinat Kristall oil depot, struck on 8 January 2025, provides fuel to the Engels-2 military airfield in the Saratov region, where Russia's strategic bomber fleet is located. This persistent trend highlights the challenge of protecting numerous critical locations against the unconventional threat posed by long-range drones. As Ukrainian troops persist in attacking essential Russian infrastructure, Russia's improvised, private defensive strategies may require evolution towards a more standardised methodology to enhance the protection of vital resources, indicating a potential arms race in the defence and counter-defence aspects of drone warfare.

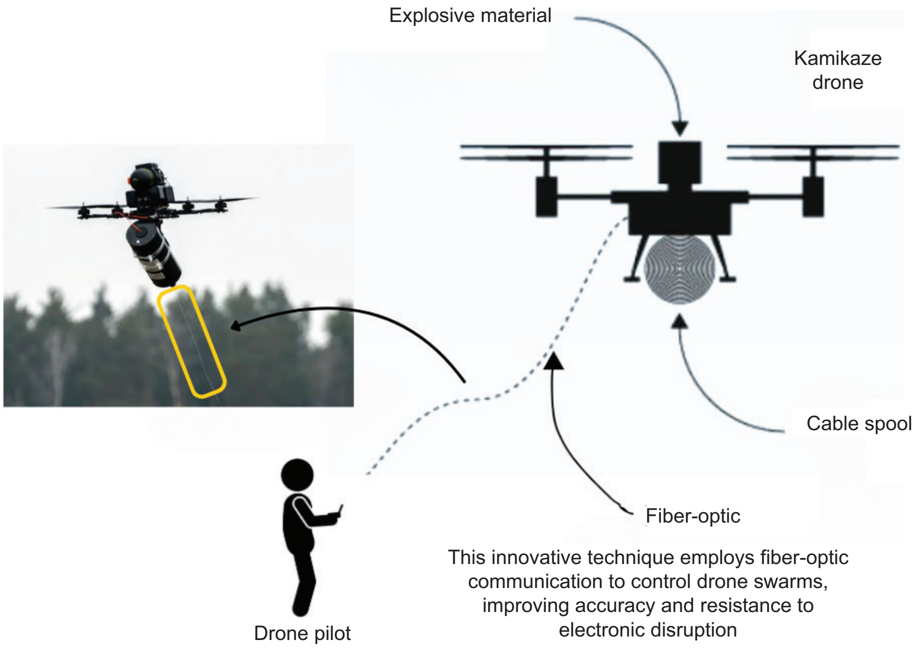
Fibre-optic FPV drones

In the cat-and-mouse game of drone development, a hallmark of this conflict, some recent drones are controlled by fibre-optic cables, rather than RF signals (Nikolov, 2024). Russia was the first to introduce fibre-optic FPV drones, using them for reconnaissance and attacks on Ukrainian forces. Russia continues to strive to produce fibre-optic spools using Chinese technologies. It imports a drone-operated fibre control system with a photoelectric module for anti-jamming capabilities over a distance of 15 km. In addition to providing crystal explicit imagery, these uncrewed aerial vehicles are immune to electronic jamming, as shown in Figure 15.

The weight of the fibre-optic conductor slightly reduces the fly time and the weapon's payload. Still, this drone can fly over 20 km into enemy lines and remain airborne for approximately

Figure 14. A sample of a net used to protect an oil tank. Available at: https://www.eurasiantimes.com/after-tanks-submarines-russian-oil-refineries/

Figure 15. The Russian military is using drones controlled by fibre-optics.



20 minutes. The defence option against this drone is to break the connector or shoot the drone out of the sky, and it should be done quite precisely, especially since the drone is hundreds of metres above the ground and not particularly large. The durability of fibre-optic cables against real-world impediments, including trees, buildings, and rugged terrain, was initially scrutinised. Russian fibre-optic drones are hunting inside Ukrainian territory.

Interceptors as air-to-air missiles

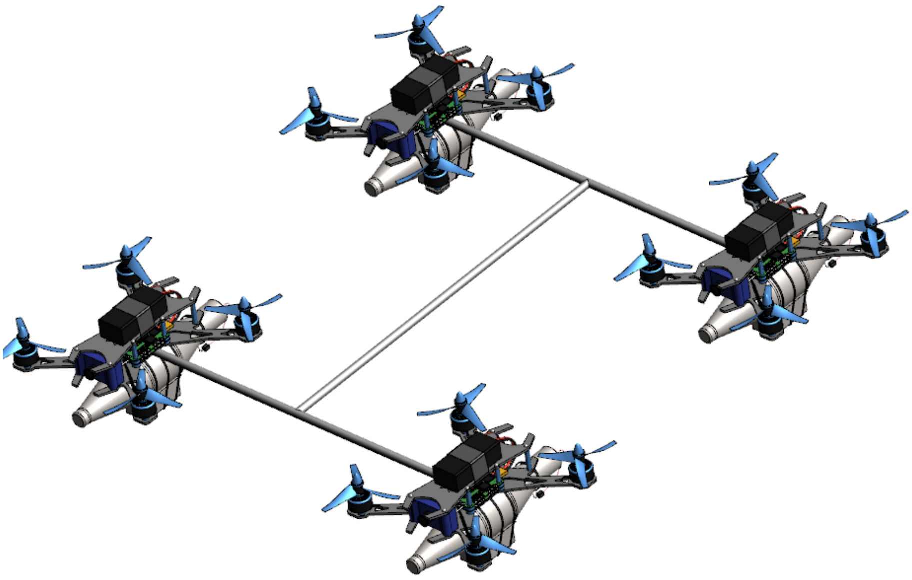
Russian developers are intensifying their efforts on a multi-rotor drone design, featuring four FPV drones that support a substantial frame, as shown in Figure 16. It is a configuration of four drones, each designed to accommodate four motors in the corners and their corresponding electronic speed controllers (ESCs). The standard flight controller of each drone receives input from sensors and user commands, and sends instructions to ESCs to adjust motor speeds, thereby controlling the drone's movement. The drones work in tandem with each other. These drones engage various aircraft types, while hexacopters are deployed to intercept and eliminate aerial drones.

Ukraine's solution to destroy Russian drones

Ukraine announced that it would start building an army of robots and implementing EW to neutralise Russian drones (*Ukrainska Pravda*, 2023). This section presents Ukrainian solutions and innovative techniques for neutralising Russian drones. Ukraine has actually used these measures to defeat Russian attacks (Sutton, 2024).

Most of the drone strikes in Ukraine are linked with Shahed-136. It has an estimated range of around 2,500 km, making it a long-range weapon capable of striking deep within enemy territory. It uses a simple GPS guidance system for navigation. It is powered by a

Figure 16. The concept of multi-rotor drone design.



small piston engine, allowing it to hover in the air before diving onto its target in a kamikaze-style attack (Bertrand, 2023; Kharuk, 2024). Although it is relatively slow and noisy, making it vulnerable to interception, its high numbers and low cost make it a persistent threat. Using this drone in saturation tactics complicates air defence efforts, as it overwhelms systems with multiple incoming threats. Conversely, rudimentary drones, such as the Shahed-136, which rely on basic GPS and minimal optical sensors, exhibit a higher susceptibility to errors and, thus, a greater likelihood of inflicting collateral damage due to their limited precision and adaptability. Various techniques and solutions are presented in the subsequent section for neutralising Russian drones.

Neutralisation of Russian drones by shooting from a helicopter

The frequency of the Shahed-136 drone attacks in Ukrainian territory presents the limits of the effectiveness of EW anti-drone solutions. To eliminate Iranian drones, Ukrainian personnel employ helicopters. Ukraine's armed forces released exclusive footage showing a helicopter destroying a Russian Shahed-136 long-range kamikaze drone, as shown in Figure 17. Mi-8 helicopters were used for these operations, equipped with nose-mounted 7.62×54-mm PKT general-purpose machine guns. Smoke fills the helicopter's cabin after several long bursts of fire, then the drone explodes and crashes. Additionally, it is reported that Russia also employs helicopters to intercept Ukrainian drones (Malyasov, 2024).

Neutralisation of Russian drones by a net covering trenches

Numerous reports discuss Russian pilots dropping a warhead from a drone or launching a kamikaze to attack soldiers in trenches. Ukrainian personnel employ a net that envelops trenches to prevent Russian suicide drone from causing harm to soldiers. It is intended to safeguard soldiers who lack armour protection.

Figure 17. Shahed-136 was targeted and shot from a helicopter (Malyasov, 2024).

Neutralisation of Russian drones by gun shooters

To neutralise a swarm of Russian drones in Ukrainian territory, shooting them out of the sky requires precise targeting, especially since the drones are hundreds of metres above the ground and relatively small (Seco, 2024). Figure 18 illustrates the gun system's capabilities as it engages a Russian drone near a roadway. The 126th TRO Brigade, known as the Ukrainian knights of night watch, reportedly traverses the countryside nightly, fervently pursuing Russian drones.

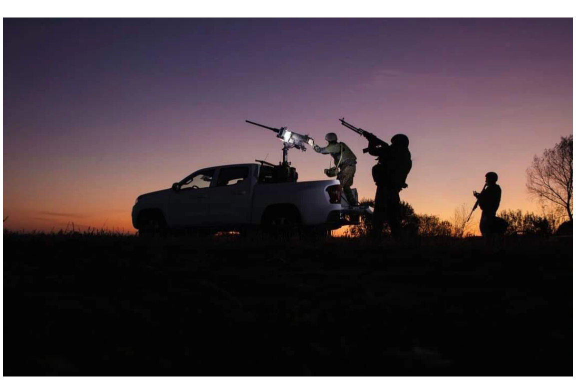
Neutralisation of Russian drones by Unmanned Ground Vehicles (UGVs)

Ground vehicle robots and drones have enhanced the practicality of remote warfare, which utilises technology to engage or influence targets from a distance without requiring direct physical presence. Following 3 years of conflict, the Ukrainians have experienced a significant number of wounded and a diminished troop count. To mitigate these challenges, they employ UGVs to eliminate Russian drones remotely (Syngaivska, 2024). Ukraine utilises high-tech, cutting-edge robot warfare. Aerial and sea drones have already destroyed much of Russia's Black Sea fleet, but land drones are still in their infancy, as shown in Figure 20.

Ukraine is putting much effort into developing robots for use on the ground:

- Robots can lay anti-tank mines (Roblin, 2024)
- They take supplies to the frontline position and stretcher to carry a wounded soldier

Figure 18. 126th TRO Brigade.



- They are easy to drive and keep soldiers out of dangerous areas
- They can replace soldiers who carry supplies on foot through dangerous areas.

While drones are prominent in the battle in Ukraine, UGVs also play a crucial role, and their development is closely monitored. Examples of UGVs are explained below:

- In addition to its weight of 1,800 kg, the Ironclad has a maximum payload capacity of 350 kg and a range of 130 km when refuelled (Shandra, 2024). The armoured hull can withstand 7.62-mm rounds, providing significant protection in combat conditions, but not entirely. The Ironclad is designed for fast deployment, with speeds of up to 20 km/h (O'Donnell, 2024).
- The Shablya M2 battle turret is fitted with a thermal camera and armour to protect against small-arms fire. Its remote operational capacity allows armed forces personnel to carry out actions from a safe distance, considerably minimising the risk to human operators (Dougherty, 2024).

Interest in UGVs stems from the significant recruitment difficulties and high casualty rates faced by both adversaries. Utilising UGVs, such as Ironclad, on the frontlines in Ukraine represents a substantial shift in modern warfare. These autonomous technologies enhance military capabilities while providing a safer and more tactical approach to warfare.

The worldwide analysis of Ukraine's utilisation of advanced technology suggests that the future of warfare will increasingly rely on unmanned and autonomous systems. Other nations have initiated the deployment of UGVs, highlighting the global trend of incorporating these technologies into modern combat.

Neutralisation of Russian UAV by aerial combat

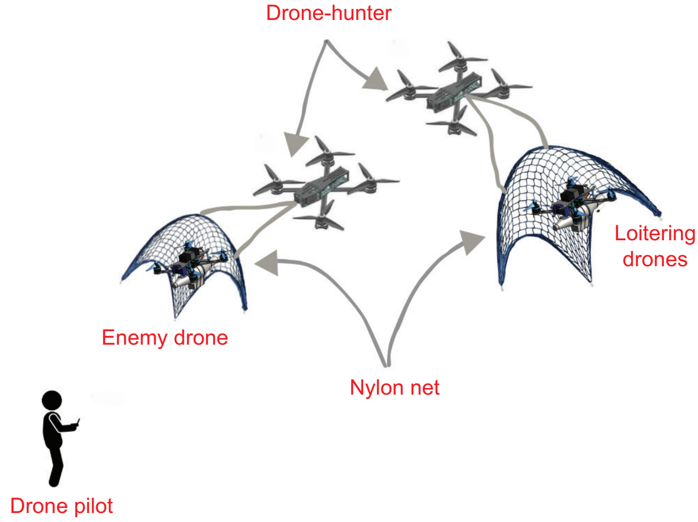
On 24 July 2024, a Ukrainian drone armed with a wooden stick neutralised a modern Russian ZALA 421 UAV in aerial combat in Kherson Oblast city (Global Defense News, Army Recognition Group, 2024). Ukraine's strategic deployment of FPV interceptor drones has substantially mitigated the threat posed by Russian Lancet drones. This approach safeguards Ukrainian military assets and exemplifies the evolving nature of modern warfare, where technological innovation and adaptability are crucial to countering advanced threats. These FPV drones have been instrumental in targeting and neutralising Russian reconnaissance drones, such as the ZALA drone, which are essential for guiding Lancet strikes. This strategy has significantly reduced successful Lancet attacks, with reports indicating a decrease of up to 90% in the number of strikes (Kulakova, 2024).

A Ukrainian project focuses on acquiring and deploying FPV drones to intercept and destroy Russian drones (Defence Express, 2025). The initiative has successfully downed over 400 Russian reconnaissance drones, including models like ZALA, Supercam, Orlan, and Lancet. In addition, Ukraine has developed a new technique for neutralising Russian fibre-optic FPV drones (Altman, 2025).

Neutralisation of Russian drone by drone hunter

Drone hunter is a new sheriff of the skies. It has four modes: attack, defence, pursuit, and tow-away, as shown in Figure 19. It is an AI-enabled, radar-guided drone that can

Figure 19. Drone hunter.



lock onto its target, deploy a net, capture the threatening drone, and tow it to a secure location (Sherman, 2023). It can be controlled from the ground if needed (Bisht, 2023; Gormezano, 2025).

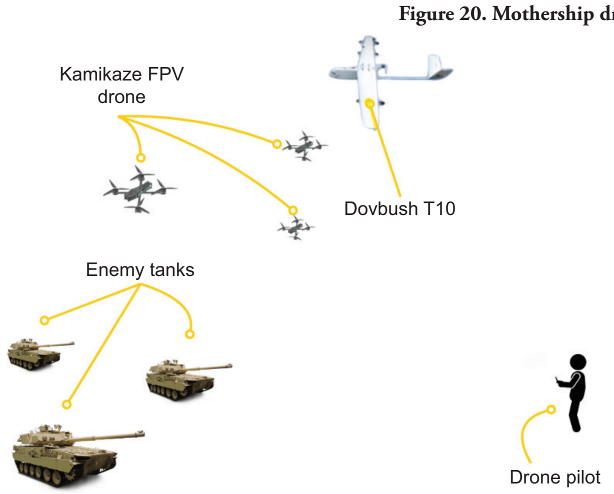
Neutralisation of Russian drones by UAV mothership

The Ukrainians have released a UAV mothership that can carry up to six FPV kamikaze drones and simultaneously act as a repeater (Dean, 2023). Domestically produced by Ukraine, the Dovbush T10 drone has assumed a new function as a mothership for FPV kamikaze quadcopters, as shown in Figure 20. It has a maximum range of 40 km and a significantly higher potential (Bhardwaj, 2024). It has a carrying capacity of around 20 kg and presents a new tactic on the frontline. Due to its design, the Dovbush T10 is a crucial signal relay node between the highly manoeuvrable one-way attackers and their operators.

Neutralisation of Russian drones by Cope cages

First-person view drones were partially responsible for some of the highest profile attacks on Ukraine's Leopard 2 and Challenger 2 tanks. Cope cages are used by Russians to protect

Figure 20. Mothership drone: Dovbush T10.



armoured vehicles from various dangers (Sheridan and Vasilyeva, 2023). Ukrainian forces also utilise the same technique. Therefore, cope cages have become a very common feature of Ukraine's armoured vehicles as the conflict continues (Trevithick, 2024).

Results and discussion

Drones have transformed military tactics, significantly altering the dynamics of warfare. In response to this multi-purpose technology, military personnel must continually monitor the skies to detect drone attacks. Despite challenges, such as limited battery life and the necessity for specialised training, both Ukrainian and Russian forces have utilised FPV technology to enhance their offensive and defensive capabilities. This study underscores the vulnerabilities of the existing technologies designed to intercept drones. It also examines the latest technologies employed in the Russian-Ukrainian conflict to counter drones. The lack of countermeasures against drones makes equipment an immediate target by drones, making it crucial to address this issue.

Drone countermeasure technologies have several drawbacks, explained as follows:

- The jammer device can disrupt radio-frequency communications of drones, but cannot neutralise autonomous drones. The jammer is unable to prevent drones from operating at a frequency that exceeds 6.2 GHz. Therefore, there is no system that effectively combats illicit drones. Anti-jammer systems have been installed in suicide drones by numerous criminals and terrorists in recent years, rendering the radio-frequency jammer incapable of neutralising them. A hostile drone can continue its mission independently even if the radio communication between the drone and the operating station is disrupted by radio frequency interference (Chaari and Al-Maadeed, 2021).

- A drone with a low radar cross-section is not detectable by radars (Mattei *et al.*, 2024).

- High-energy laser cannons have been tried against drones with encouraging outcomes; however, adverse weather condition presents a challenge (Stewart and Stewart, 2024). Other challenges include an extremely high energy requirement (3–5 kW or more) and reflective drone surfaces that can bounce the laser beam off the target, negating its effectiveness and possibly putting ground personnel or other airborne platforms at risk (Chaari, 2020).

- High-power microwave (HPM) weapons have become a significant risk to drones in 2025. HPM technique can be used to upset the electronic components of suicide drones while negating collateral damage worries. This technology gives a unique capability that prevents potential adversaries from attacking or compels them to stop a course of action. However, the US Army Research Laboratory published a report discussing the effects of fog and rain on HPMs. Extreme weather conditions influence HPM energy effectiveness. Climatic turbulence causes wavefront distortions in the microwave energy signal, impacting HPM's efficiency and causing high attenuation rate (Bringi *et al.*, 1990; Gossard, 1981). HPM's conversion efficiency is affected by atmospheric variations, physical obstructions, and weather conditions. High microwave energy can affect the army infrastructure before it affects enemy drones. To evaluate the heating phenomenon surrounding the HMP system, a prototype was developed in the laboratory to refine the concept. In this regard, a magnetron generator connected to a horn antenna was employed to transmit microwave energy throughout the laboratory. A thermal camera was utilised to evaluate the effects of microwave energy on the affected region during HMP propagation. Figure 6 demonstrates that the vicinity of the transmitter station is depicted in dark red, indicating elevated temperatures. The transmitter generates elevated temperatures that impact the electronics adjacent to the magnetron, as shown in Figure 21.

The high temperature around the antenna affects its directivity and efficiency, as illustrated in Figure 21. This heat propagation from HPM systems poses a significant challenge for any corporate army. The thermal camera of the adversary will be able to observe the transmitter location from a great distance, making it highly vulnerable to attacks by multiple forces, kamikaze drones, and aircraft.

- Full-automation drones can use various tools to plan their flight as autonomous learning systems. A radar system with the capacity to detect objects with low radar cross-section is the most effective method for detecting them.

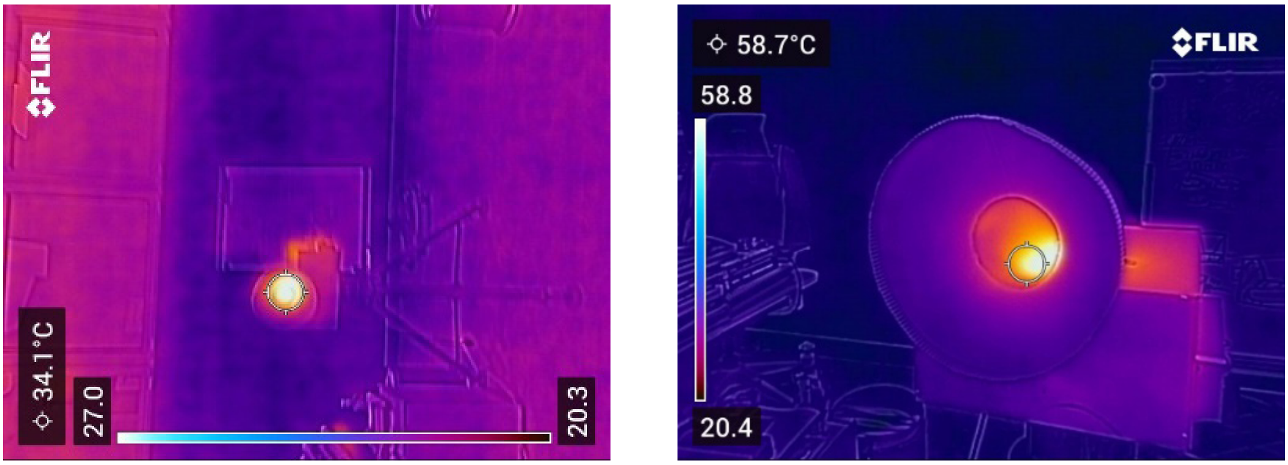
- The DJI AeroScope system does not detect all DJI drone models. The AeroScope system experiences difficulty in recognising drones produced before 2014 (Wallace *et al.*, 2024).

To mitigate the threats posed by this advanced technology, frontline areas are implementing various EW and counter-drone systems designed to disrupt enemy drones. Adapting to the war situation and utilising available resources to produce innovations is a good idea. This research presents and studies all available technologies used to destroy and stop drones before they are used in attacks as well as key robots and drones involved in the Russo-Ukrainian war. Although passive anti-drone methods, such as grid barriers and netting, are quite effective, their inconsistent results highlight the need for more standardised and potentially advanced counter-drone technologies. Based on the results of the analysis, the passive counter-drone methods have some drawbacks. The innovations employed by both adversaries during the conflict have advantages and disadvantages, as outlined in Table 6, which highlights the benefits and drawbacks of each anti-drone solution.

Conclusions

Recent events have demonstrated the effectiveness of low-cost drones in warfare and the challenges and expenses associated with establishing robust defences against drones in

Figure 21. The thermal camera shows heat propagation around the HMP system.



http://doi.org/10.35467/sdq/208347

Table 6. The new countermeasures in the Russo-Ukrainian war: their advantages and disadvantages.

Anti-drone technology	**Disadvantages**	**Advantages**
Cope cages	The technique requires mechanical maintenance, and its efficiency is very low for front loitering drones.	Ukraine combat lessons: on Monday, Libya's General Haftar held a military parade that featured Soviet-made T-72 and T-55 main battle tanks equipped with counter-drone physical protection.
Cerberus system	The vehicle can produce heat, presenting an IR signature that enables a rocket to latch onto the Cerberus system and destroy it.	This innovative technique utilises fibre-optic communication to control drone swarms, enhancing accuracy and resilience to electronic disruptions.
Shotgun	It cannot be used in urban areas.	The option is to shoot at the drone while it is in the air. The shot must be highly accurate, especially since the drone is hundreds of metres in the air and relatively small.
Nylon net barrier	Airburst artillery (155 mm, 152 mm, and 105 mm): a well-placed proximity-fused shell would shred these nets in seconds, rendering the entire corridor useless. Cluster munitions could achieve the same result with even better area coverage.	Nets are the most effective method of preventing drone attacks in the conflict.
Steel mesh net barrier		Steel mesh and nets are the most effective methods of protecting strategic areas against FPV drone attacks.
UGV robot	It can be neutralised quickly with artillery or rockets; it presents an IR signature.	Interest in UGVs stems from the significant recruitment difficulties and high casualty rates faced by both adversaries. These autonomous technologies enhance military capabilities while providing a safer and more strategic approach to warfare. (Bendett, 2024)
Aerial combat	Efficiency is low	It can neutralise its target in the sky without any effect.
Fibre-optic FPV drone	The weight of the fibre-optic conductor slightly reduces the FLF time. Initial scrutiny focused on the durability of fibre-optic cables against real-world impediments, including trees, buildings, and rugged terrain.	It provides crystal explicit imagery; these drones are immune to electronic jamming (Hambling, 2024a; Nikolov, 2024).

critical at-risk areas. Drones and robots have substantially altered the dynamics of conflict. Ukraine and Russia will continue to employ drones throughout the conflict and beyond, as these technologies have successfully addressed many of their operational challenges. In the Russo-Ukrainian war, drone defences have been largely ineffective, primarily due to the ineffective performance of jammers, as some drones are immune to jamming. As these systems become less effective, a new Counter-Unmanned Aerial System (CUAS) will be required. Currently, the most effective way to prevent drone attacks is through netting. Essentially, netting should be placed at strategic locations. Fortunately, affordable nylon netting effectively deters these attacks. Experts recommend using basic automatic weapons to target drones from the air. This indicates that novel solutions are also insufficiently effective. The threat presented by small drones is significant and likely to persist. The use of drones has become a dominant force on the battlefield. A high-efficiency system must be able to detect and stop every illegal drone.

Governments should collaborate to develop advanced counter-drone technology that prevents drones from posing risks in civilian areas and on the frontlines. The international community should pressure drone companies to stop selling their technology to conflict zones globally. FPV pilots kill people without experiencing the emotional weight of their actions. The issue is of paramount significance due to the rapid pace of technological advancements in the field of warfare. This situation has prompted a call for urgent international cooperation to establish comprehensive regulations that address the challenges posed by illicit drones. No nation is immune to the frontline drone.

Funding

This research received no external funding.

Data Availability Statement

Not applicable.

Disclosure Statement

No potential conflict of interest was reported by the author. The author obtained copyright permission for the images published in the paper. The author read and agreed to the published version of the manuscript.

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