Chapter

Unprecedented Developments in Drones on the Frontline

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Abstract

Edge technology is transforming warfare. Drones offer a more cost-effective way to wage war and conflicts. AI-driven autonomous drones are altering the international power balance. Drones, which present open-source technology, are now easily and quickly accessible to extremist groups, rebels, or regimes worldwide. Drones have created a new battlefield characterized by high efficiency and low-cost bombing of strategic enemy sites. This technology emerged with the onset of the conflict in Ukraine, where I played a key role in shifting the balance of power. Highly efficient and advanced drone technology has exposed the shortcomings of commercially available counter-drone systems. This research examines the effectiveness of drones on the evolving battlefield in many places, with a particular focus on their cost-effectiveness as a case study. The manuscript also examines three case studies of drone use that have changed the international security landscape, beginning with unprecedented drone development during the Russia-Ukraine conflict, followed by the application of drone technology in the Syrian conflict, and finally, the impact of drones on the India-Pakistan conflict. This research study also provides more details on low-tech methods for neutralizing drones.

Keywords: first-person view, geopolitics and international security, countermeasure drone, kamikaze drone, defense and security, Russo-Ukrainian war

1. Introduction

In recent years, hobby and commercial drones have become widely available anywhere. Beyond entertainment purposes, this technology has many uses, including oil and gas tank inspections, building inspections, irrigation, and many other applications [1–3]. Many companies, such as the Chinese DJI company, produce many types of drones for hobby applications. These small quadcopters can be controlled using radio frequency devices or by wearing inexpensive and readily available goggles from China parts [4]. Unfortunately, DJI drones are frequently misused in various parts of the world. As drones have become more accessible, malicious actors have begun to exploit them for illicit purposes, including terrorist groups, drug dealers, criminal organizations, and the killing of civilians in many conflict zones [5–7]. A drone can carry a high-resolution camera and fly over sensitive areas to gather private information and conduct surveillance. Drones collect data, perform surveillance, carry out reconnaissance, engage in combat, and locate mines. Similar in design to racing drones, battlefield drones operate with reduced power consumption.

Drones are lethal weapons that are challenging to protect against, despite their apparent utility. Airports and other key sites are seriously threatened by even the cheapest drones, which are only capable of carrying a few grams of explosives. The growing frequency of accidents at public buildings and airports increases the necessity for new solutions to defend against drone threats [8, 9].

Since the Russo-Ukrainian conflict, both forces have engaged in drone-centric warfare, taking advantage of these cost-effective and easily assembled drones to carry out precise attacks and defend against attacks. Despite challenges such as limited battery life and the need for specialized training, Ukrainian and Russian forces have embraced FPV (first-person view) technology, enhancing their offensive and defensive capabilities [10]. FPV drones can carry mortar bombs or RPG projectiles, while smaller ones carry small amounts of TNT wrapped around in some duct tape. They are usually detonated with a couple of rigid wires that touch upon impact [11–13]. Drones' performance depends on guidance systems; some models rely significantly on advanced GPS technology, whereas others combine inertial navigation systems with optical or infrared sensors for improved targeting. Drones have been deployed to monitor enemy forces, guide artillery, and strike targets during the Russo-Ukrainian conflict [14]. Due to their high potential in warfare, many civilian and military manufacturers have shifted their production to drones, resulting in a new era of remote warfare. As a result of ground vehicle robots and drones, remote warfare has become more practical, using technology to engage or influence targets from a distance without requiring direct physical presence [15, 16]. Remote warfare is not a novel concept. Remote warfare primarily aims to reduce soldier casualties, reduce the financial burden of conflict, and minimize the damage to tanks, vehicles, and military assets. However, drones represent the most advanced evolution in this lineage, combining robust surveillance and offensive capabilities. In this regard, the evolution of remote weaponry systems from previous generations to current standards in modern warfare is illustrated. Since the advent of drones in modern warfare, they have played a significant role in transforming the mechanics of conflict [17]. The considerable influence of drones results from three fundamental attributes. First, their diminutive size increases their ability to elude radar detection, rendering them less conspicuous and more difficult to intercept. Second, drones are relatively inexpensive and easy to use. Third, they alleviate nations' numerous challenges when incorporating them into their military inventories. Although incidents vary somewhat, one idea is clear: the drone can mean many things; therefore, we must discuss it. This book chapter is organized as follows: Section 1 is the introduction. Section 2 examines the cost-effectiveness of drones. Section 3 details the role of drones on the frontline in various locations worldwide. Section 4 presents the shortcomings of existing anti-drone and electronic warfare technology globally. Ultimately, we conclude with a discussion and conclusion.

2. Cost-effective

The rapid and effortless detection and neutralization of drones challenge many radar systems. Drones are a new factor in the present war. Powerful nations, possessing the most expensive Patriot anti-missile batteries, do not specifically design them to destroy drones used in recent attacks. Incredibly maneuverable, these small drones can torture a soldier until he is brutally killed [18].

The evolution of these essential instruments into sophisticated systems introduced new risks and had significant implications for modern warfare. Among the most critical advances in drone technology has been the development of kamikaze drones, weaponized drones, or loitering munitions. Generally, kamikaze drones perform different functions based on the accuracy and efficiency of their guiding systems. Compared to traditional remote warfare systems, such as rockets, kamikaze drones have attracted more attention worldwide. They are attracting more attention due to their many unique characteristics. As they are more affordable, easier to use, and more common, they are more likely to be used against people in a new war [19]. The primary concern regarding using low-cost, modified drones has been their capability to deliver high-explosive payloads. Drone attacks target critical infrastructure. There are many lessons to be learned from comparing missiles and drones. Both rockets and kamikaze drones use a complex guidance system to deliver precise, deadly payloads. However, kamikaze drones have distinct advantages. Introducing precision-guided missiles and other newer weapons systems has improved the accuracy and effectiveness of attacks [20]. As missiles require extensive infrastructure and specialized knowledge, they are more challenging to obtain, and their use is more restricted. Patriot missiles are not available for acquisition or use by any nation, while drones are not highly technology-dependent. It is ineffective to use missiles against them, including man-portable air defense systems (MANPADS). The drones are too small and have virtually no IR signature to be detected by a rocket.As a case study, the Geran-2 cost was estimated to be approximately $20,000 to $30,000 per drone according to many sources and reports. It is easy to manufacture or buy from Iran. Russia scaled up its domestic Shahed production by utilizing African workers and Chinese components. According to information and reports from the frontline, the Shahed-136 has a very low hit rate. Approximately 10% of hits are recorded on average. On the other hand, cruise missiles cost approximately $900,000 to $1.000,000. The missile's cost is 27 times the Shaheed drone's cost. Shaheed and missiles have the same effect and are often used for strikes against Ukrainian cities and infrastructure. **Table 1** illustrates the significant differences between drones and missiles in terms of price, battlefield sophistication, and logistics materials required for launching. Missiles can carry more explosive material than drones and have a lower likelihood of killing civilians.

Table 2 analyzes the cost-effectiveness of drones in comparison to missiles on several parameters, including cost, hit percentage, payload, technology, range to reach the target, and speed.

As a result of Sunday's attack on Ukrainian airfields, 117 drones were used to strike 41 military aircraft. Ukrainian drones hit more than 40 aircraft, including

Drone	Missile
Low price	High expensive
Low sophisticate	High sophisticate
It is easy to re-manufacture by reverse engineering	Requires high-scale staff to manufacture
No need launcher station	Need launcher station
Very high possibility of killing civilians	Very low possibility of killing civilians
Payload low explosive material	Payload high-explosive material

Table 1.
A comparison between drones and missiles.

Weapon	Cost (USD)	Hit percentage (%)	Payload (Kg)	Sophisticate	Range and speed
Shahed 136 drone [21]	35.000 USD	11–15	50	Low Sophisticate	2500 Km–185 km/h
Shahed 131 drone [22]	23.000 USD	11–15	40	Low Sophisticate	900 km–131 km/h
Iskander (k) cruise missile [23]	1 million	35–40	450	Low Sophisticate	2000 km–2000 m/s
Iskander (M) cruise missile [24]	2 million	90–95	450	High Sophisticate	2000 km–2600 m/s
Tochka cruise missile [25]	300.000 USA	75–85	480	Meduim Sophisticate	120 km–600 km/h
kalibr cruise missile [26]	6.5 million	90–95	450	High Sophisticate	2500 km–980 km/h
Zircon hypersonic cruise missile [27]	10 million	93–97	400	High Sophisticate	1000 km–10,000 km/h
Oniks cruise missile [28]	1.25 million	93–97	300	High Sophisticate	300 km–3180 km/h

Table 2.
Drone cost-effectiveness in comparison to missiles.

A-50, Tu-95, and Tu-22 M3, according to Ukraine's Security Service (SBU) sources. The report states that Russian strategic bombers are massively burning in Russia. The Security Service of Ukraine was conducting a large-scale special operation to destroy enemy bombers in Russia's rear. The SBU drones target aircraft that bomb Ukrainian cities every night. The Russian aviation has been preliminarily damaged to the tune of more than $7 billion. This unique special operation was called "Spiderweb;" others referred to it as Russia's Pearl Harbor [29]. An FPV explosive drone strike by Ukraine was carried out approximately 1700 km from Ukrainian territory. This is likely the largest and most significant drone-based sabotage operation in history. Russia's losses already exceed $7 billion. A total of 40 aircraft are known to have been destroyed: A-50s, Tu-95 s, and Tu-22 M3s. **Table 3** provides the name, price, and description of the aircraft struck by the Ukrainian drone.

Aircraft name	Price	Description
A-50	$350 million	Aircraft Long-Range Airborne Surveillance
TU-95	$30 million	One of the few long-range strategic aircraft bombers without a nose refueling probe
Tu-22 M3	$100 million	Strategic bomber

Table 3.
A list of Russian aircraft hit by Ukraine in operation spiderweb [29].

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3. Drones on the frontline in different places worldwide

This section examines three case studies related to drones' impact on power balance, geopolitics, and international security. Drones' efficacy alters numerous political strategy dynamics in Europe, the Middle East, and Asia.

3.1 Case study 1: Unprecedented drone developments during the Russia-Ukraine conflict

The Russo-Ukrainian conflict is speeding up the development of autonomous warfare technologies that haven't been seen on other battlefields, despite the widespread use of drones in modern conflicts. Substantial advancements have been made in the development of drones in Ukraine over the past three years of conflict. Dominika Kunertova investigates the development of drone technology and its impact on the battlefield. Drones have considerably altered modern battlefields [30].

- Ukrainian drones, including the most recent Bulava drones, are capable of conducting high-precision assaults on critical Belarus and Russian targets, including armored vehicles, air defense systems, and electronic warfare systems [31].
- In Russia, the Shahed 136 (Geran-2) has been upgraded to improve efficiency, accuracy, and danger. Russia is the manufacturer and introducer of new drones that possess a variety of functions and advantages during the conflict. During the conflict, Russia developed new industries and microeconomic drones, such as the Orlan-10, Orlan-20, Lancet (51/52), Garpiy-A1, etc. [32].

The following subsection presents and examines new drone techniques that can be used in the war in Europe to avoid electronic warfare and to destroy any enemy locations and goods with high accuracy and low cost.

3.1.1 Fiber-optic guided drones

The cat-and-mouse game of drone development has been a hallmark of this conflict. Drones are typically connected to their operators via radio link communication, but radio signals can be jammed. During the initial months of the conflict, jamming and electronic warfare played a significant role in neutralizing drones from both sides. To bypass these highly effective jammers, both adversaries have turned to fiber-optic drones [33–35].

- Russia was the first to introduce fiber-optic FPV drones, using them for reconnaissance and attacks on Ukrainian forces. Russia continues to strive to produce fiber-optic spools using Chinese technologies [36]. It manufactures a drone-operated fiber control system with a photoelectric module for anti-jamming capabilities over a distance of 15 kilometers (shown in **Figure 1**). They provide high-resolution videos as well as being resistant to electronic jamming. This is not a broadcast, so distributing is not very easy.
- The Ukrainian Armed Forces have been authorized to use a drone named "Hromilo Optik." In recent months, fiber-optic drones have successfully attacked Russian vehicles and positions in various configurations, demonstrating their

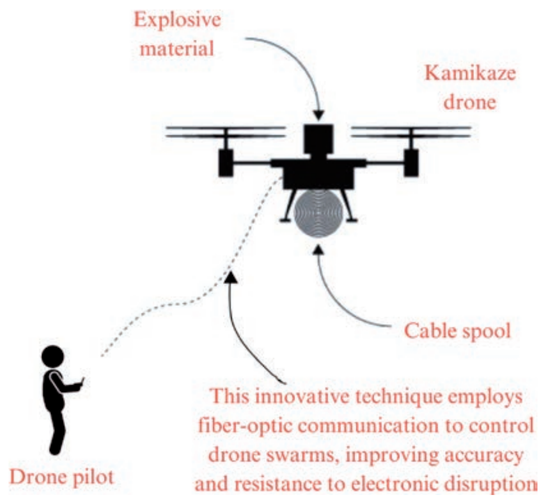

Figure 1.
Exploded view of drones controlled by fiber-optics.

effectiveness on the battlefield [37]. Ukrainian manufacturers have developed a larger drone known as the "Hromilo," with a 10-inch frame size capable of carrying powerful warheads to destroy main battle tanks with reinforced armor and fortified enemy positions. As a result of their fiber-optic guidance, these drones are substantially more resistant to electronic warfare. They can also maintain control even when operating behind enemy lines. By combining the latest technology with next-generation interference resistance, Ukraine has refined and expanded its drone capabilities further.

Fiber-optic drones from both sides are equipped with the most advanced video systems available, including thermal, low-light, and daylight cameras. These systems enable them to identify targets in any environment, 24 hours a day. Russian and Ukrainian forces can overcome electronic warfare (EW) using fiber-optics technology.

The following case studies demonstrate that both adversaries utilize fiber-optic drones to evade jamming.

- Case study 1: A Russian warhead FPV drone infiltrated a barn where a Ukrainian Bohdana wheeled howitzer was parked. The drone crashed into the howitzer's cab, causing significant damage [38].

- Case study 2: A Ukrainian drone from the Ukrainian National Guard with a fiber-optic guided drone destroyed five Russian howitzers and a Grad MLRS [39].

3.1.2 Shahed upgrades: Russia's response to pressure in drone warfare

In the past year, the Ukrainian military has shot down 14,286 Shahed drones [40]. Due to the ineffectiveness of this approach, Russia has integrated GLONASS navigation into its independent strikes. In 2025, Russia began localizing Shahed-136 production at Alabuga plants, introducing structural changes and new variants, including the K and Y series [22]. Some of the most essential sensors are pressure sensors, magnetic sensors, speed sensors, and FPGAs, which are commonly sourced from companies such as Texas Instruments, ST Microelectronics, Honeywell, and Analog Devices. More than 60% of critical components of the Shahed drone come from the USA, Europe, China, Taiwan, and other countries, despite localization [41, 42]. The conflicts have forced adaptations, but have not resulted in complete technological independence. By exploiting gray-market supply chains, Russia continues to optimize designs for cost and resilience.

Initially constructed by the Iranian military, but now assembled and upgraded by the Russian military in the following ways:

- Improved frames by shifting from cardboard honeycomb to polystyrene and fiberglass, boosting resilience [43].

- Update the navigation evolution with adaptive antenna arrays with high directivity from the Comet company. Russians install the 4G modems (late 2023) and the RTK GNSS modules (2024) to overcome jamming [44].

- Update the engines by simplifying and lightening the design, Russian update versions removed starters and flywheels.

- The upgraded drone carries a 90 kg warhead, compared to the previous 50 kg Shahed-136 version, significantly enhancing its destructive capabilities (Geran-3). The Shahed-136 drones, which are referred to as the Geran-2 in Russia, have been updated to include a more powerful warhead and supplementary ballast in the UAV design. With the heavier payload, the drone's range has decreased from 1350 kilometers to approximately 650 kilometers. This change limits its range but makes it more deadly at close distances [45, 46].

Russian "Shahed" drones are operational in a dual-warhead configuration, according to Ukrainian sources. As a consequence of a novel tactical strategy:

- Cluster dispersion: Step one, the drone discharges up to 20 cluster fragmentation submunitions over the target at an altitude of approximately 250 meters. Each submunition contains 1464 pre-formed steel fragments (3x5 mm). The casings are dispersed over a 40-by-75-meter area.

- Direct strike: Step two, the Shahed returns and impacts the target with its second warhead as a standard loitering munition. Access to the area is denied, and psychological and logistical disruptions are caused by the submunitions, which detonate between 2 and 20 hours after being dropped. The final detonation may occur as late as 20 hours later.

3.1.3 Swarm drone

Swarm drones present a high-potential system to saturate radar and the anti-drone system; this technique is called saturation mode. Saturation mode presents a weak point for the radars and the anti-drone system. Swarm drones are highly effective at diminishing the detection capabilities of anti-drone systems, like radar or cameras. The pan-tilt mechanism of any anti-drone cannot match the high speed of the drone moving in multiple directions simultaneously [47–49].

When many drones are deployed simultaneously, they distract the electronic systems, allowing some drones to breach enemy lines and effectively destroy multiple targets.

Drone swarms have become more prevalent recently, particularly during the Russo-Ukrainian conflict. Numerous recent developments have eliminated the conventional requirement for one operator per drone, substantially increasing operational efficiency.This improvement fixes a significant weakness in swarm-based warfare systems, which often struggle against communication systems that use electronic warfare tactics. Interest in drone swarms has surged amid the ongoing Russo-Ukrainian conflict.The following case studies demonstrate how both adversaries utilize swarm drones in their operations.

- Ukraine launched dozens of drones over a broad area of Russia on Monday night to eliminate three military airfields, according to reports. In 11 regions, the Russian Defense Ministry reported that its air defense intercepted approximately 160 drones during a 10-hour barrage that disrupted commercial aviation [50].

- On March 30, 2025, Russia launched 111 swarm drones and a ballistic missile, resulting in damage to Sumy, Odesa, and Donetsk [51].

3.1.4 FPV drone

Since February 2022, the Russo-Ukrainian battlefield has implemented various tactical methodologies utilizing FPV drones. Each adversary is continuously devising its next course of action.

FPV is employed for diverse purposes, including artillery direction, reconnaissance, evacuations, and direct attacks. FPV drone has evolved into a more destructive battlefield weapon capable of operating as a kamikaze unit or deploying explosives [52]. FPV and kamikaze drones are becoming increasingly significant in this new combat paradigm. These tools are scalable and affordable and highly effective in identifying hostile positions, conducting reconnaissance, and locating artillery [53].Various categories of FPV drones are employed in combat, including kamikaze, bomber, ISR, and relay drones [54]. As part of the Russo-Ukrainian war, both adversaries employed so-called kamikaze drones (shown in **Figure 2**).Kamikaze drones are relatively small battery-powered drones of various sizes and shapes used in the Russo-Ukrainian conflict. In contrast to advanced drones equipped with sophisticated sensors and communication systems, kamikaze drones are intended to remain airborne for extended periods, identify and engage targets with high precision, and then crash into the target, resulting in the drone's destruction. These drones can reach almost all frontline locations, providing unprecedented attack accuracy. The dramatic drop in parts prices, the massive improvement in navigation, the addition of automatic stabilization capabilities, and the simplification of the overall control process have made them precise, accessible, and easy to use.

Apparently, all of this explains why the Ukrainian government plans to manufacture 1 million FPV drones during the next year. Russia is not lagging behind and manufactures drones at six times this rate.

3.1.5 AI-enabled autonomous

As a result of the high-stakes environment, both the public and private sectors have prioritized technological advances, such as artificial intelligence, to enhance military capabilities. Due to this urgency, there was also a greater willingness to experiment

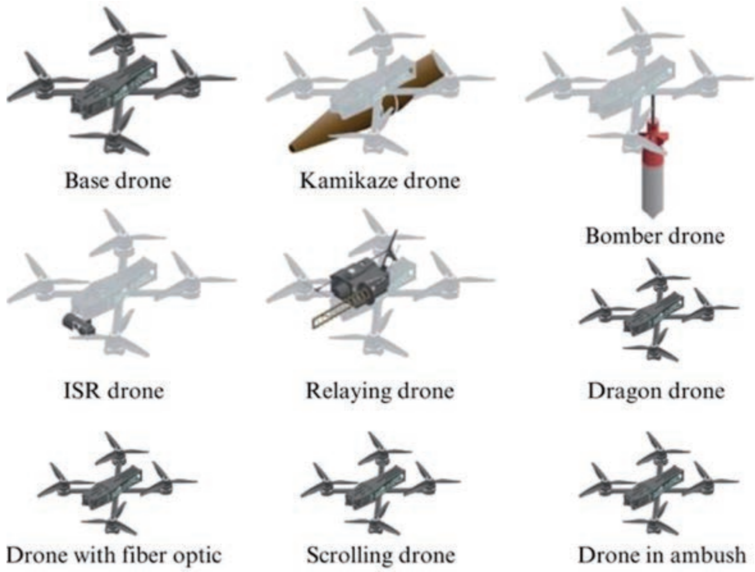

Figure 2.
Various missions of the FPV drone in the Russo-Ukrainian conflict.

with artificial intelligence, resulting in a faster deployment of AI-based capabilities during combat. Russia and Ukraine are developing dozens of AI systems to help their drones hit targets [55–57]. Drones are equipped with AI-augmented systems that can reach targets on the battlefield without pilot control and a ground control system. Using artificial intelligence, cost-effective drones carrying explosives can penetrate areas protected by extensive signal jamming, reducing the effectiveness of manually piloted drones. These advancements use human-in-loop and dependable AI systems that allow drones to operate more independently with intelligent agents built into them. Continuous communication with control stations allows these autonomous systems to evaluate their environments, exchange target data with other drones, and make mission-priority decisions. AI-enabled drones have been developing for years, but were previously perceived as expensive and experimental. In the years leading up to the 2022 conflict, Russia had developed AI-enabled drones that had some success, according to Bendett [58]. The primary objective of Ukrainian manufacturers is to develop a cost-effective AI targeting system for drones.Running AI programs on a Raspberry Pi, a tiny, inexpensive computer that has gained global popularity beyond its intended educational use, can reduce costs (shown in **Figure 3**). Makarchuk estimated that implementing a straightforward targeting system, which would latch onto a shape visible to the drone's camera, would cost approximately $150 per drone. Thermal cameras can observe heat propagation from the Raspberry Pi 5 from a greater distance. As a result, it will be more susceptible to attacks by multiple forces, such as drones, aircraft, or gunfire (shown in **Figure 4**). Infrared signatures from the Raspberry Pi, Nanojeston, or any FPGA platform can be detected by missiles and snipers.

3.2 Case study 2: Using drones to overthrow Syria's regime

From the very first day in November 2024, the opposition in Syria has used drones as a novel approach to undermine the regime, thus shifting the dynamics and

Figure 3.
AI military drones need high computer vision-based navigation.

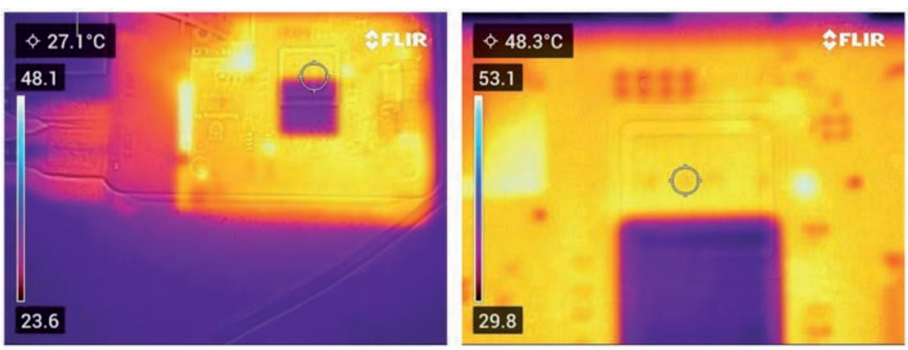

Figure 4.
Raspberry Pi 5 thermal image.

balance of power in Syria. The lightning offensive that culminated in the capture of Damascus and the fall of Bashar al-Assad's regime was decisively influenced by the sophisticated deployment of drone technology by Syrian rebel forces. The drone units of the Syrian opposition, called the Al-Shaheen brigades, are allegedly employing an unprecedented type of turbojet-powered kamikaze drone against a military base of the Syrian government [59]. Relentless drone attacks that government forces were unable to counter effectively are shown in **Figure 5**. Don and Yannick report in a published work entitled "On the Horizon: The Ukraine War and the Evolving Threat of Drone Terrorism" that the rebels' locally developed "Shaheen" drones, together with Ukrainian technical expertise, led to the rapid collapse of government forces, transforming what had been a grueling stalemate.

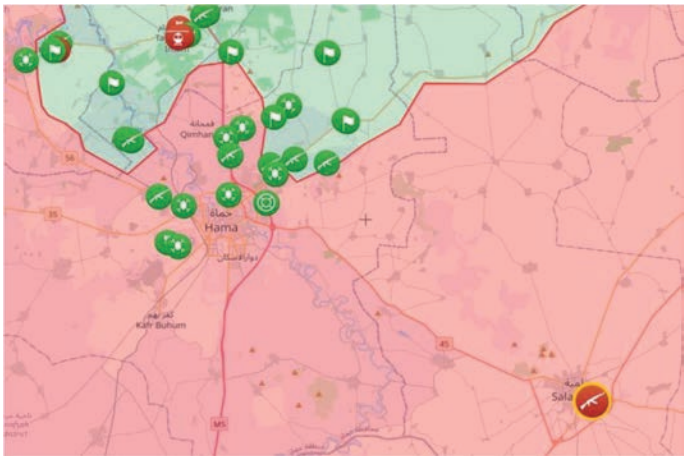

Figure 5.
Map of drone strikes against Syrian regime targets (Image credit: https://syria.liveuamap.com/).

The Shaheen drones, which were developed in-house, were the focal point of the insurgents' breakthrough, as they represented a radical improvement in their capabilities. Insurgents claimed that these fiber-reinforced aircraft exhibited remarkable precision, with a less than 5% error rate in the targeting of armored vehicles and strategic assets, and were equipped with live-stream cameras [60]. Engineers developed these systems using 3D printing and commercially available components by reverse engineering captured Russian and Iranian drones. The result was a platform that was both adaptable and resilient.

At least 200 drones were stored in a warehouse facility located in rebel-controlled Idlib Province, from which numerous operations were initiated.

Ukrainian support was essential, as approximately 20 experienced drone operators and 150 FPV drones enhanced insurgent capabilities. This assistance arrived 4–5 weeks before the offensive, providing essential tactical expertise that improved operational efficiency. Turkey also assisted Syrian rebels in developing the Shaheen drone.

3.3 Case study 3: The proliferation of drone usage extends into the India-Pakistan war

In South Asia, a drone war has erupted between India and Pakistan. In the wake of the India-Pakistan conflict, experts say the tit-for-tat attacks signify a new phase in edge technology that is dangerous. Since the start of the Indian-Pakistani conflict, drones have been used for munitions, surveillance, and reconnaissance. The Indian forces use reconnaissance drones to gather intelligence about terrorist locations in Kashmir.

- Indian troops use Israeli-made Harop loitering munitions that can fly in the air for 6 hours to attack Pakistani territory [61]. The Harop loitering equipment can carry payloads up to 16 kg. The Harop, designed for precision strikes on radar and C2 targets, is vulnerable to spectrum denial in contested airspace.

- Indian military forces have extensively used the loitering Munition Skystriker in the conflict with Pakistan. It is an Israeli drone manufactured in India. With a range of 100 kilometers and ammunition weighing between 5 and 10 kilograms, this drone has caused significant damage to the Pakistani military [14].

The Indian government accused Pakistan on 8 May of launching waves of drones and missiles at three military bases in Indian territory and Indian-administered Kashmir. Pakistani forces have reportedly recovered another nearly intact Indian Harop loitering munition, suggesting a non-kinetic takedown. Evidence points to an electronic warfare (EW) defeat likely via GPS jamming or link disruption, rather than interception by hard-kill systems. Pakistan claimed it had shot down 25 Indian drones in recent hours. The Pakistan Army Air Defense Corps used a Chinese ZU-23-2 anti-aircraft gun to fire on one-way Indian attack drones near the old Walton Airport, Lahore, in response to deep-penetration drone incursions into Pakistani airspace. The Pakistan Army successfully destroyed a large number of Harop loitering munitions [62].

- Offers valuable opportunities for reverse engineering for the Pakistani army and its partners, such as China,
- Presents questions regarding the effectiveness of the anti-drone used by Pakistani forces and the vulnerabilities of the Harop drone,
- Means a new counter-drone and electronic warfare calibration in the region.

Likewise, Pakistan uses loitering drones to strike Indian territory and to watch and observe strategic areas in India. The Pakistani military launched approximately 300 to 400 drones, known as Turkish-made Asisguard Songar models, toward Indian positions.

4. The shortcomings of existing anti-drone and electronic warfare technology globally

In this section, we will discuss two situations that utilize a new anti-drone technique to prevent any drone attacks: the first being the Russia-Ukraine conflict, and the second concerning the protection of the Pope's funeral in Rome.

4.1 Efficacy of a novel anti-drone technique in the Russia-Ukraine conflict

With the high technology provided by both adversaries, the available anti-drone system is useless. In many studies, Weston has pointed out the significant limitations of counter-drone and EW systems, especially for Ukrainian troops, since the number of attacks is extremely high. Current technologies cannot neutralize rogue drones as FPV drone attacks, including RF jammers, handheld gun jammers, lasers, high-power microwaves (HPM), and DJI Aeroscope, become more frequent. Experts have determined that the demand for anti-drone devices in the market is escalating rapidly. The jammer device can disrupt radiofrequency communication linkages with drones; nevertheless, it cannot halt autopilot-programmed, autonomous, and fiber-optic drones. The anti-drone and capture system has limitations, including a restricted range to intercept swift and nimble drones. It is well established that current anti-drone technologies cannot entirely disable drones. 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 produces the DJI drone matrix and Mavic, produces the DJI Aeroscope. The aeroscope can expose and attract the position of the drone operators. DJI Aeroscope can detect only drones manufactured after 2014.

The increasing number of attacks by modified and programmed drones shows the limitations of existing technology to kill errant drones (**Table 1**). Both adversaries, Russia and Ukraine, spend a significant amount of money to purchase technology to stop illegal drones, but current technology cannot do it efficiently. This next section discusses the high-tech solutions available for the Western European conflict.

Table 4 presented the type of damage that can be caused by the anti-drone technology, as well as the limitations and benefits of the technology, and the country that uses the technology. Russian and Ukrainian forces developed several anti-drone techniques during the conflict, including nylon nets, metal mesh shielding, drone shooting, and drone neutralization with hunter-killers (shown in **Figures 5** and **6**).

Anti-drone technique	Type of damage	Limitation	Benefit	Country
Laser weapon	Detection and destruction,	Climate-sensitive.	The UAV cameras may be blinded, or the target may be burned or destroyed.	Ukraine [63]
SERP-VS6D [64]	Detection	Suppressing radio signals	high-precision passive detector capable of identifying a variety of Ukrainian drones, including FPV drones	Russia
MOLOT (Anti-drone interceptor) [65]	Destroy	Speed limitation	Intercept air targets	Russia
Rapira 2 [66]	Detect, track, and neutralize	The ISR drone identifies it	A sophisticated radar and electro-optical suite that enables it to monitor its surroundings, detect targets	Russia
HPM weapon	Detection and destroy	Presenting an IR signature that enables a rocket to latch onto and destroy it quickly.	HPM systems produce a magnetic field, eliminating errant and suicidal drones	Ukraine [67]
GPS, GNSS Spoofing	Destroy	Spectrum sensing systems are beneficial	Could exploit the vulnerabilities of various drone systems	Ukraine and Russia [68]
DJI Aeroscope system	Detection and destruction	Challenges in identifying drones manufactured before 2014	Geofence	Ukraine and Russia [69]
Handheld gun jammer	Destroy	Effective only for short distances	High efficiency jammer	Ukraine and Russia [70]
Harpoon-3	Destroy	Low range	High performance	Russia [71]
R-330ZH Zhitel	Destroy	Presenting an IR signature	EW jamming communication	Russia [72]
L3Harris' VAMPIRE	Destroy	Low range	High performance	Ukraine [73]

Table 4.
The advantages and disadvantages of available anti-drone technology.

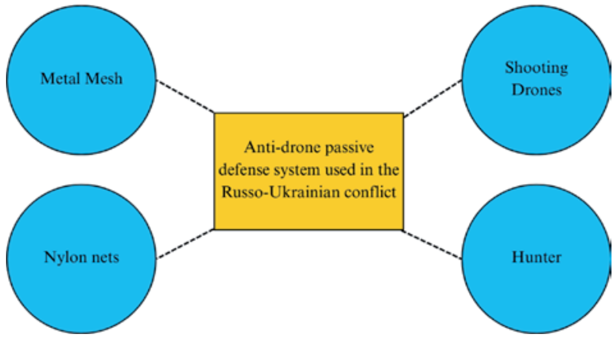

Figure 6.
A new anti-drone solution is presented in the Russo-Ukrainian conflict.

4.1.1 Neutralize fiber-optic FPV drone by nylon nets

Countering fiber-optic FPVs electronically is difficult because they are immune to jamming. To neutralize them, both antagonists utilize fishing nets [74].

- Case study 1: The Ukrainian National Guard's 14th Brigade shows a Russian fiber-optic FPV drone entangled in counter-drone netting on a Ukrainian tank. Creating last-ditch defenses when EW fails requires physical countermeasures such as mesh screens and netting [75].

- Case study 2: Anti-drone protection structures are being deployed along key roads in Ukraine. To combat FPV drones, Ukraine is reinforcing these roads with protective tunnels. These efforts aim to minimize the impact of attacks on military convoys [76].

4.1.2 Neutralize drones by metal mesh shield

This war illustrates the innovative way in which Ukraine is attacking Russian military bases using long-range drones and loitering munitions. The Russian defense industry is promoting portable counter-drone steel netting and meshes as a potential defense solution [77, 78]. These advances are designed to protect combat aircraft and helicopters from kamikaze drones and loitering attacks, demonstrating a significant shift in response to the evolving threats of contemporary warfare. Although these countermeasures may offer theoretical protection, concerns about their practicality, deployment speed, and efficacy are becoming more pronounced in the face of increasingly sophisticated drone technology. The most effective way to protect military bases and equipment from drone attacks is by using steel nets.

4.1.3 Neutralize drones by shooting

In the face of the failure of current anti-drone systems, shooting has become the best option. It is necessary to destroy them while they are still in the air. The Russian CUAS training program uses sports shooting and Olympic-style shooting expertise to provide soldiers. The skills they need to defend against FPV drones at close range [79].

- A Russian counter-drone system equipped with a novel turret is undergoing testing in Ukraine. It is armed with three PKM 7.62x54 mm caliber machine guns to engage Ukrainian drones and significant fixed-wing drones. The advantage of the installation lies in the number of machine guns and its ability to concentrate fire at a designated distance on a singular location. The Ukrainian forces use machine guns to engage Russian drones as a cheaper solution [80].

- The 28th Ukrainian Mechanized Brigade has introduced shotgun shooting as part of its recruit training. During this new training phase, recruits will acquire skills in shotgun shooting and enhance their ability to intercept drones, which has become essential for survival in today's war zone. The Ukrainian Mechanized Brigade uses the Benelli Anti-Drone M4 shotgun to eliminate a Russian FPV drone [81].

The limitation of this technique is that the crew engaged the drone at a dangerously close range.

4.1.4 Neutralization of the enemy drone by drone hunter

Drone Hunter is the new technique. It has four modes: attack, defense, pursuit, and tow-away. It is an AI-enabled, radar-guided drone that can lock onto its target, deploy a net, capture the threatening drone, and tow it to a secure location [82, 83]. It can be controlled from the ground if necessary.

- The Russians are using the UAV interceptor "Yolka" as an enemy drone countermeasure [84].

- The Ukrainian outlet Militarnyi reported on April 9 that Ukraine domestically developed a drone designed to intercept and destroy Shahed drones [85].

4.2 Air Defenses protecting world leaders at the Pope's funeral

More than 160 delegations, more than 50 heads of state, and 200,000 mourners gathered under one of the most extensive security umbrellas Rome has ever seen. Italian law enforcement and armed forces worked seamlessly to create a security dome over the capital. Italian forces utilize advanced electromagnetic anti-drone systems operated by specialized teams strategically positioned across Rome to neutralize unauthorized drones instantly. Portable electromagnetic deterrent systems emit high-intensity electromagnetic pulses on the same frequencies used to control drones, disrupting the connection with the pilot's controls. It disrupts drone communication at 2.4 GHz, 5.8 GHz, GPS L1, and GLONASS, representing fundamental range technologies [86, 87].

- Effective range around 1 km.

- Total weight around 7 kg.

- 90 minutes is the maximum working time.

The drone can be securely neutralized by activating the emergency mode, which can return it to its origin point or land at its current location. Specialist troops surrounding St Peter's Square today were observed with "drone bazookas" capable of

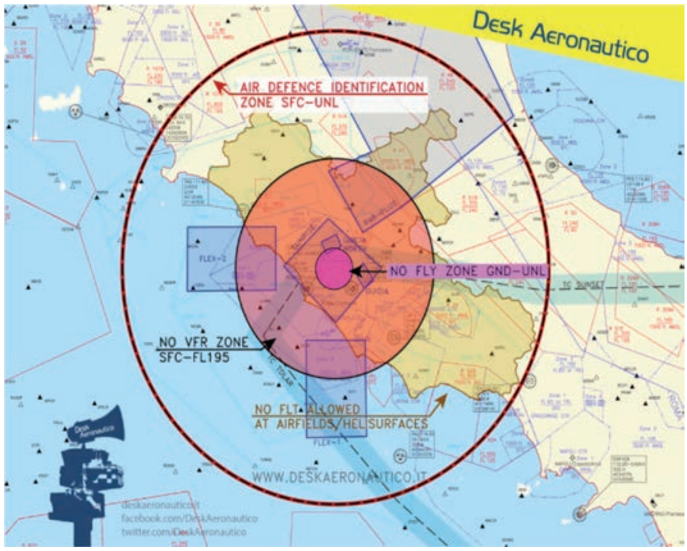

Figure 7.
Limits on airspace over Rome during Pope Francis' funeral celebrations.

disabling terrorist craft with a radio blast. According to many experts, this technology is considered weak, which is why NATO employs multiple layers of military air defense. The aerial surveillance security plan is highlighted. NATO and Italian troops are preparing to protect the Pope's funeral due to tensions and conflicts in Ukraine and various issues in North Africa from potential drone attacks [88]. Fighter jets are monitoring airspace security over Rome (shown in **Figure 7**).

5. Conclusions

Robotics and drones have demonstrated their significant potential in the future of warfare in several recent battles. Drones are effective weapons for missions such as precision assassinations, as their characteristics enable them to strike with minimal collateral damage. When compared to the precision munitions currently used in combat helicopters and infantry squads—some of which cost thousands or even hundreds of thousands of dollars—drones are an ideal weapon, rendering other alternatives economically unviable. To avoid strategic backwardness, it seems essential to leverage the advantages of drones, but their use must be regulated. Striking the right balance between manned and remotely piloted aircraft will provide policymakers with a more comprehensive range of military options. The fight against FPV and next-generation drones is no longer just about jamming; it now involves multi-layered kinetic defense and coordination amid rapidly evolving drone technology. A counter-drone force must possess high-tech weapons and equipment to perform its role in every phase of competition and confrontation, given the availability of high-tech drones. Counter-drone systems are outdated and ineffective against fiber-optic FPV drone guidance systems or AI-enabled terminal guidance systems. International security is seriously threatened by FPV drones, including from a counterterrorism perspective. Future implications for protecting the battlefield and sensitive areas will increasingly rely on layered defense and electronic warfare. No country is immune to the threat posed by drones.

Conflict of interest

The authors declare no conflict of interest.

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