International Journal of Advanced Culture Technology Vol.12 No.2 318-325 (2024)
DOI https://doi.org/10.17703/IJACT.2024.12.2.318

IJACT 24-6-35

The Rise of Drone Swarms: Military Applications, Countermeasures, and Strategic Implications

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Abstract

The rapid advancement of drone technology has led to the emergence of drone swarms, a game-changing concept in modern warfare. This study explores the military applications, countermeasures, and strategic implications of drone swarms. By examining the current trends in drone swarm development and deployment, this research highlights the potential of this technology to revolutionize the battlefield. The study also investigates the challenges and vulnerabilities associated with drone swarms, emphasizing the need for effective countermeasures. Through an analysis of multi-sensor fusion, directed energy weapons, and artificial intelligence, this research proposes comprehensive strategies to counter the threats posed by drone swarms. Furthermore, the study delves into the ethical and legal issues surrounding the use of autonomous drone swarms, underscoring the necessity for international norms and regulations. The findings of this research contribute to the understanding of the transformative impact of drone swarms on military strategy and national security, while providing valuable insights for policymakers, military strategists, and researchers in the field.

Keywords: *drone swarms, military applications, countermeasures, autonomous systems, strategic implications*

1. Introduction

The development of drone technology and its increased military utilization has been actively studied in recent years. Previous studies have analyzed various military applications of drones, such as reconnaissance, attack, and logistics, and have pointed out that drones are changing the nature of warfare [1]. However, existing research has mainly focused on the use of individual drones, and there is a relative lack of discussion on innovative operational concepts such as drone swarms.

This study aims to fill the gap in previous research by focusing on the military applicability and impact of drone swarms. Drone swarms are evaluated as game-changers in that multiple drones cooperate to perform missions, overcoming the vulnerabilities of individual drones and creating new threats. However, there are not many cases of actual deployment of drone swarms yet, and the development of technical and operational concepts is still in progress. Therefore, this study intends to investigate the development trends of each country's drone swarm development and experimental cases, and forecast future military utilization plans.

Furthermore, this study seeks to shed new light on the issue of countering drone swarms. While previous studies have only presented fragmentary countermeasures against drones, this study aims to explore comprehensive response strategies to address the threats of drone swarms. It will present measures to counter the challenges of drone swarms by complexly utilizing multi-sensor fusion, directed energy weapons, and artificial intelligence technologies [1]. Moreover, it will envision the future battlefield in the era of drone swarms and suggest the development direction that the Korean military should pursue.

Manuscript received: March 30, 2024 / revised: April 20, 2024 / accepted: May 15, 2024
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In addition, this study newly highlights the ethical and legal issues raised by the military use of drone swarms. The emergence of autonomous drone swarms is raising concerns about the risks of weapon systems beyond human control. There are also international humanitarian law issues such as civilian casualties caused by drone swarm attacks and compliance with the principle of proportionality. However, these concerns have been relatively neglected in previous studies. Therefore, this study intends to formally address the ethical and legal issues of drone swarms and trigger discussions for establishing international norms.

The activities of drones in the process of Russia's invasion of Ukraine in 2022 are noteworthy. The Ukrainian military effectively used Turkish Bayraktar TB2 drones to attack Russian armored vehicles, and drone forces had a significant impact on the course of the war. There is also an assessment that drones played a decisive role in Azerbaijan's victory in the conflict between Azerbaijan and Armenia. Recent conflict cases demonstrate the power of drone forces and enable us to gauge the destructive power of drone swarms on future battlefields.

In 2021, the Korean military also established a drone bot combat unit and is accelerating the development of drone swarm technology. The Army presented a goal of completing a drone swarm combat system by 2024. However, Korea's drone swarm development is still in its early stages compared to advanced countries, and efforts are needed to close the technological gap. Establishing a defense system to effectively counter drone swarms is also an urgent task. It is hoped that the development directions and policy suggestions presented in this study can contribute to establishing the Korean military's drone swarm preparedness strategy.

This study seeks to pioneer a new field of research on drone swarms through an interdisciplinary approach that combines military strategy and new technologies. It will not only track the development of drone technology but also provide a multifaceted view of the innovative operational concepts of drone swarms and their impact on future battlefields. Through comprehensive research covering technical analysis as well as ethical and legal discourse, it is hoped to open up new horizons in drone swarm research.

2. The Current Status and Characteristics of Drone Warfare

In recent conflicts, drones have emerged as "game-changers" that greatly transform the battlefield. The Ukraine War and the Azerbaijan-Armenia conflict are representative cases showing that drone forces can have a decisive influence on the course and outcome of a war.

During Russia's invasion of Ukraine in 2022, the Ukrainian military effectively used Turkish Bayraktar TB2 drones to strike Russian forces. The Ukrainian military identified the location of Russian troops and equipment through reconnaissance drones, and then precisely struck tanks, armored vehicles, and air defense systems with attack drones. In particular, anti-tank warfare using drones greatly contributed to the Ukrainian army's ability to stop Russian armored units. The Ukrainian military was able to achieve asymmetric effects with relatively few drone forces, inflicting serious damage on the Russian forces with minimal sacrifice.

Drones also played a decisive role in shifting the tide of war in the 2020 Nagorno-Karabakh conflict. Azerbaijan overwhelmed the Armenian army by massively deploying Israeli and Turkish reconnaissance and attack drones. Azerbaijan's drones neutralized Armenia's air defense systems and indiscriminately destroyed artillery and tanks. The Armenian army suffered unilateral damage from drones and had to accept a cease-fire while losing a significant portion of its territory. The Nagorno-Karabakh conflict is evaluated as a case that clearly shows the superiority of drone forces can determine the outcome of a war.

These cases well illustrate the military utility and impact of drones in modern warfare. Drones have the advantages of being cheaper and easier to operate than manned aircraft, and having a lower risk of loss of life. At the same time, they can be used for various missions such as reconnaissance, surveillance, and attack, making their combat effectiveness very high. As drones' performance on the battlefield becomes more prominent, countries are accelerating the acquisition of drone forces and also putting effort into developing defense systems to counter drones [1].

However, the spread of drone warfare also entails new challenges and risks. There are ethical and legal controversies surrounding the use of drone weapons, such as civilian casualties caused by drone attacks and violations of international law. There are also concerns about the possibility of misuse of drones by non-state actors such as terrorist groups. The development of drone technology is bringing about military innovation

while making the nature of warfare complex and unpredictable.

The Ukraine War and the Nagorno-Karabakh conflict are cases showing that drones have already established themselves as game-changers in modern warfare. Drones have emerged as asymmetric forces that can change the dynamics of the battlefield and enable the weak to confront the strong. In the future, drone technology will further develop, and the role and importance of drones are expected to continue to increase. Accordingly, understanding and preparing for drone warfare is emerging as a core task of military strategy.

Table 1. Status of Drone Swarm Development by Major Countries

Country	Key Drone Swarm Development Status
USA	- DARPA LCAAT program: Research on low-cost autonomous collaborative combat drone swarm - Gremlin Project: Manned-unmanned teaming technology - 103 micro-drones collective flight demonstration ('17)
China	- 1,000+ drone collective flight demonstration ('18)- Development of 48-drone simultaneous launch system - Advancement of drone swarm tactical concepts
Israel	- Operational experience with Harpy, Harop suicide drones - Developing drone swarms integrating AI and cooperative control technologies
Turkey	- Accelerating drone swarm development based on Bayraktar TB2 drone success - Employed drone swarm tactics in Azerbaijan-Armenia conflict

3. Drone Swarms: Game Changers of the Future Battlefield

A drone swarm is an innovative operational concept in which multiple drones display collective intelligence and perform attack and defense missions. Drone swarms, which overcome the limitations of individual drones and maximize the power of the collective, have the potential to change the dynamics of the game on future battlefields. This chapter examines the concept of drone swarms and their tactical operation methods, and discusses the strategic implications they will bring.

The conceptual origin of drone swarms can be found in nature. Social insects such as bees and ants create collectively intelligent behaviors based on simple behavioral rules at the individual level [1]. Drone swarms mimic this natural principle, where multiple drones autonomously interact to achieve common goals. The core of a drone swarm is to ensure the flexibility and adaptability of the entire system through distributed decision-making among individual drones rather than centralized control.

The operational use of drone swarms appears in two main aspects: attack and defense. An offensive drone swarm is a tactic in which a large number of small drones cooperate to saturate and penetrate the enemy's defense system. It is a method in which small drones equipped with radar-avoiding capabilities collectively infiltrate and reach the target point even if some drones are sacrificed. In a situation where hundreds or thousands of drones attack simultaneously, the enemy's defense network can easily be paralyzed. In fact, in 2018, during the Syrian civil war, there was a case where a Russian base was attacked by a drone swarm and suffered damage.

Defensive drone swarms are operated to protect friendly bases or assets. The concept is that small drones are linked with radar and surveillance equipment to monitor a wide area and cooperatively respond when threats are detected. Drone swarms can provide 360-degree omnidirectional vigilance and flexibly deal with simultaneous threats. In particular, drone swarms are robust against GPS jamming or communication disruption, so they can be effectively operated even in electronic warfare environments.

The biggest advantage of drone swarms is that their cost-effectiveness is very high. Small drones are inexpensive and easy to operate, making mass production and deployment feasible. It can be expected that a large number of low-cost drones operating collectively will replace expensive manned fighters or ground equipment. In addition, drone swarms have no risk of loss of life, enabling offensive and bold operations. This is attracting attention as an asymmetric force that can overturn the existing military power balance and give the weak an opportunity to confront the strong.

However, for drone swarms to be fully introduced into actual combat, there are still technical and operational challenges to overcome. Stable communication and coordination between multiple drones, control of drone swarm autonomy, and securing interoperability with friendly forces will be key issues. The issue of defending against drone swarms is also emerging as a new challenge. As existing air defense systems are difficult to effectively counter a large number of small drones, the development of new response strategies and technologies optimized for drone swarms is an urgent task.

Drone swarms are an innovative concept with the potential to fundamentally change future battlefields. It heralds a new paradigm that goes beyond improving the performance of individual weapon systems, where multiple weapon platforms exhibit collective intelligence. Military powers are already recognizing the strategic value of drone swarms and accelerating technology development. The aircraft carrier killer drone swarm demonstrated by China in 2019 symbolically showed its power. The Korean military should also strive to become a leader in drone swarm development through challenging technological development and bold force integration efforts.

Drone swarms should be noted not simply as a new weapon system, but as a game-changer that fundamentally changes the paradigm of warfare. Considering the pace of technological development, the era of drone swarms is no longer in the distant future. This is the time when wisdom is needed to proactively prepare for the disruptive innovation that drone swarms will bring and develop it into our military superiority.

Table 2. Key Technologies and Weapon Systems for Countering Drone Swarms

Category	Key Technologies & Weapon Systems	Details
Detection	Drone detection radar	Specialized radar for early detection of small drones
Multi-sensor fusion	Integration of radar, acoustic, infrared, electro-optical sensors	
Identification & Tracking	Drone identification algorithms	AI-based drone pattern recognition and threat assessment
Precision tracking systems	Simultaneous tracking of multiple drones and real-time position information	
Interception	Counter-drone electronic warfare equipment	Disruption and neutralization of drone communications/navigation
Laser weapons	Drone interception with high-power lasers	
High-power microwave weapons	Destruction of drone circuits with directed energy	

Military powers such as the United States, China, Israel, and Turkey recognize the strategic value of drone swarm technology and are accelerating technology development and actual deployment through various projects.

The United States is a leader in the drone swarm field and is conducting various projects. The Defense Advanced Research Projects Agency (DARPA) under the U.S. Department of Defense is researching technology for multiple small drones to autonomously cooperate based on artificial intelligence through the Low-Cost Autonomous Attack Technology (LCAAT) program [11]. It is also testing technology to launch and retrieve drone swarms from manned aircraft through the Gremlin project [3]. In 2017, it demonstrated 103 micro-drones performing various formations while flying collectively [19].

China is also making a mark in the field of swarming drones. In 2018, it showcased its technological prowess by staging a scene of more than 1,000 drones flying in cooperation [12]. Recently, it unveiled a launch device capable of simultaneously launching 48 drones and tactical operational concepts for drone swarms, taking a step closer to the actual deployment of drone swarms [11].

Israel, as a drone powerhouse, is concentrating on developing advanced drone swarm technologies. Based on the experience of deploying suicide drones such as Harpy and Harop in actual combat, it is accelerating the development of drone swarms [2][13]. Israeli companies are focusing on developing swarming drones that incorporate key technologies such as artificial intelligence and cooperative control.

Turkey is also accelerating the development of drone swarms, thanks to the recent strengthening of its drone forces. Encouraged by the success of the Bayraktar TB2 drone, Turkey is developing tactics in which multiple drones cooperate. In particular, the experience of dominating the battlefield by employing drone swarm tactics in the Azerbaijan-Armenia conflict became a catalyst for accelerating the Turkish military's introduction of drone swarms [6][9].

Table 3. Military Application of Drone Swarms

Category	Military Application Measures
Reconnaissance	Wide-area surveillance/reconnaissance with multiple small drones
Attack	Paralyzing defense systems through saturation attacks
Deception	Generating false indications of attack/defense with multiple drones
Defense	Multi-layered defense to protect friendly bases/assets

In this way, military powers are devoting their full efforts to the development of drone swarms. However, cases of actual deployment are still limited, and the development of operational concepts is still in its early stages. This is because various technical challenges such as communication, cooperative control, and human-machine interface remain for the actual operation of drone swarms [18].

Nevertheless, drone swarms clearly have the potential to change the dynamics of future battlefields. This is because they are emerging as an asymmetric force that can overturn the existing military power balance and give the weak an opportunity to confront the strong [1]. The power demonstrated by drones in the Ukraine war was a signal flare heralding the beginning of the drone swarm era.

In the future, as artificial intelligence and cooperative control technologies become more advanced and the autonomy of drone swarms is strengthened, their destructive power will be beyond imagination. It is emerging as an urgent task to proactively prepare for this and establish defense strategies to counter the threats of drone swarms. The Korean military should also re-recognize the strategic value of drone swarm development and strive to enhance its technological capabilities through civil-military cooperation. This is a time when wisdom is needed to swiftly respond to the disruptive innovation that drone swarms will bring.

Table 4. Paradigm Shifts by Drone Swarms

Category	Existing Paradigm	Drone Swarm Paradigm
Battlefield Environment	Platform-centric	Distributed multiple agents
Command and Control	Centralized	Decentralized autonomous cooperation
Damage Nature	Pinpoint damage	Wide-area simultaneous damage
Attack Mode	Concentrated on single targets	Saturation of multiple targets
Countermeasures	Shoot down individual platforms	Multi-layered integrated defense

4. Response Strategies to Drone Swarms

To effectively counter the threat of drone swarms, innovation is needed throughout the entire process of detection, identification, tracking, and engagement. It is essential to secure the ability to quickly detect and

identify multiple small targets in complex environments, and the ability to simultaneously engage multiple targets [1]. To this end, it is emerging as an urgent task to establish a multi-layered defense system including radar detection, electronic warfare, and interception systems.

First, high-performance radar systems are needed to detect drone swarms early. As existing radars have difficulty identifying small drones, the development of radars specialized in detecting ultra-small targets is required. ELTA Systems of Israel has developed the ELM-2026B radar optimized for drone detection and is deploying it in actual combat [13]. In addition, multi-sensor fusion technology that comprehensively utilizes various sensing means such as acoustic, infrared, and electro-optical is also attracting attention as a promising alternative [1].

Second, strengthening electronic warfare capabilities is essential. Electronic attacks that neutralize drone swarms by disrupting their communication and navigation can be an effective countermeasure. Electronic warfare capabilities have high value as an asymmetric response card that can target the Achilles' heel of drone swarms.

Third, it is urgent to upgrade the interception system that can directly strike drone swarms. As existing anti-aircraft weapons are insufficient to simultaneously counter a large number of small drones, interception means specialized for drone swarms are needed. Israel has developed and deployed the "Drone Dome" drone defense system optimized for intercepting drone swarms [13]. Directed energy weapons such as laser weapons and high-power microwave weapons are also attracting attention as promising interception means. The U.S. Navy plans to develop the "HELIOS" high-energy laser weapon and use it to counter drone swarms [19].

In this way, countering drone swarms requires the establishment of a comprehensive defense system, not a single technology. It is necessary to establish a concept of multi-layered defense that comprehensively utilizes advanced technologies at all stages of detection, identification, tracking, and engagement. In particular, the development of AI and autonomous cooperation technologies is expected to bring innovation to the drone swarm response paradigm. The Korean military should also actively utilize these advanced technologies in countering drone swarms.

However, the Korean military's current readiness to respond to drone swarms is insufficient. There is a lack of key forces such as drone-specific radars, electronic warfare equipment, and interception systems, and doctrines and response manuals for drone swarm threats have not been established. As the threat of drone swarms is becoming a reality, strengthening the Korean military's response capabilities is emerging as an urgent task.

Accordingly, the Korean military should establish a roadmap for responding to drone swarms and expand its core forces from a mid- to long-term perspective. It should actively introduce advanced weapon systems such as drone detection radars, anti-drone electronic warfare equipment, and laser interception systems. In addition, it should hurry to establish joint doctrine for responding to drone swarms, nurture professional personnel, and build a realistic training system.

Cooperation with civilian technology is also important. It is necessary to actively utilize civilian capabilities leading the development of advanced technologies such as drones and AI in the defense sector. Efforts should be accelerated to incorporate innovative civilian technologies into drone swarm response through civil-military technology cooperation projects and fostering defense startups.

Drone swarms are an innovative threat that will change the dynamics of future battlefields. Countries around the world, including major powers, are accelerating the development of drone swarms in a situation where proactive preparedness is necessary. In particular, considering changes in the security environment, such as the increase in North Korea's asymmetric threats and the transition of wartime operational control, it is more urgent than ever for the Korean military to establish a preparedness posture for drone swarms. It is a time when proactive and creative response strategies based on technological innovation are desperately needed.

5. Conclusion

The rapid development of drone swarm technology is expected to bring revolutionary changes to future battlefields. Drone swarms, in which multiple drones cooperate to perform missions, have the potential to fundamentally change the existing military paradigm. Drone swarms can play a decisive role in securing the initiative on the battlefield by saturating and overwhelming the enemy's defense system. At the same time, the

relatively weak will have the opportunity to confront the strong by utilizing drone swarms as an asymmetric force [1].

In particular, the role and importance of drone swarms are expected to increase significantly within manned-unmanned combined combat systems. The combination of existing forces such as manned fighters and ground platforms with drone swarms can create synergies that multiply combat effectiveness. Reconnaissance drone swarms providing real-time surveillance information and attack drone swarms cooperating with manned combat assets to strike targets will become a key concept of future battlefields. Furthermore, as artificial intelligence technology advances and the autonomy of drone swarms greatly improves, there is a possibility that it will evolve into a fully autonomous combat system where drone swarms derive and execute optimal tactics on their own without human control.

However, to effectively counter the threat of drone swarms, efforts at the defense R&D level are urgently needed. It is true that the current defense system is difficult to cope with saturation attacks by a large number of small drones. It is necessary to concentrate defense R&D capabilities on the development of surveillance and interception systems to counter drone swarms. It is an important task to secure innovative anti-drone systems early by utilizing multi-sensor fusion, directed energy weapons, and artificial intelligence technologies [1].

To this end, civil-military technology cooperation that rapidly transfers advanced civilian technologies to the defense sector is essential. Given the very fast pace of technological development in fields such as drones and artificial intelligence in the private sector, open innovation that actively utilizes civilian capabilities is required. Through fostering defense startups and revitalizing civil-military technology exchanges, the foundation of defense R&D should be expanded, and an institutional foundation should be laid so that challenging ideas can be quickly applied to the defense field.

In addition, efforts to strengthen the joint response posture to drone swarms should be carried out in parallel. It is necessary to integrate the anti-drone response capabilities of each service of the Army, Navy, and Air Force and cultivate joint operations execution capabilities. Establishing an organization and system, such as the creation of a dedicated unit for responding to drone swarms, establishing joint doctrine, and establishing a realistic training system, should be supported in terms of nurturing personnel.

Drone swarms have already emerged as game-changers that are changing future battlefields. Proactively preparing for and effectively responding to their threats is rising as a core task of national security. In particular, the Korean military must be equipped with a preparedness posture against drone swarms in order to respond to North Korea's asymmetric threats and stably transfer wartime operational control. It is time to be reborn as a strong military leading the drone swarm era through defense R&D, civil-military cooperation, and strengthening joint response capabilities.

Table 5. Directions for Advancing the ROK Military's Counter-Drone Swarm Capabilities

Category	ROK Military Counter-Drone Swarm Advancement Directions
Technology Development	Develop surveillance/intercept technologies such as radar, electronic warfare, directed energy weapons
Force Enhancement	Acquire and deploy early warning/defense assets against drone swarms
Doctrine Establishment	Establish doctrines for assessing drone swarm threats and joint/combined responses
Training System	Build realistic training systems for countering drone swarms

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