航 空 航 天
CHINA AEROSPACE STUDIES INSTITUTE

Survey of PRC Drone Swarm Inventions

Maj Emilie B. Stewart

This work builds upon CASI's 2018 The PLA's Unmanned Aerial Systems: New Capabilities for a "New Era" of Chinese Military Power by Elsa Kania[1] and is intended to specifically address the Chinese capacity for unmanned aerial vehicle (UAV) swarm innovation, tactics, and mission sets.

In December 2018, China unveiled its drone light show at the World Fortune Forum in Guangzhou. Then, in 2022, China Daily News released footage of a Zhejiang University team's drone swarm following a notional target through a bamboo forest. Additionally, in mid-2022, Chinese press reported drones capable of launching and swarming from the Shandong aircraft carrier. Because of these events, members of the U.S. Department of Defense and their partners and allies began speculating on China's intent and capabilities to use swarm technology during future conflict. However, China's defense apparatus has not publicly released plans for drone swarm doctrine, strategy, or research and development that would point to how such systems would specifically be used.

This paper presents the findings from surveying unclassified Chinese patent records to gain better understanding of Chinese drone swarm employment plans, advancements, and challenges. It is meant to be an exploratory study, one that evaluates Chinese inventions—both applied for and granted patents—to eliminate unknown unknowns and provide a foundation for future analysis.

Introduction

When it comes to discussing "swarms," many potential behaviors come to mind. Everything from the nano swarm impersonating an individual depicted in Michael Crichton's novel "Prey,"[2] to simply a large number of individual drones with no coordinating ability. This study will specifically address a swarm of unmanned aerial vehicles (UAVs), much like bees and birds behave, that is both relatively autonomous and collaborative, or what the United States Air Force (USAF) has termed collaborative combat aircraft–(CCAs) or Autonomous Collaborative Platforms (ACPs).[3] This is different from the kinds of "proto-swarms" seen in recent combat,

both in Syria & in the Russian-Ukraine conflict, where a mass of individually controlled UAVs overwhelms an air defense system.[4]

The following attributes are requirements for this kind of "true" swarm. First, some level of autonomous command and control—gained through artificial intelligence and machine learning (AI/ML). Next, collaborative communication mechanisms allowing drones to communicate with one another with little to no human input. Further, positioning and/or navigation is required for drones to operate collaboratively in a given space. And finally, power.

This paper will first describe the way the Chinese media talks about drone swarms. Next, it will quantitatively describe the survey results based on the invention applicant and the invention mission set. Then it will qualitatively summarize additional findings before concluding and offering avenues for future research.

How the PRC talks about drone swarms

Very little has been publicly stated from either Xi Jinping, the Chinese defense apparatus, or the People's Liberation Army (PLA) about drone swarm doctrine, strategy, or research and development that would point to how such systems would specifically be used. Of the articles that were found, swarms are talked about broadly, but did not address any Chinese characteristics that would set the research apart from other swarm scholars. In these articles, UAV swarms are defined similarly to the USAF definition and emphasizes the need for network connectivity and autonomy, "a collection of multiple drones that jointly perform a certain task and are under unified command [and] the formation of groups based on a certain number of UAVs to jointly perform the same combat mission, implement management according to unified organizational command, and achieve a specific purpose of combat activities."[i] Additionally, they speak broadly to potential benefits and challenges of swarm technology, how the whole may be greater than the sum of the parts when deployed effectively, and the challenges of maintaining connectivity, and bandwidth and power considerations.[5]

Conversely, most of the articles found yielded much commentary on UAV swarm rhetoric in the U.S.—including reprints of U.S. media reports—or bombastic reports of Chinese capabilities without any real substance. For example, when Chinese press reported two kinds of drones on the deck on the Shandong aircraft carrier, it was merely a summary of commentary from Western news outlets with some additional Chinese characteristics for flair including the remark that the new capability that would overtake the U.S. because such technology has not been demonstrated by the U.S. military.[6]

[i] Original Mandarin: **某一任**务、受统一指挥的多架无人机组成的集合体。是指基于一定数量规模的无人机编成群组，共同执行同一作战任务，按照统一组织指挥实施管理，实现某种特定目的的作战活动。

Methodology

Invention patent applications offer many advantages for understanding the current status and potential trajectory of Chinese drone swarm innovation for many reasons. While little has been publicly stated, patent applications are required to have a "Background" [背景技术] section that describes the problems or inadequacies with the "previous art"[ii] and details how the proposed invention will aim to mitigate or solve these issues. In many applications, the inventors reference gains the U.S. military has made regarding swarm technology and artificial intelligence and how their invention seeks to outpace U.S. advantages. Additionally, as opposed to research papers and conference presentations, patent applications offer a glimpse into the current state of technology and can help to either confirm, deny, or caveat capabilities alluded to in the press.

In order to best highlight Chinese drone swarm innovation, Chinese inventions were searched for by phrase drone swarm, 无人机群, from the earliest known patent application through 15 March 2023, and the following information was cataloged:[iii]

- Application Number
- Application Date
- Application/Patent Publication Number
- Application/Patent Publication Date
- International Patent Classification (IPC) codes
- Title
- Summary
- Applicant(s)/Patentee(s)
- Inventor(s)

Next, each was evaluated as to whether it met all the following criteria: the invention involved an unmanned *aerial* vehicle (as opposed to land- or sea-based); the invention involved more than one UAV operating towards a shared mission; the invention had a stated or implied defense purpose; and the invention originated in China.

Finally, each was coded based on applicant, mission application, and sophistication (described in greater detail below). From here, inferences were made to major players, priorities, and known challenges with analytical emphasis placed on entities associated with the Chinese defense apparatus.

Coding

After removing results from the data set that did not meet the criteria, they were coded based on the applicant and the mission application.

The applicants were divided into three categories as follows:

1. The Applicant/Patentee is a PLA unit or academic institution

[ii] This is an international patent law term that describes current patented inventions

[iii] Note: during this survey, no attempt was made to determine the validity of the invention, only their existence and intent

2. The Applicant/Patentee is a state-owned enterprise (SOE), academic institution, or company with ties to the PLA or national defense apparatus. Organizations were given this coding if they met any of the following criteria:
    a. Affiliated with any of the following organizations with known ties to the PLA/NSS:
        i. Aviation Industry of China [中国航空工业集团公司] (AVIC)[7]
        ii. Chinese Academy of Sciences [中国科学院] (CAS)[8]
        iii. China Aerospace Science and Technology Corporation [中国航天科技集团公司] (CASC)[9]
        iv. China Aerospace Science & Industry Corporation Limited [中国航天科工集团有限公司] (CASIC)[10]
        v. China Electronics Technology Group Corporation [中国电子科技集团公司] (CETC)[11]
        vi. State Administration of Science, Technology and Industry for National Defense [国家国防科技工业局] (SASTIND)[12]
    b. Scored as Medium Risk or higher on the Australian Strategic Policy Institute's (ASPI) China Defence Universities Tracker[iv,13]
    c. Listed ties to defense and/or the PLA on their website
3. The Applicant/Patentee is an SOE, academic institution, or company without known ties to the PLA or defense apparatus.[v,vi,vii]

Next, they were coded for mission application according to the following categories. Note, these categories were developed by the researcher and were not necessarily explicitly stated in the body of the application. Rather, they are based on current U.S. joint military doctrine for the purpose of providing a similar comparison, but do not necessarily represent their categorization in PRC/PLA thinking and doctrine:[viii]

1. Offensive. Includes kinetic fires and electromagnetic spectrum operations (EMSO).

[iv] ASPI's methodology can be found on their website: https://unitracker.aspi.org.au/about/
[v] SOEs have a stronger relationship to the CCP under Xi Jinping than in previous administrations, so theoretically these technologies could potentially be easier for current regime to leverage for defense-related applications than in previous regimes, but still, no direct defense relationship was found. Drinhausen, K., Legarda, H.; "Comprehensive National Security" unleashed: How Xi's approach shapes China's policies at home and abroad; Merics; 15 Sep 2022; https://www.merics.org/en/report/comprehensive-national-security-unleashed-how-xis-approach-shapes-chinas-policies-home-and
[vi] Items 3-5 do not rule out an affiliation, simply denotes that none was found during this research. Additionally, it should be noted that the U.S. FCC has noticed that after Chinese companies are added to the U.S. Entities List, they are sometimes recreated under a different name to avoid sanctions. ChinaTechThreat; https://www.youtube.com/watch?v=-6v2wmPCugk (accessed 24 Mar 2023)
[vii] Companies that market to generally police organizations were not listed as defense aligned unless evidence suggested they marketed solely to Chinese police agencies (i.e. People's Armed Police (PAP) or the People's Police)
[viii] Note: while all inventions meeting the stated criteria were coded for mission application, only those from the PLA or defense-aligned institution were evaluated further

2. Defense. Includes counter-UAV swarm and the use of swarms to perform anti-spoofing, and mine detection, adversary detection, early warning, operations security (OPSEC), and electromagnetic interference (EMI) detection.
3. Target tracking/acquisition.[ix]
4. Operations under degraded conditions. Includes position, navigation, and timing (PNT) and communications degradation.
5. Communication Collaboration and Command and Control (C2).[x,xi] Includes operator-controlled efficiency improvement (i.e. assigning tasks to redundant UAVs if one becomes faulty), improving safety of flight, formation optimization, collision avoidance, obstacle avoidance,[xii] task allocation, power allocation, bandwidth and other resource allocation, and general data sharing.
6. Navigation, route planning/finding.[xiii]
7. Encryption and Information Security. Includes determining authenticity of signals within a UAV group and methods to maintain information security.
8. Intelligence, Surveillance, and Reconnaissance (ISR).
9. Support Operations. Includes launch and recovery operations, wireless charging, health/status monitoring, and computer simulations.

Finally, records produced by PLA or defense-aligned organizations that machine learning inventions were further evaluated using Paul Scharre's "Swarm command-and-control models" to determine their relative level of sophistication.[14]

Results and Analysis

The Background Techniques of each patent application were evaluated for any discussion about how drone swarms might be employed as well as challenges the inventors seek to overcome. When discussing their research and reasons for developing their inventions, Chinese inventors discuss many potential uses and advantages of drone swarms, including:

- Image acquisition from multiple, cooperating vantage points[15]
- Multi-mission swarms where each UAV has a different task which make the whole stronger than the sum of its parts[16]
- Military reconnaissance, environmental monitoring, anti-terrorist stability maintenance and emergency response[17]
- Electronic countermeasures and precision strikes[18]

[ix] Distinguished from ISR if a target was specifically mentioned in the body of the record
[x] Search results that yielded technologies involving multiple UAVs not cooperating towards a shared mission were not included in this dataset (e.g. food delivery mechanisms using multiple UAVs to simultaneously deliver to multiple customers)
[xi] Communication Collaboration is inherent in any attempt to field a true drone swarm, however it was only coded as such if it was the primary objective of the invention. E.g. not collaboration for target acquisition, ISR, etc.
[xii] Obstacle avoidance (avoiding a third party) is distinguished from collision avoidance (avoiding other UAVs in the group)
[xiii] Includes obstacle avoidance when it is inherent in an expeditious path finding solution

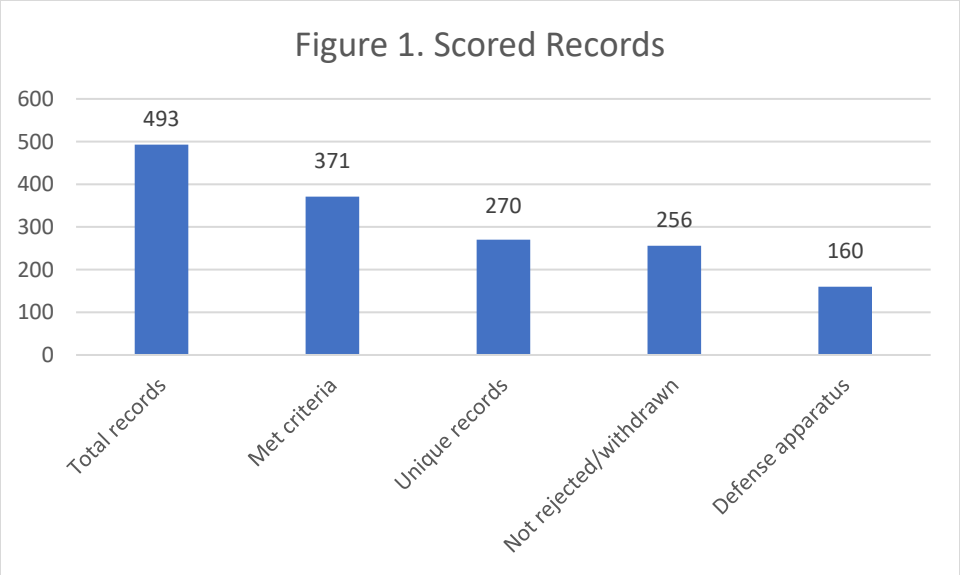
- The ability to make intelligent decisions autonomously with very little human intervention[19]
- Coordination, self-organization, parallelism, etc.[20]

However, Chinese inventors also cite many challenges to be overcome in swarming technology, including:

- Balancing operating and computing power with UAV payload size and use time; greater computing power will either necessitate a larger payload or decrease the available mission time[21]; this is especially evident when attempting to achieve the powerful information processing capabilities and intelligence of pilots; this requires a lot of computing[22]
- Balancing swarm size with spectrum congestion if each UAV competing for similar bandwidth and signals[23]
- Overcoming the potential for wide mission areas, complex and changeable environments, limited sensor perception ability; inherent difficulties in urban or mountainous regions, dynamic operating areas, etc.[24]
- Overcoming the potential for a single UAV within the swarm to fail, resulting in total mission failure[25]
- The need to aggregate and process the large amount of information collected by multiple UAV sensors under complex conditions; a large central ground station will be more accurate, but potentially less timely[26]
- Overcoming the potential for high-speed UAV flight causing the highly dynamic change of the network topology, thus affecting the connectivity of the network and protocol performance[27]
- Communication delays as the size and ranges of UAV swarms continue to grow[28]
- Ensuring reliable and robust information transmission of UAV networks under malicious interference conditions[29]

The following section will broadly discuss all the collected data; the following section will further discuss the specifics of PLA and defense-aligned inventions. Of the 493 records collected, 371 were deemed to meet the established criteria and fell into one or more of the nine previously described applications. Of these, 270 were applications or utility models (unique records)[xiv], but 14 have since been rejected or withdrawn. Those that fell within the defense apparatus, where the applicant is either the PLA or a defense-aligned institution, were further evaluated for mission application and AI/ML advances: 160 total.

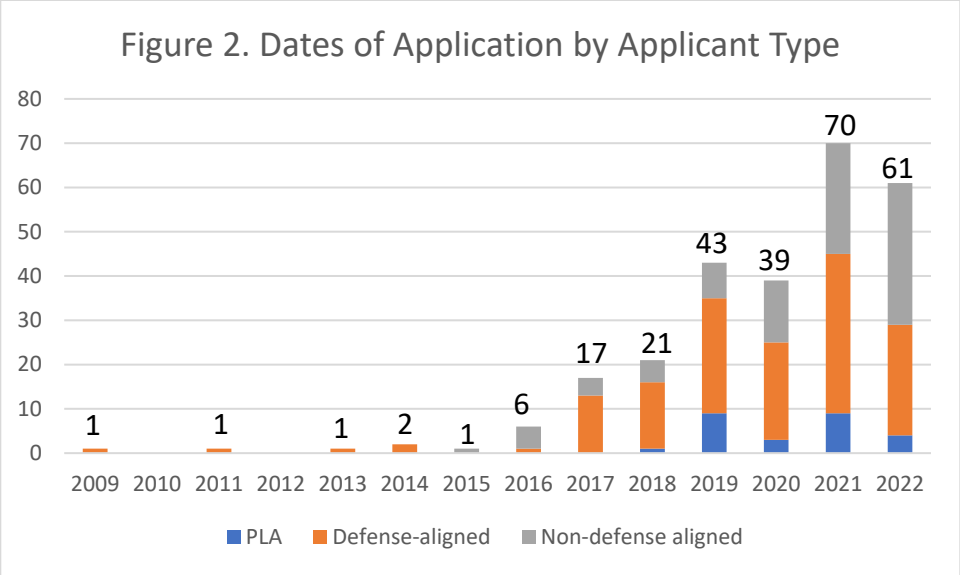
[xiv] In order to accurately calculate metrics, only applications and utility models were evaluated because granted patent records are nearly identical to their applications and would have been double counted if included in this number.



The earliest Chinese invention application found that met the established criteria was filed by Changchun University of Science and Technology (长春理工大学), an academic institution with known ties to the Chinese defense apparatus, in 2009 and the patent was granted in 2012.[30] It presented a micro unmanned aerial vehicle group autonomous management data link management scheme, operating in the 2.4GHz～2.483GH range.[31,xv] Since then, 256 Chinese inventions and utility model applications relating to drone swarms (commercial and defense) were found at the date of information cut off[xvi] including 119 granted patents. These spanned defense-aligned institutions, state-owned enterprises (SOEs), academia, private companies, and individuals.

Figure 2 shows the progression of applications by applicant type over time.[xvii]

[xv] This is the frequency standard set by the IEEE Standards Association which specifies the physical layer (PHY) and media access control sublayer (MAC) for impulse radio ultra wideband (UWB) wireless ad hoc connectivity with fixed, portable, and moving devices with limited energy consumption requirements, and supports real time precision ranging capability that is accurate to within a few centimeters. PHYs are defined for devices operating in a variety of regulatory domains; https://standards.ieee.org/ieee/802.15.4z/10230/ (accessed 20 Apr 2023).
[xvi] 15 Mar 2023
[xvii] No applications for 2023 were found in this research due to a quirk in the search tool so none are included in this chart. Eight of these applications (from multiple years) were approved as granted patents in 2023.

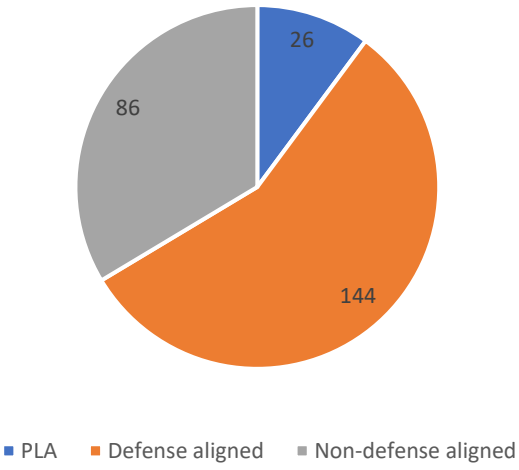


In this study, 155 unique applicants/patentees were associated with drone swarm inventions, though some applicants applied jointly. Of these, five organizations had 10 or more applications: Xidian University (西安電子科技大學; 19), Beihang University (aka Beijing University of Aeronautics and Astronautics; 北京航空航天大學; 15), Nanjing University of Aeronautics and Astronautics (南京航空航天大學; 11), The National University of Defense Technology of the PLA (中国人民解放军国防科技大学, 10), and Yifei (Hainan) Technology Co., Ltd. (一飞（海南）科技有限公司, 10). All three universities are defense aligned, but no defense affiliation was found for Yifei (Hainan) Technology Co., Ltd. See Appendix B for a full list of applicants.

Approximately 30% of applications resulted in a granted patent at the time of information cut-off date, though many of these applications are still making their way through the approval process. Of those with no associated granted patent, 130 are still pending according to the China National Intellectual Property Agency (CNIPA). Unfortunately, no information was found as to why each was withdrawn or rejected. Applications dated 1 January 2020 and later are all still pending. None of the PLA applications have been rejected or withdrawn.

Defense-aligned academic institutions and companies made up the bulk of the unique inventions (applications and utility models), at 56%. PLA inventions made up approximately 10% of unique inventions. Non-defense-aligned entities made up the remaining 34%.

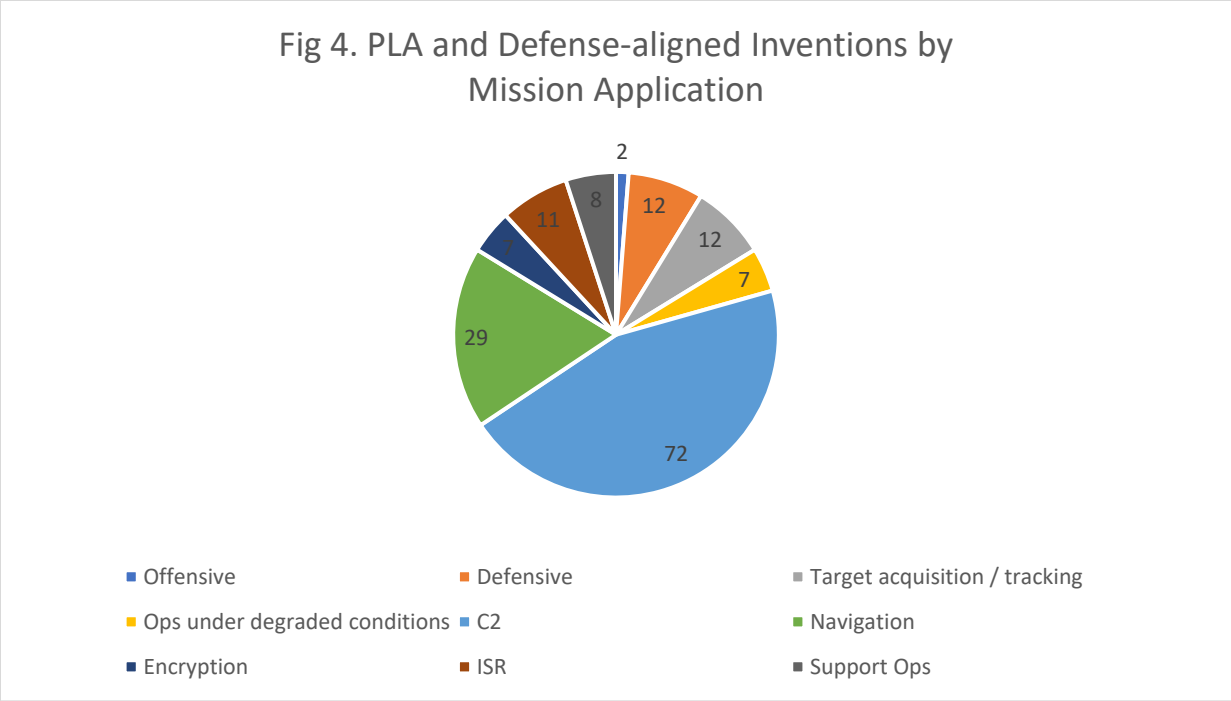
Figure 3. Inventions by Applicant Affiliation



The next section will further analyze inventions submitted by the PLA and defense-aligned applicants.

PLA and Defense-aligned Inventions

PLA and defense-aligned inventions were further analyzed for mission application and degree of collaboration. These applicants made up 170 unique records, however 10 have since been rejected or withdrawn. First, they will be discussed by mission application.



Offensive

Two applications were found with offensive missions, each with application dates in 2022 (and therefore are likely in the patent review process and will not have an approved patent until ~2024), and none by the PLA. University of Electronic Science and Technology of China (UESTC) and Xidian University [西安電子科技大學] filed these applications. Both inventions seek optimization of targeting solutions, the first for electromagnetic spectrum operations (EMSO), the second for weapon allocation. The Xidian University invention specifically seeks to develop a new machine learning neural network algorithm to accomplish the weapons allocation task[32] which it claims is more effective than using the Hungarian algorithm utilized in the UESTC invention for collaborative jamming.[33] In both inventions, the UAV swarm is used to gather data points from different perspectives and combine the inputs for optimization.

Defensive

Twelve applications were found with defensive missions, from 2019 through 2022, two of which are from the PLA. Of the twelve, only one (none PLA) has generated an approved patent, but again, the rest are likely still in the review process.

Figure 5. Defensive Records			
Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique
Defense from UAV swarm	7 (2)		
UAV swarm protection	3	1	
UAV as defense	2		
TOTAL DEFENSIVE: 12			

This category includes the sole UAV swarm invention found (from AVIC) that cited the International Patent Classification (IPC) code[xviii] for weapons, which intends to launch a fleet of counter-UAV swarm "folding-wing interceptor aircraft" (折叠翼拦截机) in an array pattern to attack an incoming UAV swarm.[34] Four of these inventions make use of existing algorithm methods, but none develop new AI/ML techniques.

Target Acquisition / Tracking

Twelve applications were found with target acquisition and/or tracking missions, from 2018 through 2022, two of which are from the PLA. Of the twelve, six (one PLA) have so far generated approved patents.

Figure 6. Target Acquisition / Tracking Records			
Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique
UAV swarm used in target acq	10 (2)	1 (1)	1
Track Blue Force UAV swarms	2	1	
TOTAL TARGETS: 12			

Of those inventions that use UAV swarms in target acquisition and tracking, these all focus on using multiple UAVs to track and select targets in dynamic environments more efficiently. Two of these are not necessarily directly defense-related (one seeks to locate gas leakages,[35] another locates the best point to extinguish a fire[36]), but the collaborative command and control exhibits target acquisition qualities. The sole invention to develop a new ML model is from Northwestern Polytechnical University (西北工业大学) and developed a new neural network technique that better solves UAV swarm target recognition accuracy. Complex neural networks are very accurate, but not timely; low-complexity neural networks are not as accurate, but are very timely.

[xviii] The International Patent Classification (IPC), established by the Strasbourg Agreement 1971, provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. A new version of the IPC enters into force each year on January 1. WIPO; https://www.wipo.int/classifications/ipc/en/

This new neural network technique leverages many optimization algorithms to train the data set in advance, allowing for the accuracy of complex neural networks, but the timeliness of low-complexity neural networks during execution.[37]

Operations Under Degraded Conditions

Seven applications were found with Operations Under Degraded Conditions applications, from 2017 through 2022, two of which are from the PLA. Of the seven, three (none PLA) have thus far resulted in an approved patent.

Figure 7. Operations Under Degraded Conditions Records

Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique
Communication degradation	4 (2)	3	
PNT degradation	3	1	
TOTAL DEGRADED CONDITIONS: 7			

Interestingly, one of these is the only invention found in this study that is built on an idea that is wholly Chinese: the *jiugongge* (九宫格) grid used to learn to draw traditional Chinese characters. Using this grid and specific lights on each of the UAVs, the inventors seek to maintain a UAV formation with relative distances between each UAV, even in a communications degraded environment.[38]

Additionally, five inventions were concerned with malicious or intentional interference specifically, while only two inventions noted interference more broadly—to include environments with line-of-sight difficulties or satellite acquisition limitations—and did not specifically address intentional interference. None developed new AI/ML methods.

C2

Seventy-eight inventions were found with communication collaboration and command and control (C2) missions, from 2009 through 2022, 10 of which are from the PLA. Of the 78, six have since been rejected and two have been withdrawn.

Figure 8. C2 / Collaboration Records			
Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique (PLA)
Fault ID & resolution	3		
Power allocation & optimization	12 (5)	7 (2)	
Bandwidth, spectrum, and C2 allocation and optimization	9	5	1
Task allocation & optimization	25 (3)	12	2
Controlled w/ EEG signals	3 (1)		
Hierarchical command structures[xix]	4	4	
Data link management	2	2	
Obstacle avoidance	1		
Formation control & optimization	12 (1)	7 (1)	1
TOTAL C2 / COLLABORATION: 78 (8 rejected, 6 withdrawn)			

Additionally, there were two PLA utility models: one that introduces an interface so that multiple UAVs from different manufacturers could be controlled from one system simultaneously,[39] and one that claims to create a better display for human operators. Interestingly, Shenzhen Daotong Intelligent Aviation Technology Co., Ltd. (深圳市道通智能航空技术股份有限公司) filed the same patent three different times on the same day, but generating three different application numbers.[40] All are still pending and appear to have entered the substantive examination process.

Hierarchical command structures (i.e. where one or more motherships connect to worker UAVs and/or slave UAVs) were used in a few different ways: to extend the efficacy of communications over long distances, to aid in information security, and to lessen the data burden on any one UAV.

Though 33 of the inventions utilized machine learning methods, only four of these introduced new AI/ML methods, including two task optimization inventions (from Tianjin University [天津大学][41] and Xidian University[42]), one bandwidth optimization invention (from Guangdong University of Technology [广东工业大学][43]), and one formation optimization invention (from Beijing Institute of Mechanical Equipment [北京機械設備研究所][44]). None of these were proposed by the PLA and all have an application date of 2019 or later.

[xix] This includes those with and without optimization algorithms, though many used the Leader, Follower and Candidate algorithm model)

Navigation

Thirty applications were found with navigation and/or path finding missions, from 2011 through 2022, three of which are from the PLA. Of the 30, 17 (one PLA) have generated approved patents. One application has since been rejected.

Figure 9. Navigation Records

Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique
Path finding optimization	21 (4)	14 (1)	1 (1)
Position optimization	8	3	1
TOTAL NAVIGATION: 30 (one rejected)			

Although 10 of the inventions utilized machine learning methods, two introduced new AI/ML methods. One, from the Army Engineering University of PLA [中国人民解放军陆军工程大学], claims a faster convergence solution of swarms navigating towards a target.[45] The other, from Beijing Huayue Information Technology Co., Ltd. [北京华跃信息技术有限公司] combines two machine learning methods to create a hybrid online/offline neural network for optimizing swarm positioning.[46]

Encryption and Authentication

Eight applications were found with encryption and authentication missions, from 2017 through 2022, none of which are from the PLA. Of the eight, three have so far resulted in an approved patent. One application has since been withdrawn. None developed new AI/ML methods.

Figure 10. Encryption and Authentication Records

Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique
Encryption	4		
Authentication	3	1	
TOTAL ENCRYPTION & AUTHENTICATION: 8 (1 withdrawn)			

ISR

Eleven applications were found with ISR missions, from 2016 through 2022, one of which is from the PLA. Of the eleven, five (none PLA) have so far led to approved patents.

Figure 11. ISR Records			
Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique (PLA)
Remote sensing	1	1	
Data collection using imagery	1		
Collection of signals	6	3	2
General surveillance	1		
General reconnaissance	2 (1)	1	
TOTAL ISR: 11			

Interestingly, one application was submitted as an invention and a utility model on the same day.[47,48] This is a tactic used to ensure one's intellectual property is protected while an invention is under substantive examination because utility models in China do not undergo substantive examination.

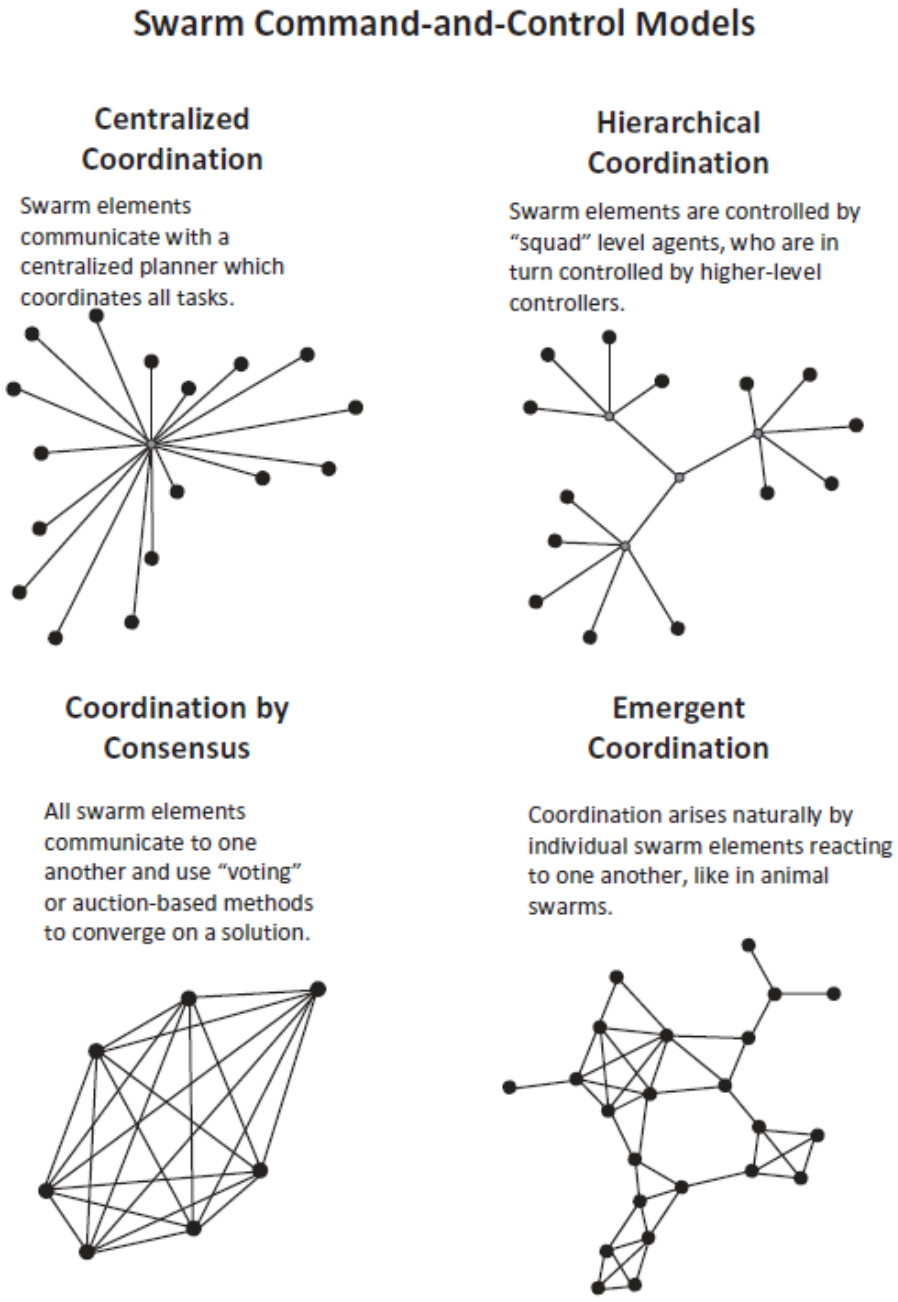
Two of these inventions developed new AI/ML methods. One from Xidian University adapts a particle swarm algorithm for regional reconnaissance where there is no defined end point.[49] Additionally, one from Shenzhen University [深圳大学] uses a YOLOv5 variant (YOLOv5-tiny) developed in China specifically for identifying small objects to collaboratively investigate dams for leakages.[50,51] Although this is not directly written for a defense application, it could be leveraged as such.

Support operations

Eight applications were found with support operation missions, from 2019 through 2022, four of which are from the PLA. Of the eight, only one (none PLA) has so far generated an approved patent.

Figure 12. Support Operations Records			
Mission	Total (PLA)	Granted Patent (PLA)	New AI/ML technique
Simulations and virtual environments	4 (2)	1	
Wireless charging	3 (1)	1	
Launch and recovery operations	7 (1)	3	
Data storage	1		
Data visualization	3	3	
TOTAL SUPPORT OPS: 18			

Next, the inventions were evaluated by organization method using Paul Scharre's Swarm Command-and-Control Models: Centralized Coordination, Hierarchical Coordination, Coordination by Consensus, and Emergent Coordination. Scharre notes that Centralized and Hierarchical Coordination can offer an optimal solution quickly, but both consume a lot of bandwidth and still takes time for information to flow up and down, even in high bandwidth environments. Coordination by Consensus conversely operates well in low bandwidth areas, but still requires direct communication among the whole swarm. Emergent Coordination functions more like animals in nature, where co-observation occurs or where the animals alter their environment to communicate—such as through pheromones or other signals—and this decentralized control bring decision making closer to the battlefield. Emergent swarms may not find the perfect solution, but will find a solution very quickly. Additionally, the decentralized command and control makes them immune to direct jamming. Unfortunately, this kind of coordination can also be harder to control because solutions may not be predictable in advance.[52]



Swarm command-and-control models. (Credit: Paul Scharre)[53]

Centralized Coordination

Very few PLA and defense-aligned inventions used Centralized Coordination in their swarms and when they did, it was to achieve a specific purpose, such as offloading some routing tasks to a central processor in order to allow the swarm to focus on more specific, time-sensitive tasks. In

these inventions, little attention was given towards how the forward-facing swarm aspects would collaborate.

Hierarchical Coordination

This was the second most popular method for PLA and defense-aligned UAV swarm collaboration. Like the Centralized Coordination method, the inventions seen in this category were mostly concerned with offloading the data analysis tasks from the forward deployed UAVs onto worker UAVs and/or motherships.

Coordination by Consensus

Among the AI/ML models developed by the PLA and defense-aligned institutions as well as those models developed elsewhere but utilized in new inventions, this was by far the most popular form of coordination. This is most often seen in models where each UAV operates as a sensor, then broadcasts the information to the swarm. The swarm network creates a matrix, or something similar, in order to develop the optimal solution for each UAV, and the UAVs adopt their respective solution from the network.

Emergent Coordination

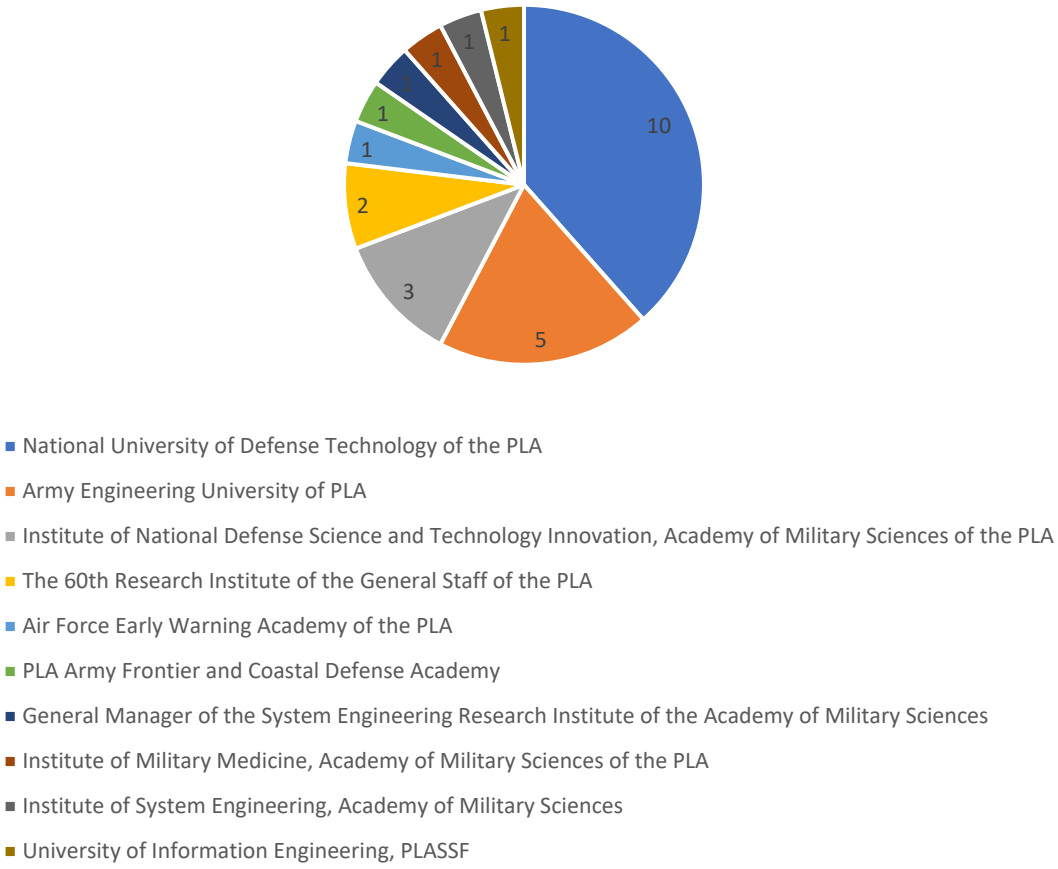
Only two inventions were found with Emergent Coordination, each using a variation of an ant colony algorithm and digital pheromones. Different from Coordination by Consensus, this method doesn't require each UAV to know what each other UAV is doing, but only those nearest to itself. In each of these inventions, the applicants used pre-existing AI/ML models in new ways, specific to their swarm.

Other findings

PLA Institutions

All but two of the applications submitted by the People's Liberation Army (PLA) were submitted by an institution within the PLA Army. The others were submitted by the PLA Strategic Support Force (PLASSF) and the Air Force Early Warning Academy of the PLA. It is unclear as to whether this is indicative of which units within the PLA will be responsible for operating UAV swarms in the future. Additionally, Kania lists two PLA Air Force units potentially associated with UAVs: 95835 部队 and 95984 部队 (potentially formerly 61135 部队). While none of these units is listed on any of the patent applications, 95835 (the PLA's first UAV unit) and has published three research papers on drone swarm technology and employment since 2019.[54] This represents a small indicator that this unit may take the lead for UAV swarms in the future and requires further analysis.

Figure 13. Number of Applications by PLA Institution



AI/ML Overall

Of the 26 PLA inventions, only one developed a new AI/ML method, as previously described in the navigation category from the Army Engineering University of PLA. Conversely, of the 134 defense-aligned inventions, nine developed new AI/ML methods in the offensive, target acquisition and tracking, communications and C2, navigation, and ISR categories. By invention output, the defense-aligned institutions are producing almost twice as many AI/ML drone swarm inventions (7% vs 4%). The earliest AI/ML invention for drone swarms (regional reconnaissance from Xidian University) appeared in 2017.

Prior Art

Prior Art or "backward citation" refers to the background scientific literature and patents related to an underlying patent. This can be helpful in determining previous methods new inventions are based on. Unfortunately, applications do not often cite the prior art because they are input by the

patent examiner during substantive examination.[55] However, it is useful when evaluating granted patents to see where the inventors' inspiration and research potentially originated.

Of the 78 PLA or defense-aligned granted patents, 64 were based on prior art, according to the substantive examination process. Fifty-nine used Chinese patents (303 total patents) and 36 used U.S. patents (51 total). Additionally, patents were used from the World Intellectual Property Office (WIPO), Australia, Canada, the European Patent Office (EPO), France, the UK, Japan, South Korea, and Russia. Evaluating influence based on prior art in patents is more straight forward because the patent must be filed in one country or international organization (WIPO or EPO). Prior art in academic papers is more nuanced because many of the papers are written jointly between academics and students at different universities, many of whom are also from different countries. More research would need to be done to evaluate the root of each prior art, if applicable.

Though much of the prior art cited comes from Chinese research, conference papers, and inventions, most of the algorithms used in the inventions (not developed by the present invention) are publicly available and were developed in the West.

Summary of findings and discussion

Not all of the evaluated inventions directly address overcoming challenges involved with drone swarm communication collaboration, some address smaller aspects of a future swarm, e.g. improving imagery sensors for collaborative collection, improving encryption across large distances, etc. However, what all the inventions do have in common is that they are all seeking optimization solutions for dealing with dynamic scenarios in large-scale combat. The medium by which to do this is by UAV swarm, which is further optimizing the war fight because they are cheaper and present limited risk to human operators. A major theme among all the inventions, regardless of primary application, is dealing with resource scarcity in a contested environment, including power, weapons, or bandwidth allocation. Additionally, many of the inventions specifically address urban environments.

The earliest drone swarm inventions focused on C2 and collaboration followed a few years later by those focused on navigation and path finding. This is logical because to create an efficient swarm, one would have to figure out the collaboration piece first as a foundation, then add mission sets and additional complexity, including path finding. Command and control and communication collaboration is also where the bulk of the inventions focus their attention, making up roughly 45% of all patent applications and utility models within the defense apparatus.

Of all the inventions found, the size of drones was not discussed in depth, though a few applications spoke to quadcopters and implied smaller UAVs.

Notably, only one of the inventions found to date address multi-mission swarms, those whose individual UAVs specialize in different missions and work together holistically to tackle a specific mission. However, this invention speaks more to the C2 structure of such a construct and

does not speak to the specific mission set this structure would address, nor to the specific tasks.[56] Most of these inventions likely exist at the classified level.

Conclusion and areas for further study

There is no agreed upon "best practice" when it comes to machine learning methods towards achieving a true swarm. A simple web search will yield hundreds of results, each with a different method depending on the desired end state. This is also what this study found relating to Chinese drone swarm technology: each invention is aiming to solve a very specific, and usually unique, question. There are some who point to earlier patents and claim, "We can do it better," but as described in the introduction, there are many challenges to overcome when designing collaborative robotic swarms, and one invention will not solve all the challenges. Additionally, some inventions seek UAV groups not in and of themselves, but to alleviate other challenges such as bandwidth throughput in congested spaces.

In 2018, Paul Scharre noted that, "it's too early to say whether swarms will be more useful for offense than defense,"[57] and because the world has yet to see a true swarm used in combat, this is still the case. Based on the inventions found, the PRC defense apparatus appears to be focusing on multiple lines of effort to evaluate the most effective technologies to improve swarming capabilities. It remains to be seen how this collaboration technology will develop into tactics, techniques, and procedures and further, into PLA doctrine.

Acknowledgements

A big thanks to USAFA Cadet First Class Andre Brikner for his help organizing the data.

Appendix A – Chinese patent law

The requirements for granting patent rights in China are laid out in the China National Intellectual Property Administration (CNIPA) Law, Chapter II, specifically Article 22 which [xx]states, "Any invention or utility model for which a patent right is to be granted shall meet the requirements of novelty, inventiveness and practical use."[58] China has three types of patents: the Invention (发明; similar to the U.S. Utility Patent which requires Substantive Examination[xxi] and expires after 20 years), the Utility Model (实用新型; no U.S. parallel, does not require Substantive Examination and expires after 10 years, and the Design Patent (外观设计; similar to, but not the same as the U.S. Design Patent).[59] All results reviewed for this research were either inventions or utility models.

China joined the Hauge in 2022, and as such is now bound by the provisions outlined in the Geneva Act of July 2, 1999 and the The Hague Act of November 28, 1960 which entered into force in China on 5 May 2022 and apply to Chinese patents filed internationally.[60]

While the concern that China is flooding the intellectual property world with faux patents is somewhat valid, this is mostly a concern of utility models.[61] Of the 371 results evaluated for this study, only 19 were for utility models (about 5%).

The results in this study were only drawn from CNIPA, not the National Defense Intellectual Property Office of the Equipment Development Department of the Central Military Commission (CMC) which is responsible for national defense intellectual property rights.

[xx] Note: While patents must prove they are practical, i.e., "can be manufactured or used and can produce positive results," a working model is not required for the patent to be granted

[xxi] Substantive Examination in China is similar to that in the US and refers to a process where the patent administration department under the State Council reviews the invention application and applicable reference material submitted by the applicant to ensure the invention is sufficiently unique from others. This process is detailed in Chapter IV of the CNIPA Law.

Appendix B – List of Applicants (PLA and defense-aligned organizations are highlighted)

Chinese	English
李水平	Li Shuiping
冉茂鹏	Ran Maopeng
沈彦辛	Shen Yanxin
徐洪军	Xu Hongjun
姚虎	Yao Hu
周梅	Zhou Mei
航天科工微电子系统研究院有限公司	Aerospace Science and Industry Institute of Microelectronics Systems Co., Ltd.
中国人民解放军空军预警学院	Air Force Early Warning Academy of the Chinese People's Liberation Army
中国人民解放军陆军工程大学	Army Engineering University of PLA
中航(成都)无人机系统股份有限公司	AVIC (Chengdu) UAV System Co., Ltd.
航空工业信息中心	AviChina Industry & Technology Co. Ltd.
北京航空航天大學	Beihang University
北京环球之翼航空科技有限责任公司	Beijing Global Wing Aviation Technology Co., Ltd.
北京华跃信息技术有限公司	Beijing Huayue Information Technology Co., Ltd.
北京计算机技术及应用研究所	Beijing Institute of Computer Technology and Application
北京机电工程研究所	Beijing Institute of Mechanical and Electrical Engineering
北京機械設備研究所	Beijing Institute of Mechanical Equipment
北京遥感设备研究所	Beijing Institute of Remote Sensing Equipment
北京理工大學	Beijing Institute of Technology
国网能源研究院有限公司；北京交通大学	Beijing Jiaotong University
北京连山科技股份有限公司	Beijing Lianshan Technology Co., Ltd.
北京邮电大学	Beijing University of Posts and Telecommunications
中国科学院长春光学精密机械与物理研究所	Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences
长春理工大学	Changchun University of Science and Technology
成都软智科技有限公司	Chengdu Soft Intelligence Technology Co., Ltd.
中國航天時代電子公司	China Aerospace Times Electronics Company
招商局重庆交通科研设计院有限公司	China Merchants Chongqing Transportation Research and Design Institute Co., Ltd.
中国人民解放军陆军边海防学院	Chinese People's Liberation Army Army Frontier and Coastal Defense Academy
中国科学院重庆绿色智能技术研究院	Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences
重庆大学	Chongqing University

重庆中宇工程咨询监理有限责任公司	Chongqing Zhongyu Engineering Consulting and Supervision Co., Ltd.
中国民航大学	Civil Aviation University of China
大連海事大學	Dalian Maritime University
大連大學	Dalian University
亿航智能设备（广州）有限公司	EHang Smart Devices (Guangzhou) Co., Ltd.
云南电网有限责任公司电力科学研究院	Electric Power Research Institute of Yunnan Power Grid Co., Ltd.
中国电子科技集团公司电子科学研究院	Electronic Science Research Institute of China Electronics Technology Group Corporation
佛山皖和新能源科技有限公司	Foshan Wanhe New Energy Technology Co., Ltd.
福州大学	Fuzhou University
军事科学院系统工程研究院系统总	General Manager of the System Engineering Research Institute of the Academy of Military Sciences
廣東德九新能源有限公司	Guangdong Dejiu New Energy Co., Ltd.
廣東容祺智能科技有限公司	Guangdong Rongqi Intelligent Technology Co., Ltd.
广东技术师范大学	Guangdong Technical Normal University
广东工业大学	Guangdong University of Technology
广东省科学院广州地理研究所	Guangzhou Institute of Geography, Guangdong Academy of Sciences
贵州师范学院	Guizhou Normal University
海南耐威科技系统技术研究院有限公司	Hainan Naiwei Technology System Technology Research Institute Co., Ltd.
海南大学	Hainan University
杭州电子科技大学	Hangzhou Dianzi University
杭州国科骏飞光电科技有限公司	Hangzhou Guoke Junfei Photoelectric Technology Co., Ltd.
哈尔滨工程大学	Harbin Engineering University
哈尔滨工业大学	Harbin Institute of Technology
哈尔滨工业大学（深圳）	Harbin Institute of Technology (Shenzhen)
哈爾濱理工大學	Harbin University of Science and Technology
河北清华发展研究院	Hebei Tsinghua Development Research Institute
合肥工业大学	Hefei University of Technology
河南机电职业学院	Henan Mechanical and Electrical Vocational College
河海大学	Hohai University
華僑大學	Huaqiao University
湖北怡辉河天科技有限公司	Hubei Yihui Hetian Technology Co., Ltd.
惠州市三航无人机技术研究院	Huizhou Sanhang UAV Technology Research Institute
湖南翰坤实业有限公司	Hunan Hankun Industrial Co., Ltd.
湖南華諾星空電子技術有限公司	Hunan Huanuo Xingkong Electronic Technology Co., Ltd.
湖南璟德科技有限公司	Hunan Jingde Technology Co., Ltd.

湖南科技大学	Hunan University of Science and Technology
中国科学院自动化研究所	Institute of Automation, Chinese Academy of Sciences
中国人民解放军军事科学院军事医学研究院	Institute of Military Medicine, Academy of Military Sciences of the Chinese People's Liberation Army
中国人民解放军军事科学院国防科技创新研究院	Institute of National Defense Science and Technology Innovation, Academy of Military Sciences of the Chinese People's Liberation Army
军事科学院系统工程研究院系统总体研究所	Institute of System Engineering, Academy of Military Sciences
江西核鹰勘测规划设计有限责任公司	Jiangxi Heying Survey Planning and Design Co., Ltd.
江阴航源航空科技有限公司	Jiangyin Hangyuan Aviation Technology Co., Ltd.
吉林大学	Jilin University
昆明理工大學	Kunming University of Science and Technology
南京浦口高新技术产业开发区管理委员会	Management Committee of Nanjing Pukou High-tech Industrial Development Zone
南京林业大学	Nanjing Forestry University
南京长空科技有限公司	Nanjing Sky Technology Co., Ltd.
南京大学	Nanjing University
南京航空航天大學	Nanjing University of Aeronautics and Astronautics
南京信息工程大学	Nanjing University of Information Science and Technology
南京邮电大学	Nanjing University of Posts and Telecommunications
南京理工大学	Nanjing University of Science and Technology
南京臻融软件科技有限公司	Nanjing Zhenrong Software Technology Co., Ltd.
中国人民解放军国防科技大学	National University of Defense Technology of the Chinese People's Liberation Army
广东东软学院	Neusoft Institute Guangdong
东北大学秦皇岛分校	Northeastern University Qinhuangdao Campus
西北工业大学	Northwestern Polytechnical University
鹏城实验室	Pengcheng Laboratory
中國人民公安大學	People's Public Security University of China
青海师范大学	Qinghai Normal University
潤泰救援裝備科技河北有限公司	Runtai Rescue Equipment Technology Hebei Co., Ltd.
中國民用航空總局第二研究所	Second Research Institute of Civil Aviation Administration of China
山东师范大学	Shandong Normal University
山東科技大學	Shandong University of Science and Technology
上海千機創新文旅科技集團有限公司	Shanghai Qianji Innovation Cultural Tourism Technology Group Co., Ltd.
上海土蜂科技有限公司	Shanghai Tufeng Technology Co., Ltd.
汕头大学	Shantou University
沈阳航空航天大学	Shenyang Aerospace University

中国航空工业集团公司沈阳飞机设计研究所	Shenyang Aircraft Design Institute of Aviation Industry Corporation of China
深圳市科比特航空科技有限公司	Shenzhen Corbett Aviation Technology Co., Ltd.
深圳市大疆創新科技有限公司	Shenzhen Dajiang Innovation Technology Co., Ltd.
深圳市道通智能航空技术股份有限公司	Shenzhen Daotong Intelligent Aviation Technology Co., Ltd.
深圳高度创新技术有限公司	Shenzhen High Innovation Technology Co., Ltd.
深圳市华琥技术有限公司	Shenzhen Huahu Technology Co., Ltd.
深圳大学	Shenzhen University
深圳市网联安瑞网络科技有限公司	Shenzhen Wanglian Anrui Network Technology Co., Ltd.
深圳市易链信息技术有限公司	Shenzhen Yilian Information Technology Co., Ltd.
四川长虹电器股份有限公司	Sichuan Changhong Electric Co., Ltd.
四川汉航科技有限公司	Sichuan Hanhang Technology Co., Ltd.
四川航天系统工程研究所	Sichuan Institute of Aerospace Systems Engineering
四川九洲电器集团有限责任公司	Sichuan Jiuzhou Electric Group Co., Ltd.
四川瑞鼎嘉扬防务科技有限公司	Sichuan Ruiding Jiayang Defense Technology Co., Ltd.
四川无境众创科技有限公司	Sichuan Wujing Zhongchuang Technology Co., Ltd.
生态环境部华南环境科学研究所(生态环境部生态环境应急研究所)	South China Institute of Environmental Science, Ministry of Ecology and Environment (Ministry of Ecology and Environment Emergency Research Institute of Ecology and Environment)
华南师范大学	South China Normal University
华南理工大学	South China University of Technology
西南交通大學	Southwest Jiaotong University
西南石油大学	Southwest Petroleum University
国网能源研究院有限公司	State Grid Energy Research Institute Co., Ltd.
国网浙江温岭市供电有限公司	State Grid Zhejiang Wenling Power Supply Co., Ltd.
中山大学	Sun Yat-sen University
中國電子科技集團公司第十四研究所	The 14th Research Institute of China Electronics Technology Group Corporation
中国电子科技集团公司第二十八研究所	The 28th Research Institute of China Electronics Technology Group Corporation
中国电子科技集团公司第五十四研究所	The 54th Research Institute of China Electronics Technology Group Corporation
中国人民解放军总参谋部第六十研究所	The 60th Research Institute of the General Staff of the Chinese People's Liberation Army
天津现代职业技术学院	Tianjin Modern Vocational and Technical College
天津现代职业技术学院	Tianjin Modern Vocational Technical College
天津职业技术师范大学	Tianjin Polytechnic Normal University
天津大学	Tianjin University
天津工业大学	Tianjin University of Technology

清華大學	Tsinghua University
电子科技大学	University of Electronic Science and Technology of China
電子科技大學長三角研究院(衢州)	University of Electronic Science and Technology of China Yangtze River Delta Research Institute (Quzhou)
中国人民解放军战略支援部队信息工程大学	University of Information Engineering, Strategic Support Force of the Chinese People's Liberation Army
武昌理工学院	Wuchang Institute of Technology
武汉大学	Wuhan University
武汉交通职业学院	Wuhan Vocational College of Communications
武汉兴图新科电子股份有限公司	Wuhan Xingtuxinke Electronics Co., Ltd.
五邑大学	Wuyi University
中国航空工业集团公司西安航空计算技术研究所	Xi'an Aeronautical Computing Technology Research Institute of Aviation Industry Corporation of China
中国航空工业集团公司西安飞机设计研究所	Xi'an Aircraft Design Institute of Aviation Industry Corporation of China
西安羚控电子科技有限公司	Xi'an Lingkong Electronic Technology Co., Ltd.
西安工业大学	Xi'an Technological University
西安热工研究院有限公司	Xi'an Thermal Engineering Research Institute Co., Ltd.
西安科技大学	Xi'an University of Science and Technology
西安电子科技大学	Xidian University
一飞（海南）科技有限公司	Yifei (Hainan) Technology Co., Ltd.
零度智控(北京)智能科技有限公司	Zero Intelligent Control (Beijing) Intelligent Technology Co., Ltd.
浙江吉利控股集团有限公司	Zhejiang Geely Holding Group Co., Ltd.
浙江时空道宇科技有限公司	Zhejiang Space-Time Daoyu Technology Co., Ltd.
浙江大学	Zhejiang University
郑州亚柏智能科技有限公司	Zhengzhou Yabo Intelligent Technology Co., Ltd.
中水珠江规划勘测设计有限公司	Zhongshui Pearl River Planning Survey and Design Co., Ltd.
中天泽智能装备有限公司	Zhongtianze Intelligent Equipment Co., Ltd.
珠海天晴航空航天科技有限公司	Zhuhai Tianqing Aerospace Technology Co., Ltd.
中聯重科土方機械有限公司	Zoomlion Earthmoving Machinery Co., Ltd.

Endnotes

[1] Kania, E.; The PLA's Unmanned Aerial Systems: New Capabilities for a "New Era" of Chinese Military Power; 29 Aug 2018;
[2] Crichton, M.; Prey; Harper Collins, 13 Oct 2009
[3] Gunzinger, M, Lee, C; The Next Frontier: UAVs for Great Power Conflict, Part I: Penetrating Strike; Mitchell Institute for Aerospace Studies; 8 Dec 2022; https://mitchellaerospacepower.org/wp-content/uploads/2022/12/The-Next-Frontier-UAVs-for-Great-Power-Conflict-FINAL.pdf
[4] The Aerospace Advantage Podcast; Episode 112 – Deploying the Swarm: Autonomous Drone Operations in Denied Environments; Mitchell Institute for Aerospace Studies; 21 Jan 2023; https://mitchellaerospacepower.org/episode-112-deploying-the-swarm-autonomous-drone-operations-in-denied-environments/
[5] 丁在永, 杨晓玲, 郝韡川; "Group combat, interpreting a new picture of unmanned battlefield" [群式作战，演绎无人战场新图景]; 20 May 2021; http://www.81.cn/jfjbmap/content/2021-05/20/content_289733.htm
[6] Global times; "One step ahead of America! Drone swarms appear on Chinese aircraft carrier" [又领先美国一步！中国航母上出现了无人机群]; 04 June 2022; https://baijiahao.baidu.com/s?id=1734649943509911160&wfr=spider&for=pc (accessed 19 Jan 2023)
[7] AVIC is an SOE and the largest defense conglomerate in China, producing aviation weapons and equipment, military transport aircraft, helicopters, airborne systems, general aviation, aviation research, and flight test equipment; "Group Profile" [集团简介]; AVIC; https://www.avic.com.cn/sycd/gywm/jtgk/jtjj/ (accessed 27 Mar 2023)
[8] CAS is an academy under China's State Council that had over 130 institutes in 2022 "About Us;" CAS; https://english.cas.cn/about_us/introduction/201501/t20150114_135284.shtml (accessed 27 Mar 2023); CAS has also provided R&D collaboration to the defense sector: "Many achievements of the Chinese Academy of Sciences appeared in the third military-civilian integration exhibition;" 18 Sep 2017; https://news.sciencenet.cn/htmlnews/2017/9/388602.shtm (accessed 27 Mar 2023)
[9] CASC is an SOE engaged in the research, design, manufacture, test and launch of space products such as launch vehicle, satellite, manned spaceship, cargo spaceship, deep space explorer and space station as well as strategic and tactical missile systems; CASC; "Company Profile;" http://english.spacechina.com/n16421/n17138/n17229/c127066/content.html (accessed 27 Mar 2023)
[10] http://www.casic.cn/; CASIC is an SOE that CASIC provides defense products in air defense, sea defense, ground strike, unmanned combat, and information & electronic countermeasures; CASIC; "Introduction of CASIC;" http://www.casic.com/n189298/n189314/index.html (accessed 27 Mar 2023)
[11] http://www.cetc.com.cn/; CETC is an SOE that produces advanced electronics for China's military and leveraging civilian technology in order to do so; Luce, M.; A Model Company: CETC Celebrates 10 Years of Civil-Military Integration; The Jamestown Foundation; China Brief Volume: 12 Issue: 4; 21 Feb 2012; https://jamestown.org/program/a-model-company-cetc-celebrates-10-years-of-civil-military-integration/ (accessed 20 Mar 2023)
[12] Administered by the Ministry for Industry and Information Technology, SASTIND's major responsibilities involve the nuclear weapon, aerospace technology, aviation, armament, watercraft and electronic industries; SASTIND; https://english.www.gov.cn/state_council/2014/10/06/content_281474992893468.htm (accessed 27 Mar 2023)
[13] Australian Strategic Policy Institute (ASPI); China Defence Universities Tracker; https://unitracker.aspi.org.au/about/ (accessed 21 Mar 2023)
[14] Scharre, P.; "How swarming will change warfare;" Bulletin of the Atomic Scientists, 2018, Vol 74, No. 6, 385-389
[15] 曲冠锦, 吴华明; "An Intelligent Decision-Making Method for Task Offloading Based on Unmanned Aerial Vehicle Swarm in Edge Computing Environment" [一种边缘计算环境下基于无人机群的任务卸载智能决策方法] (CN111160525A, 17 Dec 2019); https://patents.google.com/patent/CN111160525A/en?oq=CN111160525A (accessed 10 Jul 2023)

[16] **丁国如**, **谷江春**, **王海超**, **徐以涛**; "A UAV swarm flight trajectory optimization method for multi-radiation source tracking" [**面向多辐射源追踪的无人机群**飞行轨**迹**优**化方法**] (CN114337875A, 31 Dec 2021); https://patents.google.com/patent/CN114337875A/en?oq=CN114337875A (accessed 10 Jul 2023)

[17] **徐煜**华, 陈瑾, 俞星月, **刘典雄**, 杨旸; "An Energy Efficiency-Aware 3D Deployment Method for UAV Swarms" [一种能量效率知觉的无人机群三维部署方法] (CN111711960A, 16 Jan 2020); https://patents.google.com/patent/CN111711960A/en?oq=CN111711960A (accessed 10 Jul 2023)

[18] **王彤**, 陈金铭, 张曙光; "Single-step optimization method for UAV area coverage based on particle swarm optimization" [基于粒子群算法的無人機區域覆蓋的單步尋優方法] (CN107037828A, 24 Mar 2017); https://patents.google.com/patent/CN107037828A/en?oq=CN107037828A (accessed 10 Jul 2023)

[19] **沈培佳**, **黄郡**, **潘**继飞, 马涛, **刘方正**, 韩振中, **吴**韬; "An estimation-based energy equalization method for multi-UAV search tasks" [一种基于预估的多无人机搜索任务能量均衡化方法] (CN113759967A); China National Intellectual Property Administration [国家知识产权局]; https://patents.google.com/patent/CN113759967A/en?oq=CN113759967A (accessed 20 Mar 2023)

[20] Ibid.

[21] **曲冠**锦, **吴**华明; 17 Dec 2019

[22] Ibid.

[23] **左思文**, **刘**义, 杨超, **蒋**丽, 谢胜利; "A Mobile Edge Computing Unmanned Aid Swarm Assisted Communication Method for Explosive Traffic" [一种面向爆发性流量的移动边缘计算无人机群辅助通信方法] (CN110602633A, 2 Aug 2019); https://patents.google.com/patent/CN110602633A/en?oq=CN110602633A (accessed 10 Jul 2023)

[24] **王**锐, 张涛, **刘**亚杰, **雷洪涛**, **黄生俊**, **李**凯文, **明梦君**, 杨旭, **李文**桦; "Method and device for path planning of unmanned aerial vehicle swarm" [一种无人机群的路径规划方法及装置] (CN110823223A, 16 Oct 2019); https://patents.google.com/patent/CN110823223A/en?oq=CN110823223A (accessed 10 Jul 2023)

[25] Ibid.

[26] Ibid.

[27] **王**锐, 张涛, **刘**亚杰, **薛**亚妮, **雷洪涛**, **黄生俊**, **李**凯文, **明梦君**, 杨旭; "Method, drone, system and medium for flight control of unmanned aerial vehicles" [一种无人机群飞行控制的方法、无人机、系统及介质] (CN110703803A, 6 Nov 2019); https://patents.google.com/patent/CN110703803A/en?oq=CN110703803A (accessed 10 Jul 2023)

[28] **宋**绯, 陈瑾, **徐煜**华, 杨婷婷, **蔡源**, **宋**轩, 张潇; "Delay and energy consumption trade-off model and hierarchical learning algorithm in extended UAV network" [扩展无人机网络中的延时与能耗折中模型及分层学习算法] (CN111491315A, 18 Dec 2019); https://patents.google.com/patent/CN111491315A/en?oq=CN111491315A (accessed 10 Jul 2023)

[29] 陈勇, **吴迪**, 张余, **何攀峰**, **杜奕航**, 钱鹏智; "A method and system for dynamic spectrum allocation of UAV swarms for malicious interference" [一种面向恶意干扰的无人机群动态频谱分配方法及系统] (CN114867029A, 7 May 2022); https://patents.google.com/patent/CN114867029A/en?oq=CN114867029A (accessed 10 Jul 2023)

[30] Australian Strategic Policy Institute (ASPI); China Defence Universities Tracker – Changchun University of Science and Technology; https://unitracker.aspi.org.au/universities/changchun-university-of-science-and-technology/ (accessed 21 Mar 2023)

[31] 杨阳, **刘智**, **翁俊超**, 郑伟光; "Micro UAV swarm autonomous management data link" [**微型无人机群自治管理数据**链路] (CN101790248A); China National Intellectual Property Administration [国家知识产权局]; https://patents.google.com/patent/CN101790248A/en?oq=CN+CN101790248A (accessed 20 Mar 2023)

[32] **吴建**设, 张倩, 张祖磊, **李**亚锋, **郜君君**, 陈亮; "Weapon Target Allocation Method Based on Neural Network" [基于神經網絡的武器目標分配方法]; China National Intellectual Property Administration [国家知识产权局]; https://patents.google.com/patent/CN115222271A/en?oq=CN202210899699 (accessed 29 Jun 2023)

[33] 张天贤, **李健涛**, **刘**凯, **朱会柱**, **李**财品, 雷红文, **方学立**, **孔令**讲, **崔国**龙; "A generation method of networked radar jamming strategy based on UAV swarm" [**一种基于无人机群的**组网雷达干扰策略生成方法]; China National Intellectual Property Administration [国家知识产权局]; https://patents.google.com/patent/CN114911269A/en?oq=CN202210683593 (accessed 29 Jun 2023)

[34] 龚旭东, **吴强**, 赵雪冬, 郑宇, **曹**贺, **谷全祥**; "Low-Cost Folding-Wing Interceptor Aircraft, Swarms, and Method of Intercepting Swarms of Incoming Drones" [**低成本折叠翼**拦**截机、机群和**拦**截来**袭**无人机群的方法**] (CN114148520A); China National Intellectual Property Administration [**国家知**识产权**局**]; https://patents.google.com/patent/CN114148520A/en?oq=CN202111421563 (accessed 3 Feb 2023)

[35] 陈飞, **申志**飞, 项林英, **黄伯敏**; "A method based on distributed optimization for UAV swarm cooperative localization of gas leakage sources" [**一种基于分布式**优**化的无人机群**协**同定位气体泄漏源方法**] (CN111190438A); China National Intellectual Property Administration [**国家知**识产权**局**]; https://patents.google.com/patent/CN111190438A/en?oq=CN202010013204 (accessed 29 Jun 2023)

[36] 张洪光, **刘**华剑, **王瑞**, **刘元安**, **唐碧**华, **王**卫民, **冉静**; "An optimization method and system for planning unmanned aerial vehicle swarm rescue in forest fire" [**一种森林火灾中**规**划无人机群救援的**优**化方法及系**统] (CN109635991A); https://patents.google.com/patent/CN109635991B/en?oq=CN201811226322 (accessed 29 Jun 2023)

[37] **李琳**, 陈泓桦, 孙凌晨, **王若霜**; "A Model Design Method for Efficient Recognition and Classification of UAV Swarm Radar Targets on the Go" [**一种**针对**行**进间**无人机群雷达目**标**高效**识别、**分**类**的模型**设计**方法**] (CN115421121A); https://patents.google.com/patent/CN115421121A/en?oq=CN115421121A (accessed 29 Jun 2023)

[38] **徐**贵力, 谯睿, **程月**华, **杜昌建**; "Gridded formation method for large-scale unmanned aerial vehicles" (**适用于大**规**模无人机的网格化**编队**方法**) (CN113848988A); https://patents.google.com/patent/CN113848988A/en?oq=CN113848988A (accessed 30 Jun 2023)

[39] **卜 培和**, **毛**师彬, **薛松**, 张学铭; "A UAV cluster display and control device based on network communication" (一种基于网络通信的无人机集群显控装置) (CN211293689U); https://patents.google.com/patent/CN211293689U/en?oq=CN211293689U (accessed 30 Jun 2023)

[40] **李**伟恒; "Task planning method, task planning device and electronic equipment of cluster system" [机群系统的任务规划方法、任务规划装置及其电子设备] (CN115456488A, CN115456486A, CN115456487A, 10 Nov 22); https://patents.google.com/patent/CN115456488A/en?oq=CN115456488A; https://patents.google.com/patent/CN115456486A/en?oq=CN202211406704; https://patents.google.com/patent/CN115456487A/en?oq=202211406705 (accessed 3 Jul 2023)

[41] **曲冠**锦, **吴**华明; "An Intelligent Decision-Making Method for Task Offloading Based on Unmanned Aerial Vehicle Swarm in Edge Computing Environment" [一种边缘计算环境下基于无人机群的任务卸载智能决策方法] (CN111160525A, 17 Dec 2019); https://patents.google.com/patent/CN111160525A/en?oq=CN111160525A (accessed 7 Jul 2023)

[42] **左磊 高山**, **李**亚超, **李明**, 孙浩, **禄**晓飞, **高永**婵, **全英**汇; "Simplified Attention Network-Based Mission Planning Approach for Large UAV Swarms" [大型无人机群中基于简化注意力网络的任务规划方法] (CN113703482A, 30 Aug 2021); https://patents.google.com/patent/CN113703482A/en?oq=CN113703482A (accessed 6 Jul 2023)

[43] **左思文**, **刘**义, 杨超, **蒋**丽, 谢胜利; "A Mobile Edge Computing Unmanned Aid Swarm Assisted Communication Method for Explosive Traffic" [一种面向爆发性流量的移动边缘计算无人机群辅助通信方法] (CN110602633A, 2 Aug 2019); https://patents.google.com/patent/CN110602633A/en?oq=CN110602633A (accessed 6 Jul 2023)

[44] **魏小倩**, 陈远方, **刘洋**, 张利剑, **范新安**; "A method and device for resolving human-machine decision-making conflicts" [**一種人機決策沖突的消解方法和裝置**] (CN114488784A, 26 Oct 2020); https://patents.google.com/patent/CN114488784A/en?oq=CN114488784A (accessed 6 Jul 2023)

[45] **丁国如**, **谷江春**, **王海超**, **徐以涛**; "A UAV swarm flight trajectory optimization method for multi-radiation source tracking" [**面向多辐射源追踪的无人机群**飞行轨**迹优化方法**] (CN114337875A; 31 Dec 2021); https://patents.google.com/patent/CN114337875A/en?oq=CN114337875A (accessed 18 Apr 2023)

[46] **盛加亮**; "A UAV passive positioning track generation method and device" [**一种无人机无源定位航迹生成方法及装置**] (CN112130110A, 10 Sep 2020); https://patents.google.com/patent/CN112130110A/en?oq=CN112130110A (accessed 6 Jul 2023)

[47] **王生水**, 韩明华, 贺玉贵, **衣**晓飞, 韩乃军, **唐良勇**; "Method and system for search and rescue of unmanned aerial vehicles" [**一種無人機群搜索救援方法及系統**] (CN108832997A, 7 Aug 2018); https://patents.google.com/patent/CN108832997A/en?oq=CN108832997A (accessed 5 Jul 2023)

[48] **王生水**, 韩明华, 贺玉贵, **衣**晓飞, 韩乃军, **唐良勇**; "A drone swarm search and rescue system" [**一种无人机群搜索救援系**统] (CN209402517U, 7 Aug 2018); https://patents.google.com/patent/CN209402517U/en?oq=CN209402517U (accessed 5 Jul 2023)

[49] **王彤**, 陈金铭, 张曙光; "Single-step optimization method for UAV area coverage based on particle swarm optimization" [基于粒子群算法的無人機區域覆蓋的單步尋優方法] (CN107037828A, 24 Mar 2017); https://patents.google.com/patent/CN107037828A/en?oq=CN107037828A (accessed 6 Jul 2023)

[50] 张沛昌, **高明**辉, 邹泽雨, **蔡**伟, 赵雨森; "Cloud-side collaborative dyke detection method and device based on UAV platform" [基于无人机平台的云边协同堤坝检测方法及装置] (CN115147744A, 25 Jul 22); https://patents.google.com/patent/CN115147744A/en?oq=CN115147744A (accessed 6 Jul 2023)

[51] Q. Yu, M. Cheng, W. Zhang, Y. Tan and T. Huang, "Tiny Object Detection with Lightweight YOLOv5 Based on Attention Mechanism," *2022 6th Asian Conference on Artificial Intelligence Technology (ACAIT)*, Changzhou, China, 2022, pp. 1-6, doi: 10.1109/ACAIT56212.2022.10138007.; https://ieeexplore.ieee.org/document/10138007

[52] Scharre, P.; "Commanding the Swarm;" War on the Rocks; 25 Mar 2015; https://warontherocks.com/2015/03/commanding-the-swarm/ (accessed 28 Feb 2023)

[53] Scharre, P.; "How swarming will change warfare;" Bulletin of the Atomic Scientists, 2018, Vol 74, No. 6, 385-389

[54] Kania, 2018

[55] Goldstein, R.; "What is a Patent Citation?"; https://www.goldsteinpatentlaw.com/what-is-patent-citation/ (accessed 6 Jul 2023)

[56] **左磊 高山**, **李**亚超, **李明**, 孙浩, **禄**晓飞, **高永**婵, **全英**汇; "Simplified Attention Network-Based Mission Planning Approach for Large UAV Swarms" [大型无人机群中基于简化注意力网络的任务规划方法] (CN113703482A, 30 Aug 2021); https://patents.google.com/patent/CN113703482A/en?oq=CN113703482A (accessed 10 Jul 2023)

[57] Scharre, P.; "How swarming will change warfare;" Bulletin of the Atomic Scientists, 2018, Vol 74, No. 6, 385-389

[58] CNIPA, China National Intellectual Property Administration Law, https://english.cnipa.gov.cn/col/col3068/index.html (accessed 3 Feb 23)

[59] United States Patent and Trademark Office; Introduction to Utility Model Patents in China; 17 Apr 2018; https://www.uspto.gov/sites/default/files/documents/ChinaWeb_IntroUMPsinChina_TMoga.pdf (accessed 18 Apr 2023)

[60] World Intellectual Patent Office (WIPO); China Joins the Hague System; 5 Feb 2022; https://www.wipo.int/hague/en/news/2022/news_0005.html (accessed 18 Apr 2023)

[61] USPTO; "Trademarks and patents in China: The impact of non-market factors on filing trends and IP systems;" Jan 2021; https://www.uspto.gov/sites/default/files/documents/USPTO-TrademarkPatentsInChina.pdf (accessed 10 Mar 2023)