

Swarm Concept and Swarm UAV Systems

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Introduction

Swarm behavior; It is the behavior that causes living things with a colony structure such as birds, fish and some bacteria to clump together and move or move with the members of the swarm. The swarm behavior was first tested by computer graphics specialist Craig W. Reynolds in 1986 by examining bird flocks in a computer environment with a simulation program called BOIDS. The simulation allowed the swarm to act with simple factors according to the basic rules (Reynolds Engineering & Design). The ability of living things to solve problems that they cannot solve individually, as a swarm, is called swarm intelligence.

In swarm behavior, the movements are determined by a common intelligence, which indicates swarm intelligence. Swarm intelligence; If it is adapted to herd technologies, maximum efficiency and sustainability are obtained from the herd by dividing the same task among multiple herd members (Kaplan, 2021).

History of Swarm Technologies

In this part of the article, the general swarm systems in the field of robotics will be addressed as “swarm robot systems”. In the other subjects of the article, the member elements of the swarm robot systems (UAV, IDA and IKA) will be explained in detail and system distinction will be made. Swarm robot technologies are a field that examines swarm behaviors in natural life and tries to adapt them to robot systems. The field of swarm technologies is trying to adapt the swarm functions of living things such as ants, birds and fish in natural life, such as organizing among themselves, having an autonomous structure, cooperation and coordination, to robot systems as a flexible, scalable and robust structure. Swarm robot systems; it generally operates without a central entity to control the swarm members. Communication between swarm members is robot-to-robot or robot-to-environment (roboticsbiz.com, 2022). An example of herd life in nature is given in figure 1.

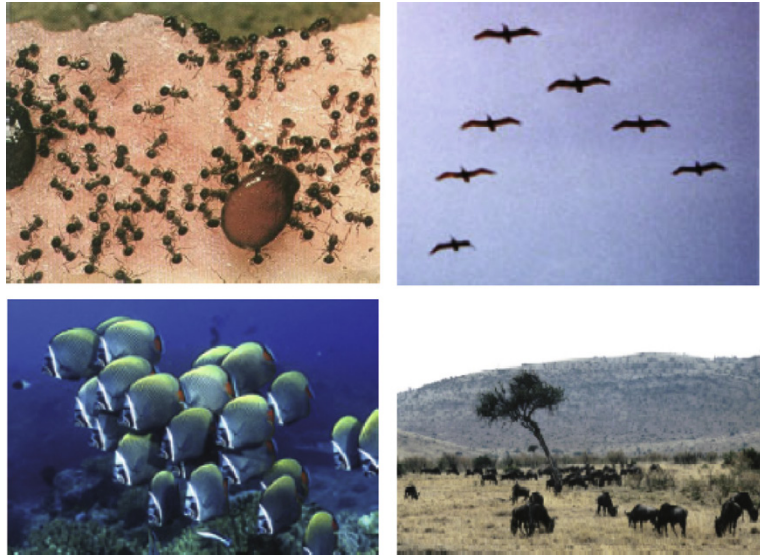


Figure 1. Swarm life in nature (Song et al., 2013).

In the field of robotics, the subject of “swarm” was used in G. Beni’s work “The concept of cellular robotic system” in 1988, and in “Approach to the dynamically reconfigurable robotic system” by T. Fukuda and S. Nakagawa. As G. Beni has stated, cellular robotics operates autonomously in an n-dimensional environment and is coordinated with limited communication without a central entity. According to G. Beni, these robots cooperate in a coordinated way to achieve a common goal (Cheraghi et al., 2021).

T. Fukuda, on the other hand, stated that as a result of his studies, a group of robots that act with the logic of a swarm can come together like cells in the human body and do complex tasks. In 1989, G. Beni and J. Wang, using the term swarm intelligence at the seventh Japan Robot Society Meeting, claimed that robot systems could display intelligent behavior by coordinating them (Eberhart et al., 2001). Ronald Kube and Hong Zohng; In 1993, they built a multi-robot system (swarm robot) inspired by the behavior of natural swarms. Gregory Dudek and his teammates for the swarm robots in the same year; He worked on the concepts of swarm size, communication range and spacing, communication topology between swarm elements, communication bandwidth, swarm organization, swarm heterogeneity or homogeneity, which describe the abilities of swarm elements. In these studies, which can be considered the ancestors of swarm systems, the concepts such as swarm robot, multi-robot system or swarm systems are synonymous, but the use of these concepts in different names is the reason why they did not have a clear terminology at that time.

Beni, who studies swarm systems, suggested in 2004 that swarm members should have a simple, identical, scalable and local communication system. The concepts put forward by Beni form the basis of swarm systems even today (Cheraghi et al., 2021). A number of system examples are given in Figure 2.

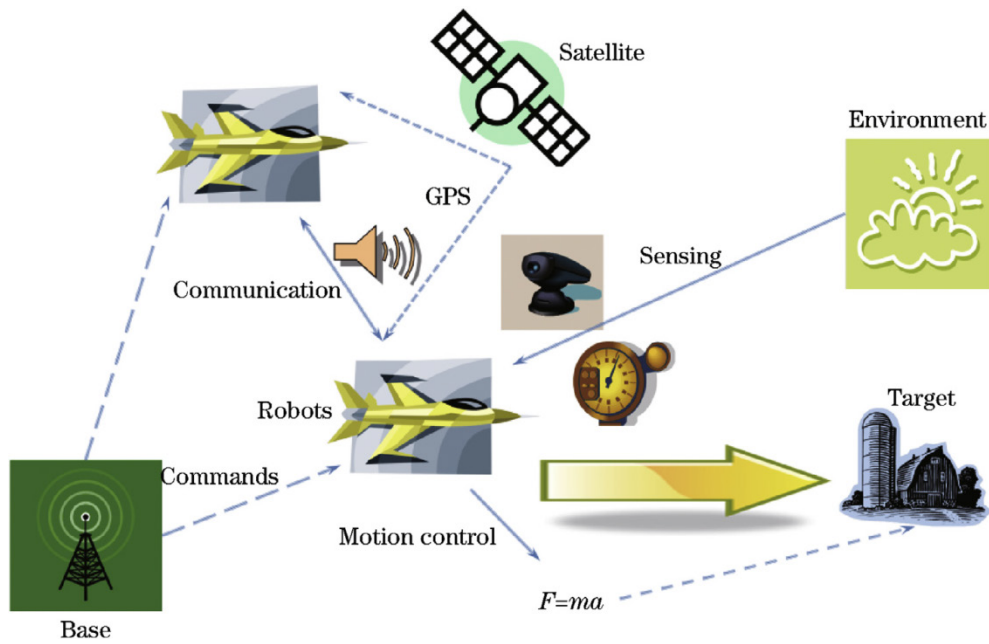


Figure 2. An example of a swarm system (Tan & Zheng, 2013).

Swarm Intelligence and Robotics

Swarm robots; It is a system that works for a certain purpose by using swarm intelligence software and swarm communication methods in coordination with robots that can work alone. For the efficient and successful implementation of swarm robots in the field, technology that can organize quickly and take on different formations is needed. This need has found itself in light, small, cost-effective and sacrificable robots (UAV, UGA and IDA) (Alemdar, 2021).

Swarm robots; they communicate with each other by swarm algorithms receiving and giving various data to communication units of swarm elements using swarm communication. In general, in swarm algorithms, swarm elements act according to local rules and the general behavior emerges from the interaction of swarm elements with each other or with the environment. According to the “Swarm Robotic Behaviors and Current Applications” study, by converting individual robots to the field of swarm robotics; It exhibits behavior based on a local rule set, which can range from simple reactive mapping between sensor inputs and actuator outputs to elaborate local algorithms. The behaviors in question include the interaction of swarm robots among themselves or with the environment (Schranz et al., 2020). Figure 3 shows an example array of swarm robots.



Figure 3. Swarm robots (Hanet al., 2015)

Interactions; It includes reading the data from the sensors of the swarm member, processing the swarm member's task computer or the computer of the relevant unit, and transforming the processed data into a response by the actuators (Floreano & Mattiussi, 2008). By repeating this interaction, the basic behavior of the herd is defined. Before entering the usage areas or working principles of herd robots, it is necessary to examine the basic principles of "herd intelligence", which scientists create by observing animal herds in nature and abstracting their behavior patterns.

Awareness

Awareness, which is one of the factors that form the basis of herd intelligence, is important for a good application of herd intelligence. In its interaction with the environment, the swarm member needs to instantly transmit critical elements or situations to the swarm of which he is a member, by scanning his surroundings in general threat/opportunity or friend/enemy dilemma. It provides awareness by detecting the threat/opportunity data individually at the right time and transmitting the relevant data to the other members of the swarm. Awareness determines the fate of the herd (Alemdar, 2021).

Autonomy and Self-government

The biggest difference of swarm intelligence from typical robotic hierarchy processes is that each element in the swarm can collect data on its own with its sensors and make decisions with the relevant data, and react with the decision taken by the microcontroller by using the actuators on the robot, which is the swarm member. The swarm algorithms of the swarm robots were previously developed with common procedures according to the swarm task. Although the roles of the herd members in the herd are similar, they may differ according to the task design of the herd. In swarm systems, in order to minimize the need for the swarm's communication system, it is generally requested that the swarm decide autonomously according to the instantaneous state of the swarm member without receiving a command from the system (Alemdar, 2021).

Solidarity

One of the situations in which the swarm-like communities and swarm intelligence give priority to their basic behaviors is the survival of the swarm. For this reason, every member of the swarm should give their basic reactions to the outside in solidarity with their swarm. Here, the survival of the individual herd is not important, but the survival of the herd itself. Another issue in solidarity is that the swarm immediately starts another task after performing the relevant task, and this is cyclical (Alemdar, 2021).



Figure 4. Circular swarm robots (Canciani et al., 2019)

Resiliency

Although the concept of Flexibility, which means the swarm's rapid recovery after the relevant situation, is referred to as "Resiliency" in the English literature, there is no exact equivalent for its use in swarm systems. In any disaster that may happen to the herd, the herd's realization of the current losses and the rapid improvement of the herd explains this concept within the herd system. No matter how heavy the loss or losses of the herd members are, the herd intelligence should analyze this situation and instead make a new role distribution within the other herd members or the herd. It should also adapt quickly to this new situation (Alemdar, 2021).

Swarm UAV: Robotic State of Bees

Swarm UAVs, a robotic copying of the behavior of bees between natural swarm systems; It consists of a large number of UAVs that perform the task in a coordinated way within the herd to perform a task with the operator or the decision mechanism within the herd (After et al., 2016)

The sensors of the swarm UAVs can be the same or different depending on the tasks, the autonomy levels and the platform types. In this case, we can use the homogeneous and heterogeneous classification that we use in swarm systems for swarm UAVs. Although the level of system complexity is low in homogeneous swarm UAV systems, sensor type, information processing capacity or flexibility capabilities according to tasks are more limited than heterogeneous systems. In heterogeneous swarm UAV systems, the diversity in the UAV mission capability and the high sensor capability in the payloads

carried separately by the swarm elements are very beneficial to the swarm, but technical complexity is beneficial compared to homogeneous systems (Oskoei, 2014).

Basically, two control architectures are used in swarm UAV operations, “centralized” and “decentralized”. The central control architecture of the UAV system in the swarm has a low level of autonomy and autonomy. There is no mutual communication structure between the UAVs in the swarm. The operator or operators of the system provide the coordination of the herd by getting information from each UAV system separately. For this reason, task assignment for the UAV system is made in advance. The advantages of low autonomy in the central control architecture are that the system is simple and easy to optimize, but the herd is less durable in case of system redundancy or communication problems.

On the other hand, the decentralized, that is, distributed control architecture, in the UAV system, the herd needs to have high autonomy and mutual communication. UAVs with this structure should be able to receive and share information by communicating in order to transfer sensor data among themselves. It should be able to make the necessary decisions in response to incoming information. In this case, the role of the operator in the herd moves to a higher level of management.

Distributed control architecture has a more complex structure than centralized architecture because they require a high level of autonomy. In a distributed or decentralized control architecture, since the tasks and information are distributed among the UAVs, the system is more durable, but it is more important because of its flexibility and redundancy. This makes it easier for UAVs to adapt to dynamic environments. The scattered herd; It is more resistant to damage that may occur in UAVs by cooperating within the system.

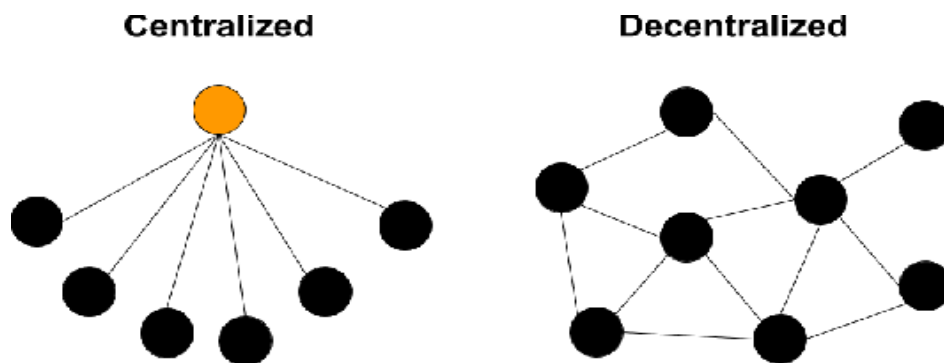


Figure 5. Central and Decentralized structures (Madey, 2013)

Formation Deployments in Herd Systems

Another issue in swarm systems is their deployment depending on the location and task. There are 3 deployment tubes, namely “Static Swarm”, “Dynamic Swarm” and “Hybrid Swarm”. In static swarm formation, swarm members are selected before the task by establishing trust in communication, trust and cooperation among swarm members by the system that controls the flight on the ground. In the static herd, participation in the herd is prevented from the beginning of the task, and new members are not included in

the herd. In dynamic herd formation, new members are allowed to join or leave the herd at any time, either before or after the task. The addition of new robots from the same control mechanism or group to the herd is called Closed-Dynamic Swarm Formation. In the Open-Dynamic Swarm Formation, any third-party robot can be included in the herd and the relevant assignment can be made. In dynamic herd formation, difficulties such as secure communication and cooperation among herd members come to the fore (Akram et al., 2017). Hybrid flock formation allows static flock formation and dynamic flock formation to work together as a single body. In this formation, there is a flock with a static herd behavior in the center of the herd. The static swarm in the center allows other swarm members (UAV) to join the flock.

Communication and Interaction in Swarm UAV Systems

In this section, Swarm Systems and the internal and external interactions of Swarm UAVs, which are a structure of Swarm Systems, and communication ways will be examined. Coordination among herd members is among the important conditions for successfully performing tasks in herd systems. The transfer of the information received from the sensors of the swarm elements and the processing of this information and its distribution to the swarm elements are important for swarm communication. UAV systems included in swarm robots establish swarm interaction with wireless connection due to their fast and very flexible movement and wide task areas (Zhu, , 2015).

Current Swarm UAV systems include a ground control system that provides command and control. Here, the relevant data is transferred to the ground control system, providing information to the operator and the commands transmitted by the operator are delivered to the swarm elements. UAVs transmit location information (GPS, if available), speed and data from payloads to the ground control system as telemetry. In these systems, receivers and transmitters use unlicensed radio frequencies such as 900 MHz to transfer data (Campion et al., 2018). The general representation of swarm communication is given in Figure 6.

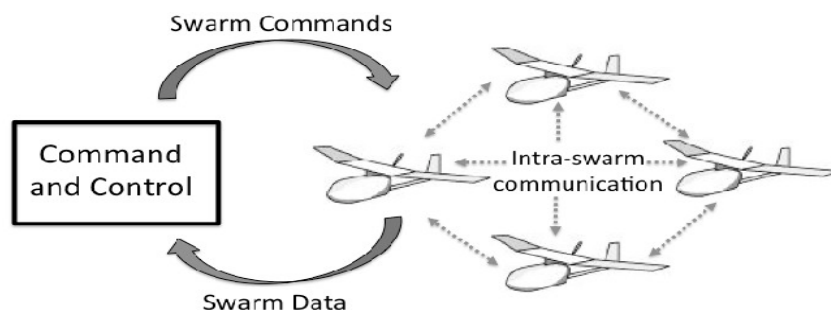


Figure 6. General display of swarm communication (Madey, 2013)

Swarm communication is divided into two as “Direct Communication” and “Indirect Communication” when we look at the communication and coverage area within the swarm. Direct Communication is used when swarm systems are from a single center and have limited coverage for the respective task. In this communication method, they

communicate directly between the swarm elements and the ground control system or station without a base station. Communication modules such as ZigBee, which are used for direct communication, have low power consumption, low delay communication and low cost.

Indirect communication, on the other hand, provides communication between the UAVs in the herd and between the ground control station without distance restrictions. In this communication method, there are fixed base stations or mobile base stations between the herd and the ground control station, and the communication between the systems is ensured. Communication units such as GSM or satellite communication are used in indirect communication that enables long-distance data transfer. This situation increases the power consumed, the cost spent for communication and the delay between units in direct proportion to the increase in the coverage area.

The data transfer within the swarm UAVs is divided into three as Broadcasting, Inquiry and Synchronization. This distinction is outlined in the STM Thinktech February 2019 report titled “HOT UAV SYSTEMS: A Future Forecast for Modern Warfare”. Broadcasting; It realizes the current state of the swarm element by sharing it with other swarm members. In Inquiry, the swarm element sends a message containing the relevant data from other swarm elements. Synchronization sends a message to the herd leader of the pack containing the synchronization request. Relevant swarm elements that receive the request broadcast the data to other swarm elements.

Swarm UAV and Battlefield

UAV systems first begin their historical process with the logic of remote control. It is accepted as the first use of UAV for military attack by Austria on August 22, 1849, by putting time-controlled fuse bombs in 200 balloons and sending them to Venice, Italy. “Ruston Proctor Aerial Target”, the first unmanned aerial vehicle or aircraft, was designed in 1916. In 1917, the gyroscope-controlled automatic aircraft became the first official unmanned aircraft of the US Army (Kahveci & Nazlı, 2017).

Unmanned aerial vehicles, which are modern and comply with today’s definition of UAV, have been developed since the 1960s. Ryan Model 147, an unmanned aerial vehicle developed by the USA, was used in the Vietnam War in the 1970s. UAVs, which send videos and pictures to the operator console where the UAV is controlled, were first used in the Gulf War in 1991 (Ekmekcioğlu & Yıldız, 2018). Turkey’s UAV development process started with the agreement signed by the Undersecretariat for Defense Industries with TAI in 2004. The first automatic flight test of the successful Bayraktar Blok A, performed by Baykar Defense in 2009, made significant contributions to Turkey’s national UAV development adventure (Aydın, 2017). Bayraktar TB2, which made its first flight on April 29, 2014; With its armed configuration, it was actively used as an armed force along with reconnaissance, intelligence and surveillance in Operation

Euphrates Shield, Operation Olive Branch, Operation Claw, Kiran and Peace Spring (URL-1).

Clustered use of drones was first seen in 2018 at the Russian-controlled Khmeimim Air Base in western Syria. The attack on the base was carried out by an anti-regime group. Russian personnel detected 13 UAVs that were preparing to attack at low altitudes and prevented them with EW & SHORAD systems (URL-2). On 14 September 2019, a clustered drone attack was carried out on Aramco's oil facilities in Abqaiq and Khurais in Saudi Arabia. The attack was carried out with 25 UAVs in the form of two sequential waves. Analysis after the attacks revealed that the facility in Abqaiq received 19 hits. The Saudi Arabian air defense layer, which consists of the MIM-104 Patriot and Crotale Short Range Air Defense Systems developed by France, could not stop the UAV attacks (Joshi, 2021).

Turkish Armed Forces; targeted the Syrian Armed Forces in the countryside of Idlib in 2020 with the use of clustered (Herd) armed UAVs. Using UAV systems in droves, the Turkish Armed Forces destroyed more than 200 targets, 5 helicopters, 23 tanks, 23 guns and the Russian-made BUK and Pantsir Air Defense systems in a short time (Urcosta, 2020).

References

- After A. Kolling, et al .(2016). "Human Interaction with Robot Swarms," IEEE Transactions on Human-Machine Systems, Vol. 46.
- Akram, R. N., Markantonakis, K., Mayes, K., Habachi, O., Sauveron, D., Steyven, A., & Chaumette, S. (2017, September). Security, privacy and safety evaluation of dynamic and static fleets of drones. In *2017 IEEE/AIAA 36th Digital Avionics Systems Conference (DASC)* (pp. 1-12). IEEE.
- Alemdar, A. (2021, January 15). Suru Dronelar 'Askeri Doktrinleri' nasıl etkileyecek? DefenceTurk. <https://www.defenceturk.net/suru-dronelar-askeri-doktrinleri-nasil-etkileyecek>
- Alemdar, A. (2021, January 15). Suru Dronelar 'Askeri Doktrinleri' nasıl etkileyecek? DefenceTurk. <https://www.defenceturk.net/suru-dronelar-askeri-doktrinleri-nasil-etkileyecek>
- Aydın, F. (2017, December 20). Birçok alanda kullanılan İHA'ların Türkiye serüveni. GZT. <https://www.gzt.com/jurnalist/bircok-alanda-kullanilan-ihalarin-turkiye-seruveni-2911729>
- Boids (Flocks, herds, and schools: A distributed behavioral model). (n.d.). Reynolds Engineering & Design. <https://www.red3d.com/cwr/boids/>
- Campion, M., Ranganathan, P., & Faruque, S. (2018). UAV swarm communication and control architectures: a review. *Journal of Unmanned Vehicle Systems*, 7(2), 93-106.
- Canciani, F., Talamali, M. S., Marshall, J. A., Bose, T., & Reina, A. (2019, May). Keep calm and vote on: Swarm resiliency in collective decision making. In *Proceedings of workshop resilient robot teams of the 2019 ieee international conference on robotics and automation (ICRA 2019)* (p. 4).

- Cheraghi, A. R., Shahzad, S., & Graffi, K. (2021, September). Past, present, and future of swarm robotics. In Proceedings of SAI Intelligent Systems Conference (pp. 190-233). Springer, Cham.
- Eberhart, R. C., Shi, Y., & Kennedy, J. (2001). Swarm intelligence. Elsevier.
- Editorial. (2022, September 6). Advantages and history of swarm robotics (SR) explained. RoboticsBiz. <https://roboticsbiz.com/advantages-and-history-of-swarm-robotics-sr-explained/>
- Ekmekciolu A., Yildiz M. (2018). The Use of Unmanned Aerial Vehicles in Military and Civil Fields : USA and Turkey Models and Sone Policy Offers. Türk İdare Dergisi. Sayı 486, ss. 169-227
- Floreano, D., & Mattiussi, C. (2008). Bio-inspired artificial intelligence: theories, methods, and technologies. MIT press.
- Han, Z., He, J., Geng, Y., Xu, C., Xu, L., & Duan, S. (2015, August). CRLB for TOA based near-ground swarm robotic localization. In 2015 IEEE 12th Intl Conf on Ubiquitous Intelligence and Computing and 2015 IEEE 12th Intl Conf on Autonomic and Trusted Computing and 2015 IEEE 15th Intl Conf on Scalable Computing and Communications and Its Associated Workshops (UIC-ATC-ScalCom) (pp. 1853-1858). IEEE.
- Joshi, S. (2021). ‘Drone swarms’ are coming, and they are the future of wars in the air. The Print, 2.
- Kahveci, M., & Nazlı, C. A. N. (2017). Unmanned Aerial Vehicles: History, Description, Legal Status In The World And In Turkey. Selcuk University Journal of Engineering, Science and Technology, 5(4), 511-535.
- Kaplan S., (2022, November 6). Takım Uydular: 21 Yüzyıl Uzay Oyuncuları. Dergiler. DefenceTurk. https://www.defenceturk.net/dergiler#dfliip-df_75428/1/
- Madey, A.G., and Madey G. R., 2013. “Design and evaluation of UAV swarm command and control strategies.” Proceedings of the Agent-Directed Simulation Symposium. Society for Computer Simulation International. USA.
- Oskoei E (2014). Swarm of UAVs: Search & Rescue Operation in Chaotic Ship Wakes, Master Thesis by, KTH Royal Institute of Technology.
- Schranz, M., Umlauft, M., Sende, M. ve Elmenreich, W. (2020).Swarm robotic behaviors and current applications. Frontiers in Robotics and Artificial Intelligence. 7 , 36.
- Song, Y., Hao, Q., & Zhang, K. (2013). Review of the modeling, simulation and implement of intra-body communication. Defence Technology, 9(1), 10-17.1
- Srivastava, D., Pakkar, R., Langrehr, A., & Yamane, C. (2019, March). Adaptable UAV swarm autonomy and formation platform. In 2019 IEEE Aerospace Conference (pp. 1-6). IEEE.
- Tan, Y., & Zheng, Z. Y. (2013). Research advance in swarm robotics. Defence Technology, 9(1), 18-39.
- Urcosta, R. B. (2020). The revolution in drone warfare: The lessons from the Idlib de-escalation zone. Air Force Journal of European, Middle Eastern & African affairs, 3(2), 50-65.
- URL-1: Türkiye’nin gökyüzündeki başarı imzası: Yerli İHA ve SİHA’lar. (2020, March

3). TRT Haber: Son Dakika Haberler ile Türkiye'nin Haber Kaynağı. <https://www.trthaber.com/haber/gundem/turkiyenin-gokyuzundeki-basari-imzasi-yerli-ihave-sihalar-464449.html>

URL-2: <https://harkul.com.tr/blog/siha-suru-teknigi-ve-savasin-degisimi/>

Zhu, X., Liu, Z., & Yang, J. (2015). Model of collaborative UAV swarm toward coordination and control mechanisms study. *Procedia Computer Science*, 51, 493-502.

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To Cite This Chapter:

Dunder, O. & Kaplan, S. (2022). Swarm Concept and Swarm UAV Systems. In S. Kocer. & O. Dunder (Eds .), *Current Studies in Basic Sciences, Engineering and Tecnology* (pp. 183–193). ISRES Publishing.