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Operational Application Analysis And Modeling Of Swarm EW UAV

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Abstract. At present, the research on the operational application of Swarm EW UAV(S.E.U) is focused on the combat theory and qualitative analysis. First, this paper analyzes the operational advantages of S.E.U, then studies the operational process of S.E.U, gives the flow chart and analyzes the OODA loop. Finally, the target assignment model and the attacking effectiveness model of S.E.U are established by using the planning theory and method to carry out the target distribution of S.E.U, as an example.

1. Introduction

The battlefield environment of the intelligent war is more complex and varied in the future, and the mobility and protection of a variety of combat targets are much stronger and more intelligent. To a certain extent, they can make adaptive action by self-perceived in the battlefield situation. Swarm tactics can sense the battlefield situation, then intelligently adjust the marshalling and target distribution, according to the task needs, battlefield environment and threat characteristics. By more efficient battlefield coordination, they can better achieve the scale of cluster operations, better adapt to the operational requirements of intelligent warfare.

From the development trends of EW and UAV, S.E.U will be the important equipment in order to seize the electromagnetic power in the intelligent war, with a high degree of intelligence and coordination. Swarm tactics of EW UAV will be an important tactic to compete for electromagnetic power, too.

The basic connotation, main influence and equipment development trends of the future unmanned combat based on swarm tactics are studied[1], and the study of swarm tactics has very important practical significance. But one UAV can only interfere with one part of the radar detection area. Multiple UAVs can interfere with their enemy's radar, through the coordination of their respective routes and jamming signals[2]. Mark J. Mears proposed the concept of UAV cluster collaborative electronic attack, including collaborative route planning and resource allocation[3]. At present, the application research of S.E.U focuses on the theory of combat and qualitative analysis, and lacks quantitative work.

On the basis of analyzing the existing work at home and abroad, this paper introduces the connotation of swarm tactics, analyzes the advantages of swarm tactics applied to EW and the operational application of S.E.U, then uses the planning methods on the swarm target allocation model. This paper explores the use of quantitative methods to study the "bee group" combat application.

2 Operational advantages of S.E.U

2.1 Basic connotation of Swarm tactics. As a special biological group of nature, swarm moves with a large number of sports units (bees) in the free flow of action usually. It often implements fast, self-organizing and intensive (clustered) attacks against real or potential threats to ensure their own security. Because the bottom of the power unit (a single bee) with a high degree of self-organization and self-synergy, this kind of swarm type of intensive attack action can complete the combat mission [1] ,often with the adjacent combat unit (a single bee) in close cooperation.

The phenomenon that swarm behavior emerges only by simple rules of the single bee is one of the representatives of group intelligence. "Bee group" acts without center control in the nature, but manual swarm needs to follow the instructions of human beings to complete specific tasks [4].

2.2 Main features of Swarm tactics. Swarm tactics have the following three main features [1,5,6].

a. “no center”

All unmanned combat platforms in the swarm are in an equal position, forming no subordinate relationship. Each one is equipped with a specific chip, which produced by common procedures, interfaces and protocols. On this basis, superior commander of the swarm gives orders and monitors them.

b. self-organization and coordination

Unmanned intelligent combat platforms implement by mass deployment, and quickly form an information sharing network. In this network, each combat individual is a network node, and able to exchange a variety of combat data and damage data. After receiving the combat command, individual can builds up a huge attack cluster and implementation of the target attack together, through close coordination.

c. diversified modular combination

Swarm can be composed of one single or multiple types of unmanned combat platform, according to the needs of the task. When executing the task, small swarm can be elicited from the big swarm to meet a variety of combat needs, via the same set of command and control system.

2.3 Operational Advantages of S.E.U. S.E.U is the important weapons for the electromagnetic power in the future of information warfare. Swarm EW is also a key application area of swarm tactics, and can greatly change the current situation that the center is human, task planning requirements high, and command decision time is long, with regard to UAV. Compared with the traditional electronic warfare weapons equipment, S.E.U has the following three advantages [1,4].

a. Ability of intelligence and reconnaissance is high

S.E.U can organize their own reconnaissance mission in a short period of time, allocate their own reconnaissance objectives efficiently, and complete the effective reconnaissance coverage of electromagnetic targets in a specific battlefield, including repeated reconnaissance of the important targets, continuous intelligence collection in complex conditions, and grasping the changes in the battlefield situation timely and fully.

b. Effection of electronic attack is well

The members of this swarm can share the intelligence with others, allocate offensive tasks independently, and select the attack signal style according to the current situation and target information. The members can also release noise, false targets and other interference signal from multiple angles to the enemy target precisely, so that it is difficult to defend for the enemy.

c. Situation evaluation is real-time and efficient

The members of this swarm which implement online assessment mission can evaluate the attack effection in a short time, and share the assessment results in real time in the group. Members attacking targets may change the direction of attack quickly, and realize closed loop of swarm EW, due to the results of reconnaissance and assessment.

3 Operational Application Process of S.E.U

At present, most of the countries which has strong military power are all stepping up to develop some projects about swarm. The S.E.U which can operate EW tasks are the vital research direction of these projects. But now there are no mature swarm which are used to EW specially. According to intelligence data now, the situation of operational application process of S.E.U can be analyzed probably as illustrated in Fig. 1 and 2.

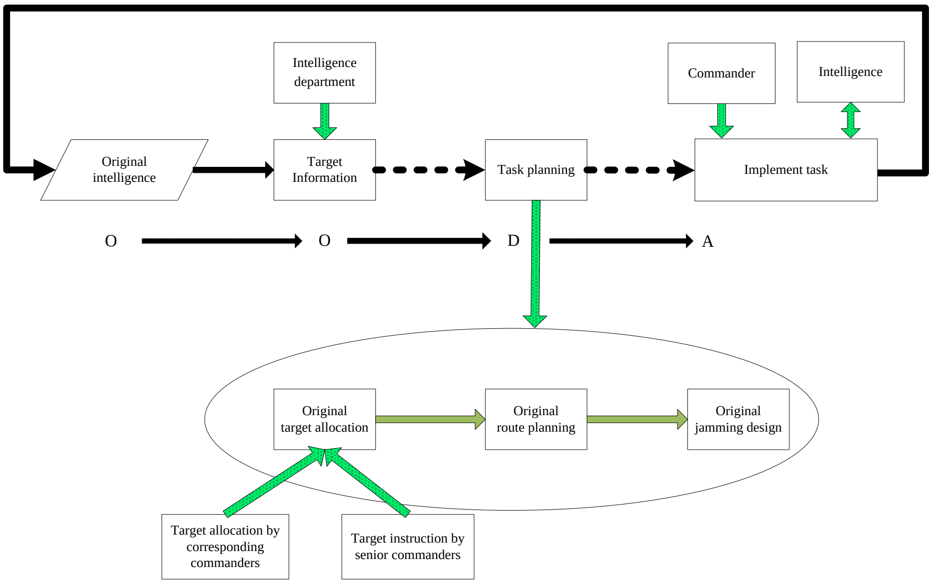

Fig. 1: Operational application process of S.E.U

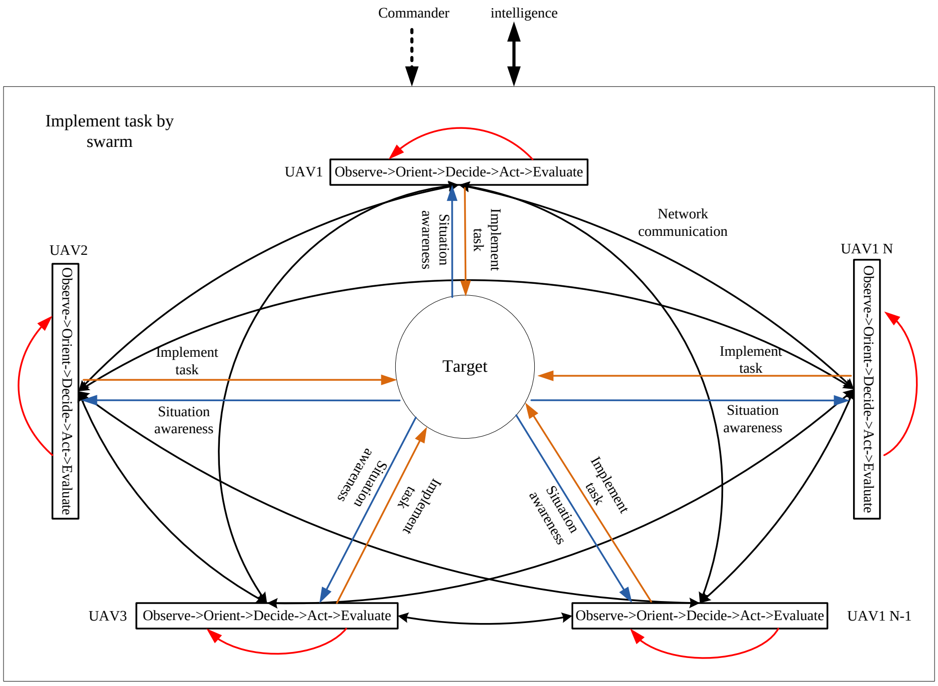

Fig. 2: Inner OODA loop of S.E.U

The intelligence department make the initial intelligence data fused together, then, give the UAV commander some target information which they deserve. Compared with the task plan of the distributed EW UAV, the task plan of the swarm UAV is very simple, that the commander only should make sure the attacking target of every single UAV roughly before operation , according to some rules or orders, as well as carry out route planning and original jamming design. The task planning is the necessary step for the S.E.U which possess high intelligence. The commander can merely input his operational intention into the swarm UAV that the UAV would execute task planning by themselves.

When carrying out the task, the swarm will own the autonomic collaboration ability, and distribute the task type and attacking aim between the members, on the base of the task requirement and battlefield situation at present. The members contact others by communication link, so they can share the situation awareness information to make decision. The member itself can complete the "observe-orient-decide-act-evaluate" closed-loop process. The member can not only optimize the task by itself, but also execute coordinated action with other members, which can come to the maximum of the group efficiency.

The commander may intervene or control the swarm UAV. The intelligence gathered by the swarm UAV can transmitted to the intelligence department, at the same time, the intelligence department may also support some intelligence to the swarm UAV. The swarm UAV with high intelligence will take great influence to EW, which can accelerate the OODA loop, alleviate the burdens of human cognition, and improve the EW effect.

4 Target Assignment Model of S.E.U

Taken these S.E.U which execute radar countermeasure as an example as illustrated in Fig. 3, a target assignment model is established, according to planning theory and method.

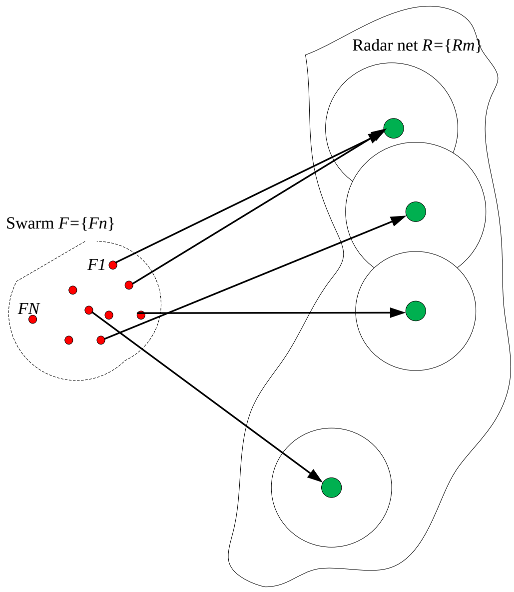

Fig. 3: Target assignment of the S.E.U

4.1 Target Assignment Model. Assuming that one swarm $F = \{F_n\}(1 \le n \le N)$ is composed of N radar countermeasure UAV, and attack the radar net $R = \{R_m\}(1 \le m \le M)$ comprised of M radars. According to the above analysis, some following assumptions are established for simplicity.

a. state uniqueness assumption

Every UAV has only one state at the same time. The state collection of UAV is, $S = \{S_1 = \text{reconnaissance}, S_2 = \text{attack}, S_3 = \text{evaluation}\}$ and every UAV F_n only possesses one and only one state $S_{n,p} \in S(1 \leq p \leq 3)$. When the state of F_n is p, $S_{n,p} = 1$, and other states $S_{n,p} = 0$. The conclusion is: $\sum_{n=1}^{N} \sum_{p=1}^{3} S_{n,p} = n$.

b. target uniqueness assumption

Every UAV can attack one radar at most meanwhile. Assuming that $G_{n,m}$ represents the relation between F_n and radar R_m. If F_n attacks R_m, $G_{n,m} = 1$. If F_n does not attack R_m, $G_{n,m} = 0$. The situation that more than one UAV hit only one radar is permissible.

c. minimum quantity of states assumption

To optimize the overall operational effectiveness of the swarm, assuming that more than D UAV are in the state of reconnaissance, and more than E UAV are in the state of evaluation, at the same time.

Attacking effectiveness function $J(F_n, R_m)$ is defined to measure the effect of F_n attacking R_m. Relative position between them, equip performance and terrain conditions are all important independent variable of the function with other arguments.

On the basis of the above analysis and hypothesis, in order to achieve the maximal attacking effectiveness of the swarm the state and the target of every member should be identified clearly, then the target assignment model is set up.

1) Objective function

$$\max \quad J = \sum_{n=1}^{N} \sum_{m=1}^{M} \sum_{p=1}^{3} S_{n,p} \times G_{n,m} \times J(F_n, R_m).$$

2) State uniqueness assumption

$$\forall n, \sum_{p=1}^{3} S_{n,p} = 1 \qquad (S_{n,p} = 0 \text{ or } 1).$$

3) Target uniqueness assumption,

$$\forall n, \sum_{m=1}^{M} G_{n,m} = 1 \qquad (G_{n,m} = 0 \text{ or } 1).$$

4) Minimum quantity of states assumption

$\sum_{n=1}^{N} S_{n,1} \geq D,\ \sum_{n=1}^{N} S_{n,3} \geq E$.

The simultaneous equations is:

$$\max_{J(F_n, R_m)} \quad J = \sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{p=1}^{3} S_{n,p} \times G_{n,m} \times$$

$$\begin{cases} \sum_{p=1}^{3} S_{n,p} = 1 & (\forall n, S_{n,p} = 0 \text{ or } 1) \\ \sum_{m=1}^{M} G_{n,m} = 1 & (\forall n, G_{n,m} = 0 \text{ or } 1) \\ \sum_{n=1}^{N} S_{n,1} \geq D \\ \sum_{n=1}^{N} S_{n,3} \geq E \\ \sum_{n=1}^{N}\sum_{p=1}^{3} S_{n,p} = n \end{cases}$$

4.2 Attacking Effectiveness Model. To evaluate the effectiveness of F_n attacking R_m, this paper uses the stand-off jamming to radar net (SOJ) as an example, and gives one method to calculate attacking effect function $J(F_n, R_m)$, as shown in Fig. 4.

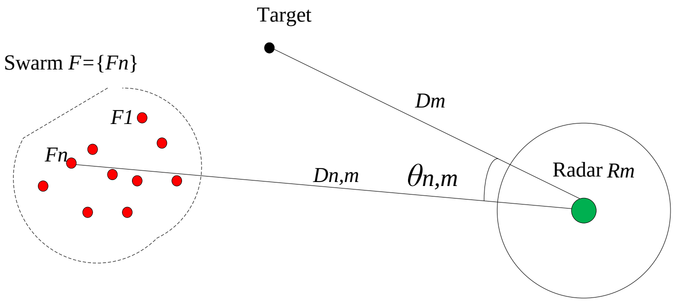

Fig. 4: relative position relation between UAV and targets

In presence of ECM, radar jamming equation[8] represents the factors which influence the radar detection range. It is simple to calculate and easy to understand, if the jamming-signal-ratio (JSR) is taken as an example which assesses attacking effectiveness,

According to the radar equation, the echo power of by R_m is:

$$P_{r,m} = \frac{P_m G_m^2 \lambda_m^2 \sigma}{(4\pi)^3 D_m^4} \tag{3}$$

Where P_m is the echo power of R_m, G_m is the emitting antenna gain of R_m, D_m is the distance between R_m and the target, σ is the RCS of R_m, and λ_m is the wavelength of R_m.

According to the radar equation, the jamming power from F_n to R_m is $P_{j,n,m}$ in SOJ.

$$P_{j,n,m} = \frac{P_{j,n} G_m(\theta) G_{j,n} \lambda_m^2 B_{r,m} \gamma_{j,n,m}}{(4\pi)^2 D_{n,m}^2 B_{j,n}} \tag{4}$$

Where $P_{j,n}$ is the jamming power of F_n, $G_{j,n}$ is the emitting antenna gain of the jammer in F_n, $B_{r,m}$ is the receiver bandwidth of R_m, $B_{j,n}$ is the jammer bandwidth of F_n, and $\gamma_{j,n,m}$ is the polarization loss from the jamming signal of F_n to the emitting antenna of R_m. $G_m(\theta)$ is the emitting antenna gain of R_m where the azimuth is θ.

Because of (3) and (4), the attacking effect function $J(F_n, R_m)$ is :

$$J(F_n, R_m) = J_{n,m} = \frac{P_{j,n,m}}{P_{r,m}} = \left(\frac{P_{j,n} G_m(\theta) G_{j,n} \lambda_m^2 B_{r,m} \gamma_{j,n,m}}{(4\pi)^2 D_{n,m}^2 B_{j,n}}\right) \Big/ \left(\frac{P_m G_m^2 \lambda_m^2 \sigma}{(4\pi)^3 D_m^4}\right)$$

$$= 4\pi \times \frac{P_{j,n}}{P_m} \times \frac{G_m(\theta) G_{j,n}}{G_m^2} \times \frac{B_{r,m}}{B_{j,n}} \times \frac{\gamma_{j,n,m}}{\sigma} \times \frac{D_m^4}{D_{n,m}^2} \quad (5)$$

5 Conclusion

This article analyzes the possible operational application process of S.E.U, compares with the present operational application process of EW UAV nowadays, and gets the conclusion that the reflection which the S.E.U will bring is subversive. At least, the OODA loop will speed up, and the EW effectiveness will boost. It takes the S.E.U executing the radar countermeasure task as an example, then constitutes a target assignment and attacking effectiveness model according to the planning theory and method.

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