Advances in Computer, Signals and Systems (2021) 5: 22-28
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2021.050205
ISSN 2371-8838

Rule-Based Unmanned Swarm Collaborative Control Method

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Keywords: Unmanned swarm, Collaborative control, Attack defense confrontation

Abstract: Aiming at the new combat mode based on unmanned swarm in the future, an attack defense confrontation model based on unmanned swarm is established, in which a rule-based unmanned swarm collaborative control mode is proposed. The control method of achieving unmanned cluster goal coherence and team coordination is realized by improving the Vicsek model and enhancing the synergy ability of unmanned cluster. In order to verify the operational effectiveness of the control mode, the unmanned swarm operation experiment is carried out. The results show that the rule-based unmanned swarm collaborative control mode can effectively improve the success rate of combat.

1. Introduction

Direction of arrival (DOA) estimation of multiple narrowband sources is a major research issue in array signal processing. Under the increasingly complex international situation, the information-based modern war model continues to develop, the gap in military strength between the United States, Britain, Russia, China and other military powers is also shrinking. Maintaining the advantage of military strength is the top priority of the current national defense task[1]. Because of its advantages of strong concealment, high survival rate, recyclability and high autonomy and intelligence, unmanned swarm combat has become an indispensable new combat mode in the future battlefield, promoting the transformation of modern war from informatization to intelligence[2].

The development and origin of unmanned swarm combat technology comes from scientists' research on biological cluster behavior. Through the observation and analysis of biological swarm such as bird colony, fish colony and ant colony, it is found that the individuals in the biological population follow the corresponding rules, show all kinds of group behavior, and emerge the characteristics of group intelligence[3], which makes the group composed of individuals with low intelligence have complex group intelligence behavior, and the concept of swarm system has been developed in many years of research[4]. Before the swarm system is popularized and applied to combat, the combat system that can perform combat tasks composed of unmanned equipment benefiting from artificial intelligence technology is called unmanned system[5]. The unmanned system with the ability to observe and collect battlefield data, judge data information and make decisions and actions can be called intelligent unmanned system[6]. Unmanned swarm combat technology is the combination and development of intelligent unmanned system and swarm system in the field of military operation[7].

Because the unmanned swarm combat equipment is still in the long-term innovation and development stage[8], and there are few cases of actual assembly and actual combat, the unmanned swarm combat experiment and modeling and simulation are important ways and means to verify the combat concept, combat effect and guide the R&D, design and innovation of unmanned swarm equipment[9]. Due to the dynamics, complexity and autonomy of unmanned swarm, the collaborative control of swarm is one of the key research directions and difficulties in unmanned swarm combat[10].

Aiming at the difficult problem of collaborative control in unmanned swarm combat, this paper establishes an attack and defense confrontation model based on unmanned swarm. At the same time, a rule-based unmanned swarm collaborative control mode is proposed, and the effectiveness of the collaborative control mode is verified by combat experiments.

2. Rule-Based Attack Defense Confrontation Model of Unmanned Swarm Collaborative Control

The model improves the classical agent combat model Einstein proposed by the U.S. Naval Analysis Center (CAN, Center for Naval Analysis)[11], and constructs a rule-based attack defense confrontation model of unmanned swarm collaborative control. In the model, each agent represents a soldier. It has three states: good, injured and dead. Each agent is represented by a feature weight vector:

$$\vec{\omega}=(\omega_{AF},\omega_{AE},\omega_{IF},\omega_{IE},\omega_{TF},\omega_{TE}) \quad (1)$$

Where, $-1 \le \omega_x \le 1, \sum|\omega_x|=1$. The value of x is $\{x|AF,AE,IF,IE,TF,TE\}$. Each weight vector consists of six components: our side good weight component (ω_{AF}), enemy good weight component (ω_{AE}), our side injury weight component (ω_{IF}), enemy injury weight component (ω_{IE}), our side target weight component (ω_{TF}), and enemy target weight component (ω_{TE}).Our target is the target point, while the enemy's target is all our personnel. Each agent takes itself as the center and has an observation range with radius R ($R>0$).The observation range of individual agent is:

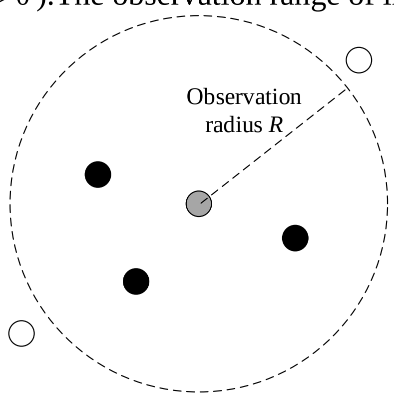

Fig.1 Observation Range of Agent

Among them, the gray sphere is the central agent, the black sphere is the agent within the observation range of the central agent, and the white agent is the agent outside the observation range. At time t, the set of individuals within the observation range of the central agent satisfies the following conditions:

$$\left\| \text{Agent}_j(t) - \text{Agent}_i(t) \right\| \le R \quad i, j = 1, 2, \cdots, N \quad (2)$$

Where, $\text{Agent}_i(t)$ and $\text{Agent}_j(t)$ are the location coordinates of the corresponding agent, and $\left\| \text{Agent}_j(t) - \text{Agent}_i(t) \right\|$ represents the Euclidean distance between them. The agent will combine the Vicsek model[12] and the values of their respective feature weight vectors to determine their own mobile strategy in the battlefield environment. The agent sorts all possible moving targets through the penalty function Z, which is defined as:

$$z(B_{xy}) = \frac{1}{\sqrt{2r_{F,S}}}\left[\frac{\omega_{AF}}{N_{AF}}\sum_{i\in AF}^{N_{AF}} D_{i,B_{xy}} + \frac{\omega_{AE}}{N_{AE}}\sum_{j\in AE}^{N_{AE}} D_{j,B_{xy}}\right] + \frac{1}{\sqrt{2r_{E,S}}}\left[\frac{\omega_{IF}}{N_{IF}}\sum_{k\in IF}^{N_{IF}} D_{k,B_{xy}} + \frac{\omega_{AE}}{N_{AE}}\sum_{l\in IE}^{N_{IE}} D_{l,B_{xy}}\right] + \omega_{TF}\frac{D'_{TF,B_{x,y}}}{D_{TF,B_{x,y}}} + \omega_{TE}\frac{D'_{TE,B_{x,y}}}{D_{TE,B_{x,y}}} \quad (3)$$

Where B_{xy} is the coordinate position of the environment where the agent is located; AF, IF, AE, IE, TF, TE and N_x are respectively defined as our side good agent set, our side damaged agent set, enemy good agent set, enemy damaged agent set, our side target set, enemy target set and the total number of class N_x agents within the current agent observation range; $1/\sqrt{2r_{F,S}}$ is the square scale factor; $1/\sqrt{2r_{E,S}}$ is the enemy scale factor; $D_{X,Y}$ is the distance from X to Y; $D'_{X,Y}$ is the set from all target sets to the location of the current agent. The penalty function Z can effectively weigh the value of the current agent trying to move the target, and its subscript is the same as that of the agent feature weight vector. Through the penalty function, all possible moving targets are sorted, and the top 20% target points are selected to form the target set $S_i(t)$. Let the moving direction of agent i at time t be $\theta_i(t) \in (-\pi, \pi]$; The speed is v. Then the position update formula at time t + 1 is:

$$Agent_i(t+1) = Agent_i(t) + v(t) \quad (4)$$

The vector form of speed is $v(t) = [v\cos\theta_i(t),\ v\sin\theta_i(t)]^T$, where the calculation formula of $\theta_i(t)$ is:

$$\theta_i(t) = \arctan\frac{\sum_{j\in S_i(t)} \sin\theta_j(t)}{\sum_{j\in S_i(t)} \cos\theta_j(t)} \quad (5)$$

$S_i(t)$ in the formula is obtained according to the ranking result of formula (3).

3. Unmanned Swarm Collaboration Status

When there is a command agent, the agent cluster will be divided into teams. The command agent selects the moving direction according to the rules, and the subordinate agent of the command agent moves according to the target direction selected by the command agent. Test the rule-based collaboration control mode, randomly initialize 300 unmanned swarm agents in a 5 * 5 area, and set the characteristic weight of each agent to $\vec{\omega}$=(0.25,0.25,0.25,0.25,0.25,0.25). It does not distinguish between our side or the enemy, and the quantity is regarded as equal during calculation. The random initial state of unmanned swarm is shown in the following figure:

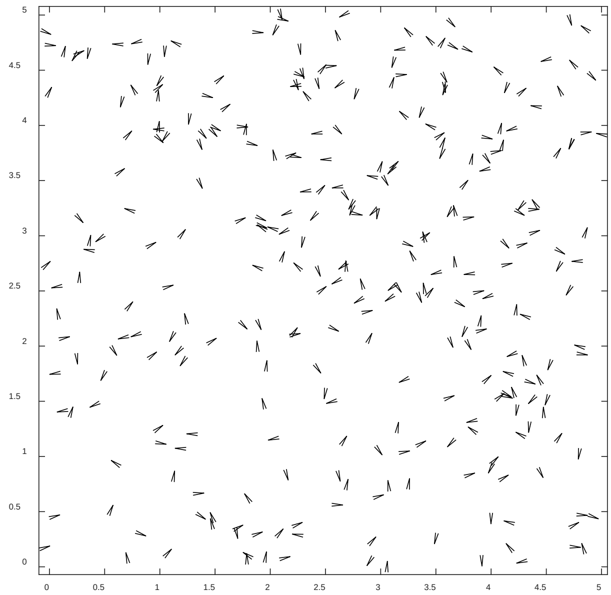

Fig.2 Random Initial State of Unmanned Swarm

When all agents in the unmanned swarm randomly specify the same target direction, that is, the target direction is the same, its state is as shown in the following figure:

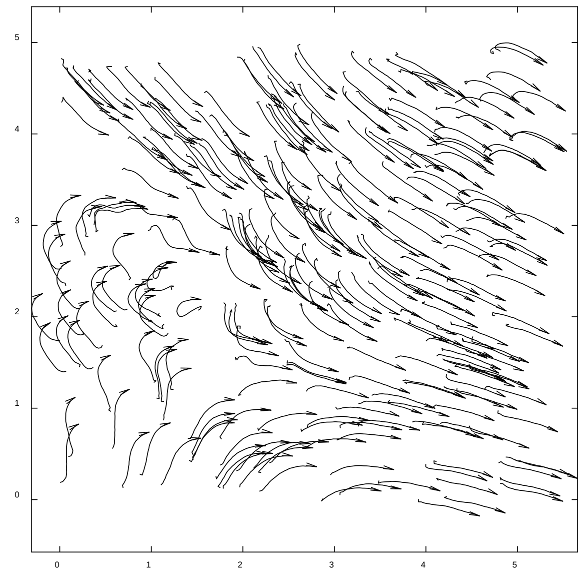

Fig.3 Unmanned Swarm Target Direction Consistent State

Each agent in the figure has a trajectory. When there are command agents and different target directions in the unmanned swarm, 20 of them are randomly selected as command agents and randomly assigned to a target direction. The other agents are randomly assigned to each command agent to form different teams. The coordination state diagram of unmanned swarm unit is as follows:

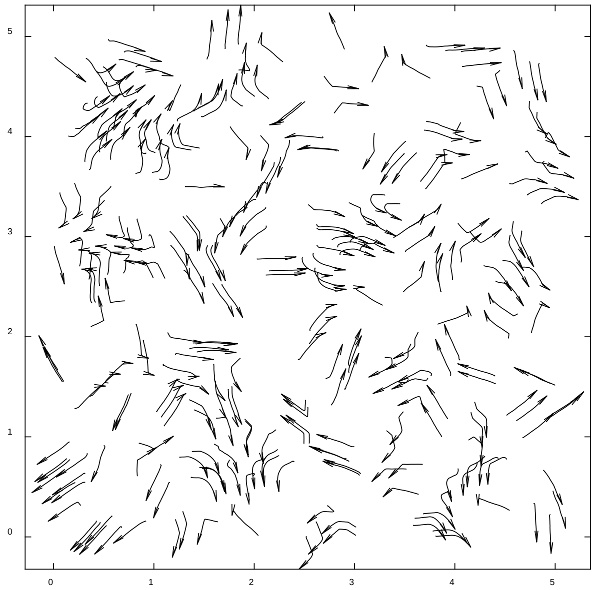

Fig.4 Collaboration State Diagram of Unmanned Cluster Unit

Each agent in the figure has a trajectory line, which can be seen that there is an obvious trend of cooperative movement of units.

4. Attack Defense Confrontation Experiment

Set up a two-dimensional battlefield environment and build it into an unbounded two-dimensional coordinate system. Randomly generate a target point and several our agents and enemy agents within the battlefield [- 1,1]. We carry out tasks in teams, and there is a captain in each team. The captain can detect all enemy agents in the battlefield and command the team members to avoid and attack. The map sets up two enemy ambush areas. When the enemy enters the area, only the captain can detect and notify all team members. Battlefield parameters are set to: Agent radius is 0.05, ambush area is 0.3, target point radius is 0.05, our speed is 3, enemy speed is 4.

Our combat mission is to contact the target point. If any of our personnel contacts the target point, it will be our victory. The enemy's task is to destroy us. When the distance between the two is less than the sum of their radii, we will successfully destroy us, die permanently and end the battle. If all our personnel end the battle or the attacking party fails to reach the target point within the specified deployment, it shall be regarded as victory of the enemy. The schematic diagram of battlefield initialization is as follows:

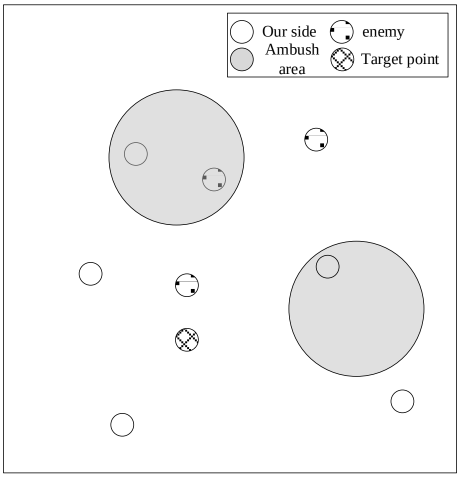

Fig.5 Battlefield Initialization

The enemy adopts the rule-based collaborative mode, and our side adopts their own action mode and rule-based coordination mode to conduct combat experiments. The combat results are as follows:

		Table 1. Combat results	
Our quantity	Enemy quantity	Collaborative control mode	Our combat success rate
10	5	Respective action	60.7%
10	5	rule-based	90.3%
10	6	Respective action	51.2%
10	6	rule-based	85.5%
10	7	Respective action	32.8%
10	7	rule-based	64.9%

The results show that the combat success rate of rule-based collaborative control mode is far better than that of non collaborative mode. However, our combat success rate is affected by the number of enemies. When the number of enemies is too high, it will be more difficult for us to win.

5. Conclusions

Aiming at the mode of unmanned swarm combat, an attack defense confrontation model based on unmanned swarm is established. The collaborative control mode of swarm is studied, and a rule-based collaborative control mode of unmanned swarm is proposed. The results of combat experiments show that the collaborative control mode can effectively improve the combat success rate and provide the possibility for the actual combat of unmanned swarm combat in the future.

6. Acknowledgments

Thank all the teachers who provided guidance during my study and my friends who helped me.

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