Study on the dynamic adjustment of UAV formation based on purely azimuthal passive positioning

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Abstract. In recent years, with the continuous development of unmanned aerial vehicle (UAV) technology, the application of UAV formation flight has also more and more extensive, but the UAV formation is easy to be interfered with by the outside world, which affects the formation. In this paper, we use pure orientation passive positioning, the least squares method to fit the UAV orientation, according to the superior and inferior arc model, cross-positioning, to reduce the UAV formation to emit electromagnetic wave signals to the outside. Firstly, the dynamic adjustment model of UAV formation is established to simulate the dynamic adjustment of two kinds of UAV formation from circular UAV formation to conical UAV formation and from rectangular UAV formation to conical UAV formation, and the simulation results show that the dynamic adjustment scheme of UAV formation under the model has a closer change distance and a shorter change time.

Keywords: UAV formation, purely azimuthal passive, least squares, Cross-location, Superior and inferior arc models.

1. Introduction

In recent years, unmanned aerial vehicle (UAV) technology has ushered in a mammoth development, and UAVs have been applied to all walks of life; however, the formation control and dynamic adjustment of UAVs are known as the hot and difficult issues in current research. In practice, due to the influence of the external environment or changes in mission requirements, UAV formations often need to be adjusted in real-time to maintain the reasonableness of the formation. Traditional adjustment methods mostly rely on global positioning information, but in some environments, GPS signals may be limited or even invalid, which puts forward higher requirements for UAV formation control. Therefore, in this paper, we reduce the electromagnetic interference to UAV flight by pure azimuthal passive positioning method. The optimal adjustment scheme of UAV formation is studied in that case. Contribute to the research of UAV formation flight.

In this study, with the initial state of UAV known, the initial position and target position of UAV are first fitted according to the pure azimuthal passive positioning method and the least squares method, and the dynamic adjustment model of UAV formation is established based on the nearest transmission distance of UAVs under inferior arcs and the triangular UAV transmitting signal model, according to which the dynamic adjustment model of UAV formation is sympatrically applied to the circular and rectangular UAV formations. According to the fitted coordinate information, a detailed UAV adjustment scheme is proposed to be obtained.

2. Dynamic adjustment of drone formations

2.1. Modelling of dynamic adjustment of UAV formations

In this study, one UAV is set to be located at the center of the circle, and the remaining nine UAVs are uniformly distributed on the circumference, which has a radius of 100 meters. With the knowledge of the initial position of the UAVs, the nine UAVs are dynamically adjusted so that the nine UAVs are uniformly distributed on the circumference with a radius of 100 meters, and at most three UAVs are selected as the transmitting signal UAVs on the circumference in the process of adjustment. In this paper, the polar coordinates initial position image as well as the target position image will be

constructed according to the initial position of the UAVs. By analyzing the distance between the two, the UAV position will be adjusted [1].

In this paper, the initial state and target state of the UAV are first fitted using the least squares method, which is often used in statistical studies to correlate links in a set of data using the relationship between the function's independent and dependent variables[2]. In a set of data in the largest case to meet this set of data, the error is small, usually used to calculate the Euclidean paradigm to evaluate the error of the standard.

Usually, face maps are made based on the laws of motion of the problem and the given data. Determine the representation of $S(x)$ by considering $\|\delta\|_2^2$ least squares as a weighted sum of squares.

$$\|\delta\|_2^2 = \sum_{i=0}^{m} \omega(x_i)\left[S(x_i) - f(x_i)\right]^2 \tag{1}$$

$\omega(x) \geq 0$ Is a weight function on [a,b] which indicates that the weight of the data at different points $(x_i, f(x_i))$ is different, and usually indicates the number of repeated observations at a point $(x_i, f(x_i))$. The problem of fitting a curve by least squares $S(x)$ is to find a function $y = S^*(x)$ that minimizes (1). Transform this problem into a problem of minimizing the point $\left(a_0^*, a_1^*, \cdots, a_n^*\right)$ of a multivariate function.

$$I(a_0, a_1, \cdots, a_n) = \sum_{i=0}^{m} \omega(x_i)\left[\sum_{j=0}^{n} a_j \varphi_j(x_i) - f(x_i)\right]^2 \tag{2}$$

From the necessary conditions for finding the extreme value of a multivariate function, there are

$$\frac{\partial I}{\partial a_k} = 2\sum_{i=0}^{m} \omega(x_i)\left[\sum_{j=0}^{n} a_j \varphi_j(x_i) - f(x_i)\right]\varphi_k(x_i) = 0, (k = 0,1,\cdots,n) \tag{3}$$

If you remember

$$\sum_{j=0}^{n} (\varphi_k, \varphi_j) a_j = d_k, (k = 0,1,\cdots,n) \tag{4}$$

$$(\varphi_j, \varphi_k) = \sum_{i=0}^{m} \omega(x_i) \varphi_j(x_i) \varphi_k(x_i) \tag{5}$$

$$(f, \varphi_k) = \sum_{i=0}^{m} \omega(x_i) \varphi_j(x_i) \varphi_k(x_i) \equiv d_k, (k = 0,1,\cdots,n) \tag{6}$$

Then (2) can be replaced by

$$\sum_{j=0}^{n} (\varphi_k, \varphi_j) a_j = d_k, (k = 0,1,\cdots,n) \tag{7}$$

(4) Is called the normal equation and has the matrix form

$$Ga = d \tag{8}$$

Among them. $a = (a_0, a_1, \cdots, a_n)^T$, $d = (d_0, d_1, \cdots, d_n)^T$

$$G=\begin{bmatrix}(\varphi_0,\varphi_0)(\varphi_0,\varphi_1)\cdots(\varphi_0,\varphi_n)\\(\varphi_1,\varphi_0)(\varphi_1,\varphi_1)\cdots(\varphi_1,\varphi_n)\\\cdots\cdots\cdots\cdots\cdots\cdots\\(\varphi_n,\varphi_0)(\varphi_n,\varphi_1)\cdots(\varphi_n,\varphi_n)\end{bmatrix} \tag{9}$$

Since $\varphi_0,\varphi_1,\cdots,\varphi_n$ is linearly independent, $|G|\neq 0$ there exists a unique solution to the system of equations (4)

$$|G|\neq 0 \tag{10}$$

The least squares solution of the function $f(x)$ is thus obtained as

$$S^*(x)=a_0^*\varphi_0(x)+a_1^*\varphi_1(x)+\cdots+a_n^*\varphi_n(x) \tag{11}$$

It can be proved that $S^*(x)$ for any form of $S(x)$

$$\sum_{i=0}^{m}\omega(x_i)\left[S^*(x_i)-f(x_i)\right]^2\leq\sum_{i=0}^{m}\omega(x_i)\left[S(x_i)-f(x_i)\right]^2 \tag{12}$$

That is, by solving the normal equation for a set of data, the coefficient solution for a unique set of polynomials can be obtained. The relationship between the initial position and the target position is fitted according to least squares.

According to Figure 1, it can be seen that the green point is the initial position and the red point is the target position [3]. The analysis yields that except for the UAVs numbered 0 and 1 whose positions do not need to be adjusted, in this paper, the UAVs that need to be adjusted are gradually adjusted using least-squares fitting for the UAVs that have deviations [4].

When the offset length and angle are tuned to the final target coordinates, the correct UAV distribution can be calculated, and the initial position is adjusted to the nearest red target position according to the principle of shortest path adjustment. Meanwhile, the data transmission as well as the measurement distance under the inferior arc model is superior to the superior arc model, so in the process of UAV adjustment, the principle of small arc priority is followed.

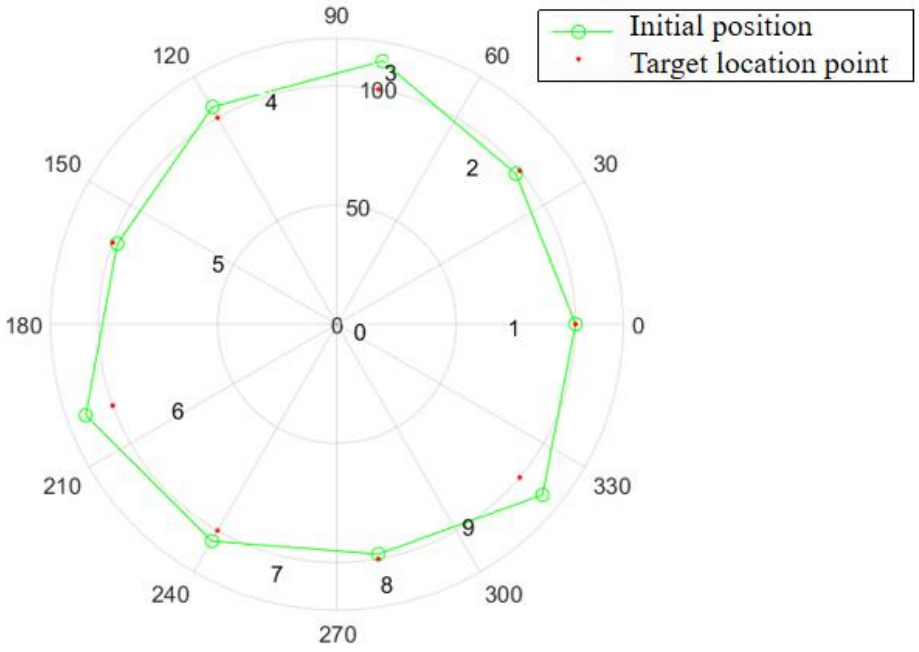


Figure 1. Comparison of the initial position of the drone formation with the fitted target position.

In the selection of transmitting UAV signals for adjusting the position of the receiving signal UAV, the same priority is given to the adoption of the triangular model, and in the event of encountering the problem that transmission positioning cannot be realized, the three UAVs on the circumference are selected as transmitting UAVs according to the principle of selecting transmitting UAVs, and the position adjustment information is sent to the UAVs that are receiving the signals [5].

The sequence of position adjustment of UAVs receiving signals is followed in this paper to prioritize the adjustment of UAVs with large angular deviation and large distance deviation [6]. According to the above principle, considering the angle deviation and distance deviation, the distance between the initial position and the target position is calculated using mathematical formulae based on the polar coordinates of the initial and destination positions.

$$D = \sqrt{\rho_1^2 + \rho_2^2 - 2\rho_1\rho_2\cos(\theta_1 - \theta_2)} \tag{13}$$

According to the principle of inferior arc priority, the selection principle of signal transmitting UAVs, and the priority of adjusting the position of UAVs with large deviation, the corresponding dynamic adjustment algorithm of UAV formation is designed. According to the solution, the adjustment program from the initial position of the UAV to the target position is obtained.

2.2. Analysis of a dynamic adjustment model for UAV formations

According to the UAV formation dynamic adjustment model to bring the data to solve, get the number of UAV initial addresses and target addresses to deviation distance, see Table 1 below.

Table 1. Table of the deviation distances between the initial position of the drone and the target position.

serial number	2	3	4	5	6	7	8	9
metric	2.00	12.01	5.02	2.01	12.00	5.00	2.02	12.01

According to the principle of inferior arc priority, the principle of selecting the UAV that transmits signals, and the priority of adjusting the position of the UAV that has a large deviation, the algorithm is used to calculate the effect of adjusting the UAV to the target position according to the initial position, and the adjustment scheme is as follows.

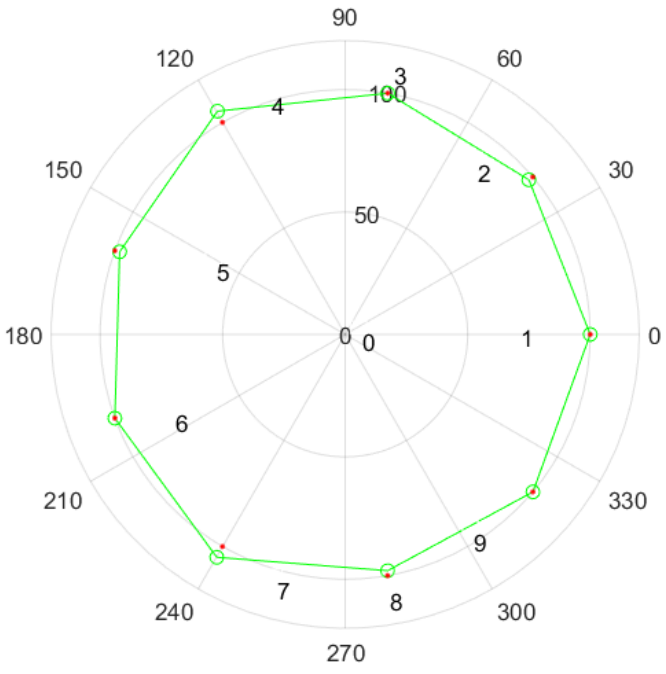


Figure 2. Effect after adjusting drones 3, 6, and 9.

According to Figure 2, it can be seen that after adjusting the position of UAVs with large deviation, the position offset of UAVs has been effectively adjusted, and then the UAVs with smaller deviation distances are adjusted to get the final target distribution. The specific adjustment program is shown in Table 2 below.

Table 2. Table of drone adjustment programmes.

Number of adjustments	Signalling drones	Signal-receiving drones	Adjustment distance
1	FY00,FY01	FY09	12.01
2	FY00,FY01,FY09	FY03	12.01
3	FY00,FY01,FY03,FY09	FY06	12.00
4	FY00,FY03,FY06	FY04	5.02
5	FY00,FY06,FY09	FY07	5.00
6	FY00,FY07,FY09	FY08	2.02
7	FY00,FY04,FY06	FY05	2.01
8	FY00,FY01,FY03	FY02	2.00

3. Dynamic Simulation of Tapered UAV Formation Formation

3.1. Modelling the positioning of UAVs receiving signals in a conical formation

In the formation under the conical formation, this paper takes the center of the conical formation as the origin of the polar coordinates and establishes the polar coordinate week. As shown in Figure 3 below, FY05, FY08, and FY09 are the transmitting signal UAVs, and the rest of the UAVs are the passive receiving signal UAVs, in the process of UAV formation adjustment, priority is given to the three transmitting UAVs to make positioning adjustment, and then radiate to the surrounding UAVs that are receiving signals.

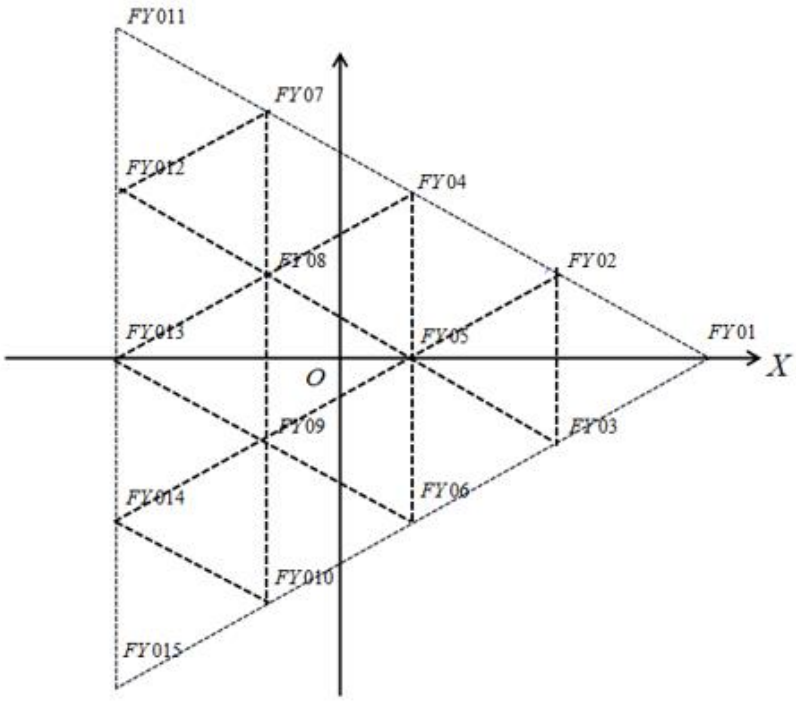


Figure 3. Distribution of drones in polar coordinates.

The localization coordinate model of each position of the conical UAV, so that the center O of the triangle formed by UAVs FY08, FY09, and FY05 is the origin to construct the polar coordinate system.

Assuming FY05 (a, 0), the drones of two neighbors on a straight line are equidistant $\sqrt{3}a$.

The mathematical formula was used to derive the polar coordinates of the UAV in the rest of the bearings are shown in Table 3, which establishes the positioning model of the conical UAV.

Table 3. Polar coordinates of drone cone position.

Drone formation	$\rho(m)$	$\theta(rad)$	Drone formation	$\rho(m)$	$\theta(rad)$
FY01	4a	0	FY09	a	$-\frac{2\pi}{3}$
FY02	$\sqrt{7}a$	$\arccos\frac{5\sqrt{7}}{14}$	FY010	$\sqrt{7}a$	$-\arccos\left(-\frac{\sqrt{7}}{14}\right)$
FY03	$\sqrt{7}a$	$-\arccos\frac{5\sqrt{7}}{14}$	FY011	4a	$\frac{2\pi}{3}$
FY04	2a	$\frac{\pi}{3}$	FY012	$\sqrt{7}a$	$\arccos\left(-\frac{2\sqrt{7}}{7}\right)$
FY05	a	0	FY013	2a	π
FY06	2a	$-\frac{\pi}{3}$	FY014	$\sqrt{7}a$	$-\arccos\left(-\frac{2\sqrt{7}}{7}\right)$
FY07	$\sqrt{7}a$	$\arccos\left(-\frac{\sqrt{7}}{14}\right)$	FY015	4a	$-\frac{2\pi}{3}$
FY08	a	$\frac{2\pi}{3}$			

3.2. Dynamic adjustment of drone formations

Explore the conical formation UAV according to the pure azimuth passive positioning for two different initial states, adjusted to the standard conical adjustment scheme, compare different initial states, and explore the adjustment efficiency of adjusting different shapes. In this paper, the net shape and rectangle shape are selected as the initial state, and then the conical formation formation is adjusted [7].

Adjustment program with a garden shape in the initial state

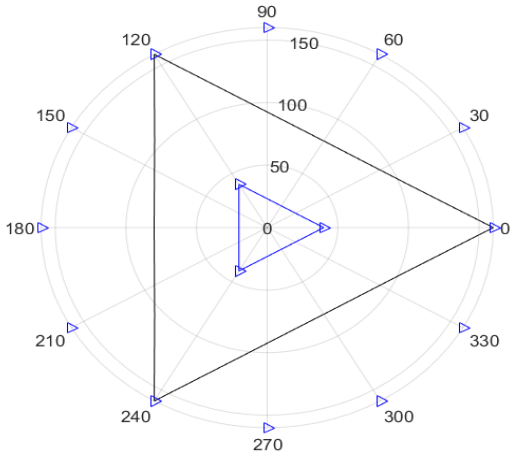


Figure 4. Initial state diagram of the drone.

The initial state is a circular UAV formation, adjusted to a conical formation, FY05, FY08, and FY09 are located in the center of the circle, and the rest of the UAVs are uniformly distributed around the circumference of the circle, according to the model locating coordinates, set an as 40m, and find the coordinates of the famous UAVs, as well as the initial coordinates, and the initial positional state diagram is shown in Figure 4.

The blue marking of the outer circle of the initial state diagram of the UAV is the initial position of the UAV, and the adjustment distance of the UAV for passively receiving signals is calculated according to the initial polar coordinates and the destination conical polar coordinates[8], because the initial setting of the FY05, FY08, FY09 is located in the center of the circle and maintains the equilateral triangular formation, and there is no deviation of the position, so in adjusting the position

of the deviating UAVs, the maximum deviation is taken as the priority adjustment item, and gradually the UAV positions are adjusted, and the specific adjustment scheme and adjustment distance are shown in Table 4 below.

Table 4. Table of circular to conical UAV scheduling schemes.

Number of adjustments	Signal transmitting drones	Signal-receiving drones	Adjustment distance (m)
1	FY05,FY08,FY09	FY13	59.53
2	FY05,FY08,FY09	FY12	59.53
3	FY05,FY08,FY09	FY14	59.53
4	FY05,FY08,FY09	FY04	59.53
5	FY05,FY08,FY09	FY06	59.53
6	FY05,FY08,FY09	FY07	59.53
7	FY05,FY08,FY09	FY02	59.53
8	FY05,FY08,FY09	FY03	59.53
9	FY05,FY08,FY09	FY10	59.53

According to the adjustment scheme using software for simulation, the UAV adjustment effect path diagram, red is the adjustment path of the UAV, green and blue colors are the initial UAV positioning, yellow is the adjusted target positioning, the middle three UAVs are the sending signal UAVs, the simulation effect obtained Figure 5.

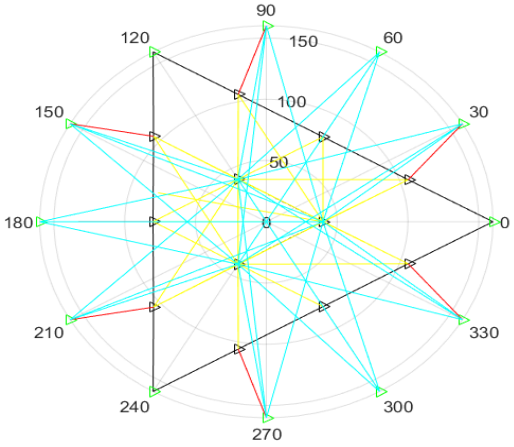


Figure 5. Effect of drone adjusting the path.

(2) Adjustment scheme with a rectangular initial state

The initial state is a rectangular UAV formation, adjusted to a conical formation, this initial state is also set for FY05, FY08, and FY09 and is located in the center of the circle, according to the model positioning coordinates are also set for 40m, according to a to find out the position of the UAVs in each initial state polar coordinates. The initial state diagram is shown in Figure 6 below.

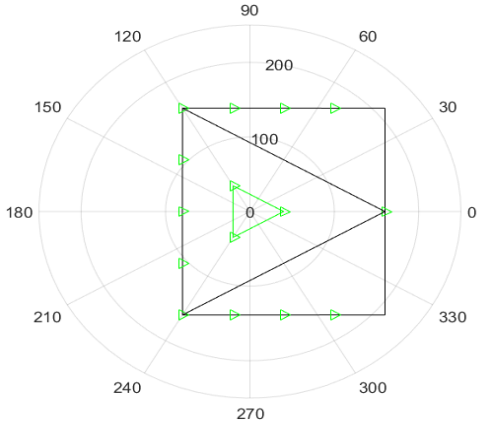


Figure 6. Initial state diagram of the drone.

According to the initial UAV position polar coordinates and the destination UAV position polar coordinates to derive the UAV adjustment distance, set FY05, FY08, and FY09 is located in the center of the circle and maintains the equilateral triangle formation, the position has no deviation, for the transmitting signal UAV [9]. Adjust the position deviation UAVs according to the transmit signal UAVs. The specific adjustment program is shown in Table 5 below.

Table 5. Rectangular to conical UAV scheduling scheme.

Number of adjustments	Signal transmitting drones	Signal-receiving drones	Adjustment distance (m)
1	FY05,FY08,FY09	FY02	103.92
2	FY05,FY08,FY09	FY03	103.92
3	FY05,FY08,FY09	FY04	69.28
4	FY05,FY08,FY09	FY06	69.28
5	FY05,FY08,FY09	FY07	34.64
6	FY05,FY08,FY09	FY10	34.64

Set FY05, FY08, and FY09 are located in the center of the circle and maintain the equilateral triangle formation, for the launching signal UAV, according to the adjustment program using the software for simulation yellow is the adjusted target positioning, green-blue is the initial positioning of the UAV [10], red is the UAV's adjusted path, the simulation effect obtained is shown in Figure 7 below.

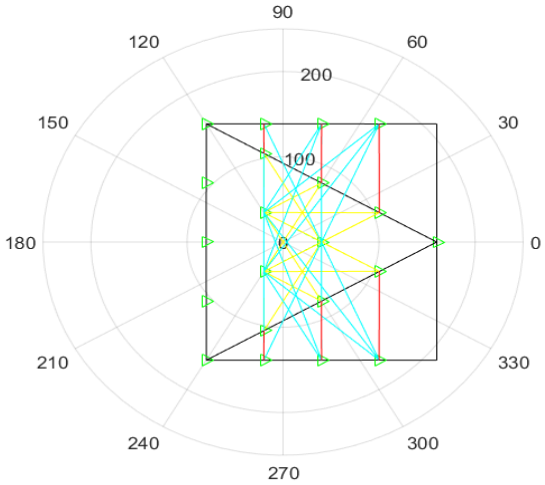


Figure 7. Effect of drone re-routing.

UAV clusters often perform their missions in different formation formations, and different formations have different transmission effects. In this paper, based on the pure azimuthal passive positioning method, a dynamic adjustment model of UAV formation is established to simulate the transformation of a circular UAV formation to a conical UAV formation and a rectangular UAV formation to a conical UAV formation, and the simulation results show that the adjustment speed and the adjustment distance of the UAV formation are both optimal under this model.

4. Conclusions

In this study, the initial state of the UAV case, using pure azimuth passive positioning method, the UAV formation to form a circular formation, this paper uses the least squares method to first fit the initial position of the UAV and the target position, according to the trans mission distance of the UAV under the inferior arc of the nearest UAV and the triangular UAV transmits the signal model, to derive the optimization model, to establish the dynamic adjustment model of the UAV formation. Priority adjustment of UAVs with large deviations gets the detailed UAV adjustment scheme. In the actual UAV swarm flight, there are multiple flight formation formations, this paper constructs two initial states of circle and rectangle, and uses mathematical formulas to derive the positioning model of

conical formation UAVs, which is dynamically adjusted to the conical formation through the purely azimuthal passive positioning method, and obtains the detailed UAV adjustment scheme.

This paper establishes the dynamic adjustment model of UAV formation according to the dynamic adjustment of UAV formation. It provides a research idea for UAV formation flight. The model is applied to the transformation of circular UAV formation and rectangular UAV formation for simulation, and a detailed and efficient UAV formation dynamic adjustment scheme is obtained. The feasibility of the UAV formation dynamic adjustment model applied to the field of UAV formation control is proved.

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